Tracing Error with Björk's Mandibular Structures

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The tracing errors associated with the structures used in Björk's method of mandibular superimposition are investigated using multiple tracings of fifty lateral cephalometric radiographs. The horizontal error levels were much less than the vertical, midline structures more reliable than bilateral structures, and the lower third molar tooth germ more reliable than the inferior dental canal.

KEY WORDS: • CEPHALOMETRICS • IMPLANTS •

BROADBENT'S 1931 introduction of the cephalometer (cephalostat) inspired a large number of studies of the development of the dentition and growth of the face. Initial growth studies such as those by BROADBENT (1937) and later BRODIE (1941, 1953) superimposing longitudinal cephalometric radiographs on planes representing the cranial base, showed an average tendency for the face to grow linearly downward and forward in a translatory manner, away from the rest of the skull. In his study *The Face in Profile*(1947) BJÖRK showed a marked tendency for the face to swing (rotate) forward during growth, with the mandible showing the greatest shift.

In 1951 BJÖRK started using small inert metallic implants as radiographic markers in the jaws of a small number of children, and in 1963 he published results of a study of 110 Danish school children of both sexes. BJÖRK's 1963 report showed that certain internal structures of the mandible maintained a constant relationship to the implants, their position in relation to adjacent bone being unaffected by the remodeling associated with growth. He therefore suggested that for clinical purposes, in the absence of implants, a method of superimposition could be based on these natural reference structures, which have become known as *Björk's structures.*

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Some investigators, notably MATHEWS AND WARE (1978) and MATHEWS AND PAYNE (1980), have questioned the validity of the structural method of superimposition but BJÖRK (1969) was quite clear in referring to the natural reference structures as being "relatively stable," and therefore more suitable for many reference purposes than some other anatomical outlines known to be less stable.

Superimposition on Björk's mandibular structures has been used by an increasing number of workers in studies on facial growth and to demonstrate the various effects of treatment upon the dentition and the face. SKIELLER (1967) superimposed longitudinal radiographs on Björk's structures to assess the aetiology of increased overbite. MILLS (1973) also used Björk's structures to assess the aetiology of the deep overbite associated with Class II division 2 malocclusions.

Other growth studies using the Björk structures included ISAACSON ET AL. (1977), SOLOW (1980), BRYANT (1981), MCNAMARA (1981), ARI-VIRO AND WISTH (1983), and BJÖRK ET AL. (1984). The use of these structures to show effects of various treatments has also increased. OZEROVIC (1972) and LUDER (1981, 1982) used these structures to assess the changes during myofunctional appliance treatment. Other studies investigating the effects of treatment have been carried out by RIEDEL (1974), SINGER (1974, 1980) and others.

In their guidelines for case presentation, the Treatment Study Group of the British Society for the Study of Orthodontics (1984) have recommended the use of Björk's structures for the superimposition of cephalometric tracings of treated orthodontic cases.

Very few investigations have been made into the reliability of anatomical outlines, in contrast to the voluminous literature relating to the reliability of other cephalometric reference points. ARI-VIRO AND WISTH (1983) evaluated the structural growth prediction suggested by Björk in 1969. As an initial part of that study, the reliability of tracing Björk's mandibular structures was investigated using 42 pairs of longitudinal lateral cephalograms. However, angular changes in the nasion-sella line were evaluated, so any horizontal errors would have gone undetected. The claim by the authors of the proven reliability of Björk's structures therefore applies only to investigations restricted to vertical relationships.

Satisfactory cephalometric analysis is dependent upon the reliability of the measurements involved. The purpose of the present study is to analyse the errors inherent in the process of tracing these anatomic reference structures.

— Materials and Methods —

Fifty pre-treatment lateral cephalograms were selected from the records of patients referred to the Leeds Dental Hospital. The only criterion for selection was that each radiograph showed the presence of at least one lower third molar with some degree of crown calcification. This calcification could be up to and including complete crown formation, but before root formation had commenced. The selection of the radiographs was not limited to those of only the best quality, so that a cross section representative of routine radiographs taken in everyday orthodontic practice was examined.

Each of the radiographs was traced by both authors, one a postgraduate student in Orthodontics, the other an experienced Orthodontist and himself an author of a study on cephalometric error (GRAVELY AND BENZIES 1974). Before any tracing was carried out, the tracers defined the criteria for identification of the various cephalometric landmarks and anatomical outlines to be used. The tracings were repeated after an interval of no less than seven days.

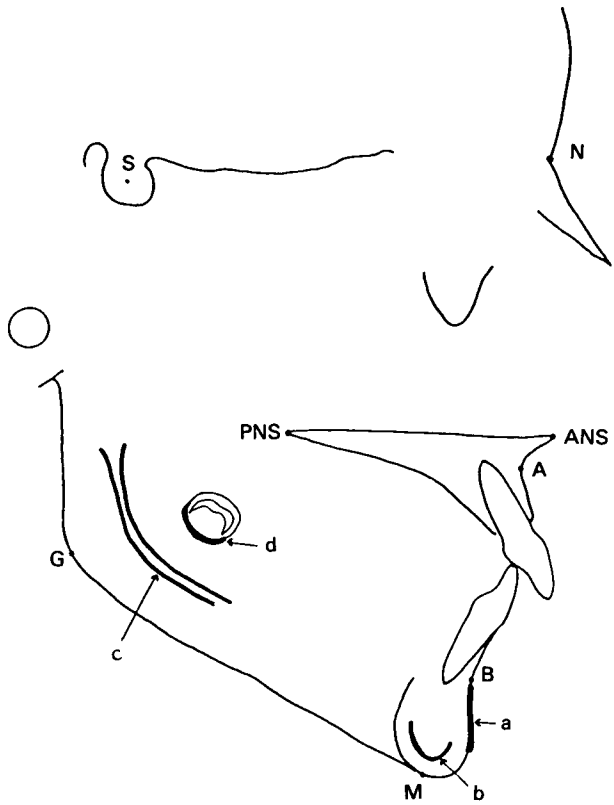

Fig. 1 Cephalometric tracing, showing the eight cephalometric points and the outlines of Björk's four mandibular structures (heavy lines):
a. The anterior contour of the bony chin.
b. The inner contour of the cortical plate at the lower border of the symphysis.
c. Mandibular canal.
d. The lower contour of the lower third molar tooth germ.

The following were drawn on each tracing.

1. The eight cephalometric points shown in Figure 1.
2. Björk's mandibular structures, defined as follows:
   a. The anterior contour of the bony chin.
   b. The inner contour of the cortical plate at the lower border of the symphysis.
   c. The contour of the mandibular canal.
   d. The lower contour of the mineralized lower third molar tooth germ prior to root formation.

If the radiographic outlines of bilateral structures did not coincide, a line was drawn equidistant from the two images.

Before any superimpositions were done, an error study was carried out on twenty pairs of tracings selected at random. Superimposition tests, as described later, were carried out on these tracings and repeated again after a period of seven days.

The results were tested for systematic error using the paired "t" test, and for random error by assessing the error of the method (DAHLBERG 1940).

All superimposition tests were carried out by the first Author, using an online digitiser. Pairs of tracings of the same radiograph were superimposed to test both intra- and inter-tracer reliability. The eight cephalometric points were entered from both tracings in the pair to be tested. These digitised points were used to calculate angles S-N-A, S-N-B, A-N-B, and Go-Me/ANS-PNS (the maxillary/mandibular plane angle, MMPA).

The differences between the measurements made for the above angles from each of the two tracings were computed, and the results used later to compare the error levels of the two tracers with each other and with those of previously published studies.

Björk's structures were tested by fixing the first tracing in the pair under investigation to the digitiser board and recording S-N-B and MMPA. The second tracing was then superimposed on Björk's mandibular structures, with a thick cardboard mask covering the rest of the tracing, and when the best fit was obtained, points B, M and G on the second tracing were digitised. The differences in the angle S-N-B and MMPA so produced are representative of the errors present in the horizontal and the vertical directions respectively.

Five such superimposition tests were carried out to test the following:

A. All of Björk's structures.

B. The anterior structures on their own (the anterior contour of the bony chin and the inner contour of the cortical plate at the lower border of the symphysis).

C. The posterior structures on their own (the lower third molar tooth germ and the inferior dental canal outline).

D. All the structures except for the lower third molar outline.

E. All the structures except for the outline of the inferior dental canal.

The statistical significance of the differences between the tracings were assessed by the error of the method (DAHLBERG 1940) to test for random error, and a paired 't' test for systematic error.

— Results —

Results of the error tests shows the digital recording process to be reliable for the angular measurements using the eight cephalometric landmarks. No significant systematic errors were found, and the random errors were small (table 1). The error study also shows the measurement process to be reliable for Björk's structures; the random errors are small, and any statistically significant systematic errors are due to small values for the standard error of the mean rather than large mean differences, so they are not considered to be of clinical significance (Tables 2 and 3). Thus, the measurement errors inherent in the system of point registration are small and hence the measurement process is valid for use in the present study.

Table 1 shows that angle A-N-B was traced more reliably then S-N-A or S-N-B. Tracing of MMPA was least

reliable, the error of the method being approximately twice as high as for A-N-B. As with the error tests, the significant systematic errors are again not considered to be of clinical significance, as the mean differences are small. Both tracers showed similar degrees of random error for the four angles investigated. Intra-tracer error was less than inter-tracer error for angles S-N-A and S-N-B. This was not the finding for angle A-N-B or for the MMPA. The most reliable angle (A-N-B) still showed an appreciable degree of error (error of the method value of 0.51°), even under these ideal test conditions, while the error of the method value was 1.15° for the least reliable angle (MMPA).

The results of test A of the five superimposition tests (A to E) are described first. This represents the superimposition process using all of the structures together, providing the best basis for comparing the results of the other four tests.

Table 1

Errors within and between Examiners
(Error of the method values in degrees)

	Error of the method	t
S-N-A		
Error test	0.42	0.227
Within examiner A	0.83	1.130
Within examiner B	0.75	0.578
Between examiners T1	1.18	4.405**
Between examiners T2	1.15	2.930**
S-N-B		
Error test	0.36	0.614
Within examiner A	0.65	2.435*
Within examiner B	0.65	1.037
Between examiners T1	1.04	4.737**
Between examiners T2	1.15	3.375**
A-N-B		
Error test	0.26	0.110
Within examiner A	0.51	1.291
Within examiner B	0.48	0.572
Between examiners T1	0.51	0.908
Between examiners T2	0.42	1.289
Go-Me/ANS-PNS (MMPA)		
Error test	0.61	0.473
Within examiner A	1.07	1.431
Within examiner B	1.15	3.273**
Between examiners T1	0.99	3.342**
Between examiners T2	1.03	1.670

*=Significant at the 5% level
**=Significant at the 1% level

Table 2

Paired 't' test
(systematic error)
for five superimposition tests

Test	Angle	Error Test	A/T1/T2	B/T1/T2	A/B/T1	A/B/T2
A	S–N–B	0.914	3.412*	0.638	0.513	1.407
	MMPA	1.428	2.337*	1.112	1.972	0.830
B	S–N–B	0.381	3.191*	0.885	2.640*	1.251
	MMPA	0.422	2.364*	1.512	3.315**	1.700
C	S–N–B	2.079*	0.053	0.821	1.421	1.638
	MMPA	2.079*	0.571	0.361	0.215	0.968
D	S–N–B	0.662	2.446*	0.965	0.567	1.005
	MMPA	0.609	1.475	0.616	1.311	0.753
E	S–N–B	2.449*	1.139	0.966	1.266	2.803*
	MMPA	1.597	1.294	0.405	0.089	0.074

Test A All the Structures
Test B The anterior structures
Test C The posterior structures
Test D All the structures except the lower third molar tooth germ
Test E All the structures except the inferior dental canal

Table 3

Error of the method
(random error, degrees)
for the five superimposition tests
(same as Table 2)

Test	Angle	Error Test	A/T1/T2	B/T1/T2	A/B/T1	A/B/T2
A	S N B	0.15	0.15	0.15	0.14	0.18
	MMPA	0.50	0.61	0.81	0.69	0.71
B	S N B	0.15	0.15	0.17	0.13	0.17
	MMPA	0.96	0.71	1.09	1.01	1.14
C	S N B	0.35	0.88	1.14	0.94	1.38
	MMPA	1.17	3.47	4.72	3.72	5.01
D	S N B	0.15	0.17	0.17	0.15	0.19
	MMPA	0.55	1.09	1.10	1.10	1.45
E	S N B	0.14	0.16	0.15	0.15	0.20
	MMPA	0.44	0.59	0.83	0.81	0.77

Test A shows that the random horizontal errors (S–N–B) were very small; the random vertical errors (MMPA) were three to four times as large as those in the horizontal direction (table 3). No clinically significant systematic errors were found (table 2), and little difference between the intra- and inter-tracer error levels.

When the anterior structures were used on their own, the horizontal error levels were low, but vertical errors were higher vertical (tables 2 and 3, test B). The posterior structures were even less reliable, especially in the vertical direction (table 2 and 3, test C).

Comparing the results for tests D (ignoring the lower third molar) and E (ignoring the inferior dental canal) with those of test A (all the structures), it is seen that there is no increase in the random horizontal error levels when either of the two posterior pairs of structures are ignored (Table 3). However, the random vertical errors (MMPA) are higher when the outline of the lower third molar tooth germ is ignored for superimposition purposes. This indicates that the outline of the lower third molar tooth germ is a more reliable posterior structure than the structure than the inferior dental canal.

— Discussion —

Use of Björk's mandibular structures for superimposition purposes has been accepted almost without question, even without adequate evaluation of their reliability. The present study has assessed the errors inherent in the tracing of these anatomic structures. It is essential to quantify the error inherent in the method of measurement, and to assess the level of their reliability when traced by the two investigators, before any discussion of the reliability of the use of the Björk structures.

The errors inherent in the system of point registration and measurement are small, and as the same tracings were digitised on two occasions there can be no question of tracing or projection errors affecting the measurements. Table 4 compares the error of the method values for the error analysis of the present study with those of other investigations. The random errors in the present study were smaller than those of Björk (1947) and Solow (1966). This may be due to use of a digitiser rather than a protractor. Werner's (1955) results were very similar to those of the present study, but the author did not state how the measurements were recorded.

Table 4

Comparison of the error of the method values for the present study with prior publications (degrees)

angle	Björk 1947	Werner 1955	Solow 1966	Present Study
S N A	–	0.36	0.63	0.42
S N B	–	0.37	0.52	0.36
A N B	–	0.27	0.41	0.26
MMPA	0.99	–	0.84	0.61

An interesting finding to emerge from the error study was that, for the more reliable structures (random error $< 0.2°$), measurement error accounted for almost all the total random error. Therefore, attempts to improve the reliability of Björk's structural method of superimposition should be aimed at reducing measurement error rather than on improving identification of the structures.

It is well accepted that the main source of most cephalometric errors is landmark identification (Baumrind and Frantz 1971; Gravely and Benzies 1974). This may well be the case where a single point must be identified, but the error analysis in the present study shows that this may not necessarily be the case for identification and tracing of anatomical outlines such as Björk's structures.

The reliability of tracings made by the two investigators was similar, and is consistent with those of previously published studies.

To eliminate the effect of projection error between successive radiographs, only one radiograph was used from each of the fifty individuals in the present investigation. The vertical errors involved in tracing Björk's structures were found to be much greater (as shown for the MMPA) than the horizontal (as for angle S-N-B).

This is an important finding. Studies have been undertaken, using Björk's anatomic reference structures for superimposition purposes, to demonstrate changes produced in antero-posterior skeletal form, or to show horizontal changes in tooth position. The findings of the present study show that the results of such investigations may be regarded as relatively reliable. By contrast, studies investigating vertical relationships should be treated with more caution, even though the vertical errors were found to be less than the error associated with tracing and measuring the MMPA.

The anterior (midline) structures were found to be more reliable than the posterior (bilateral) structures, especially in the horizontal direction. Mathews and Payne (1980) found that "chin point was the most stable structure," and therefore the most valid for use as a natural reference structure. The present study also shows that the anterior contour of the bony chin is the anatomical landmark traced with the greatest reliability.

It was because the posterior structures were expected to be unreliable when taken on their own that tests of reliability were carried out in which either the base of the third molar crypt or the outline of the mandibular canal were excluded (Tests D and E). This can be important to the clinician, because third molars may be absent or not be at the correct stage of development for superimposition purposes. Likewise, although the inferior dental canals will always be present, they are often not clearly visible on the radiographs.

Of the posterior structures, the lower borders of the lower third molar tooth germs were found to be the more reliable, and the outlines of the inferior dental canals much less so. These findings refer only to the vertical errors, there being very little difference between the horizontal errors for these structures.

No significant differences were found in the error levels either between or within examiners.

— Conclusions —

This study quantifies the horizontal and vertical errors associated with the tracing of Björk's mandibular anatomic reference structures. The level of reliability with which each individual structure can be traced is also assessed, and although the systematic changes were found to be small, there was still a sizable random error inherent in the process of

superimposition of the tracings. Horizontal errors were less than the vertical errors.

From the findings in this study, the following method of superimposing on Björk's mandibular structures is suggested. The tracings should first be superimposed on the anterior contour of the bony chin to establish the horizontal relationship (this structure has been shown to be the most valid and most reliable of the structures). Then, the "best fit" of the remaining structures is used to complete the superimposition. Greater emphasis should be placed on the lower contour of the lower third molar tooth germ than on the outline of the inferior dental canal, which the present study shows to be less reliable. Where the lower third molar tooth germs are not symmetrical, it is suggested that an imaginary line drawn between them be used for the superimposition.

Having established that Björk's structures can be traced with an adequate level of reliability, both between and within examiners, future reliability studies should now be aimed toward the superimposition process for series of longitudinal cephalometric radiographs.

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