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A critical evaluation of the pitchfork analysis

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SUMMARY The pitchfork analysis has gained increasing acceptance among researchers and clinicians to evaluate the effects of orthodontic treatment that can be measured on lateral cephalometric radiographs. It is primarily used in Class II cases to distinguish between the skeletal and dental effects of such treatments. The aim of this study was to conduct an objective evaluation of the pitchfork analysis by comparing cephalometric data obtained by that method with those using the more conventional and established method of Björk.

The pitchfork analysis consistently provided an overestimation of the skeletal effects and an under-estimation of the dental changes. These results indicate that the pitchfork analysis is not sufficiently sensitive to distinguish between the skeletal and dental effects of orthodontic treatment.

Introduction

During the last decade the pitchfork analysis (PFA) of Johnston (1985, 1996) has been used by several investigators to interpret biological growth and orthodontic treatment effects on lateral cephalometric radiographs (Harris *et al.*, 1991; Luecke and Johnston, 1992; Paquette *et al.*, 1992; Suwannee and Johnston, 1993; Livieratos and Johnston, 1995; Kapust *et al.*, 1998). It has been stressed that the PFA enables a clear distinction between skeletal and dental changes in the sagittal dimension (Johnston, 1985, 1996). The PFA has been applied to describe therapeutic effects caused by different appliances and/or treatment strategies on orthodontic Class II patients. Measurement data are usually recorded in the form of diagrams that give the appearance of pitchforks (Figure 1). The diagrams provide a differential insight and permit informative comparisons. However, the reproducibility of the PFA may not be high as indicated by two investigations (Hashim and Godfrey, 1990; Keeling *et al.*, 1993), which resulted in conflicting data.

The crucial point in cephalometric analysis is whether or not the chosen design of evaluation provides clinically reliable interpretations of true biological happenings. In the PFA, local superimposition of the maxilla and reference to the occlusal plane play the key roles. Depending on treatment modalities, various degrees of rotational effects may occur on the structures of the facial cranium, particularly if certain techniques such as Begg (Begg and Kesling, 1971; Levin, 1977; Papaioannou-Maragou and Papaioannou, 1994) and appliances like Herbst (Pancherz, 1982, 1984), Jasper Jumper (Blackwood, 1991; Cash, 1991; Cope *et al.*, 1994) and others of similar designs are used. In planning and comparing treatment strategies, a sound basis of analysis is of utmost importance to arrive at quantitative data that reflect the real biological events.

Björk's approach (Björk, 1995; Björk and Skieller, 1956, 1976, 1977a,b, 1983) is generally acknowledged to have attained the highest degree of accuracy among various superimposition methods (Brodie, 1941; Steiner, 1953; Broadbent, 1935, 1937; Ricketts, 1960, 1979) that evaluate craniofacial growth and orthodontic treatment effects (Baumrind *et al.*, 1987a,b; Nielsen, 1989). The confidence in this method stems from the fact that structures that are least influenced by orthodontic manipulations are used as reference for the overall superimposition

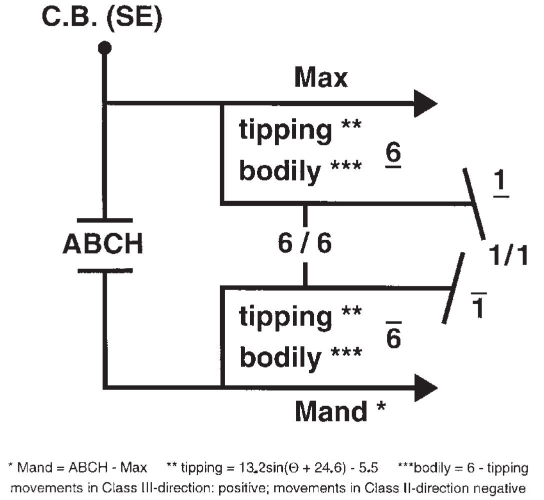

Figure 1 The pitchfork diagram as proposed by Johnston (1985). The maxillary translation (Max) in relation to the cranial base is measured at the intersection point of the cribriform plate and greater wing of the sphenoid bone (point SE). The apical base change (ABCH) is the difference between sagittal displacement of the maxilla and mandible. The molar intercuspation (6/6) and overjet (1/1) changes are calculated by adding the dental changes ($\underline{6}$ and $\overline{6}$ or $\underline{1}$ and $\overline{1}$) to the ABCH. The mandibular skeletal change (Mand) is calculated by subtracting Max from ABCH. If the amount of tipping of the molars in relation to bodily movement is of interest, it is calculated using the tipping angle Θ. The formula is shown in the diagram.

and that data derived from implant studies have provided the guidelines for local superimpositions. Björk's method is well suited to evaluate individual cases and it provides a comprehensive picture of the dentofacial changes. However, when group results have to be presented in tabular form, the differential algebraic derivatives for the skeletal and dental contributions to the correction of malocclusions are extremely difficult. From this point of view, the PFA-diagrams of Johnston (1985, 1996) provide impressive readability.

The aim of this investigation was to compare the methods of Johnston (1985, 1996) and Björk (Björk, 1955; Björk and Skieller, 1956, 1976, 1977a,b, 1983) so as to make a critical evaluation of the reliability of interpretations based on the former.

Materials and methods

The material used in this investigation consisted of pre- and post-treatment mean tracings of a group of 26 patients that originated from a previous study (Teuscher, 1988) and similar longitudinal radiographs from two additional selected cases of a low- and a high-angled patient, so as to arrive at distinctly differing data. This approach was taken because in a clinical situation, not only the average of a group of patients is important, but also the extreme deviation in an individual patient as in the chosen exemplary cases. All radiographs under investigation were standardized cephalograms and were traced manually. The tracings were then scanned and the superimpositions of Johnston and Björk were performed with the aid of a computer system (Deneba Canvas®, version 3.5.3, South Miami, Florida).

Pitchfork superimposition of Johnston

The tracings were superimposed as described by Johnston (1985, 1996). All measurements are defined positive if they contribute to Class II correction and negative if they aggravate the Class II relationship. For instance, a forward movement of the maxilla or upper dentition would result in negative numerical values, whereas a similar movement of mandible or lower teeth would be positive.

For *skeletal measurements*, the tracings were superimposed on the nasal line, with the maximum coincidence along the anterior contour of the keyridge and the lingual palatal curvature (Figure 2). Any maxillary rotational effects, which might have occurred, were thus eliminated. It has to be understood that, when a rotational repositioning becomes necessary to reach coincidence of the nasal lines, all structures to be analysed would be repositioned accordingly. After the maxillary superimposition was completed, the functional occlusal planes at the initial and final stages were determined and then averaged (Johnston, 1985) so as to obtain the mean functional occlusal plane (MFOP).

The maxillary skeletal change (Max, Figure 1) was measured at the intersection point of the

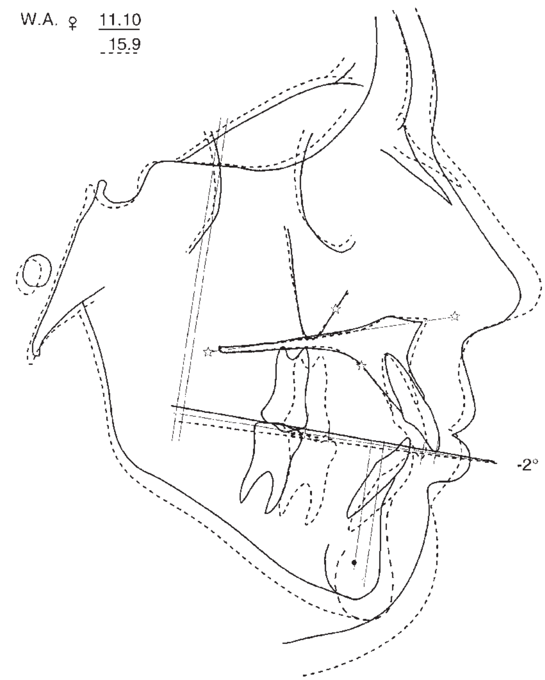

Figure 2 Subject 1: pitchfork superimposition I. The superimposition (open asterisks) is on the nasal line, palatal curvature and anterior contour of the keyridge. All measurements are carried out parallel to the mean functional occlusal plane (MFOP). Max is measured at the SE-points, ABCH at the D-points, upper molar change at the mesial contact points and incisor-change at the incisal edges. Additionally, the tipping angle of the upper molars can be evaluated.

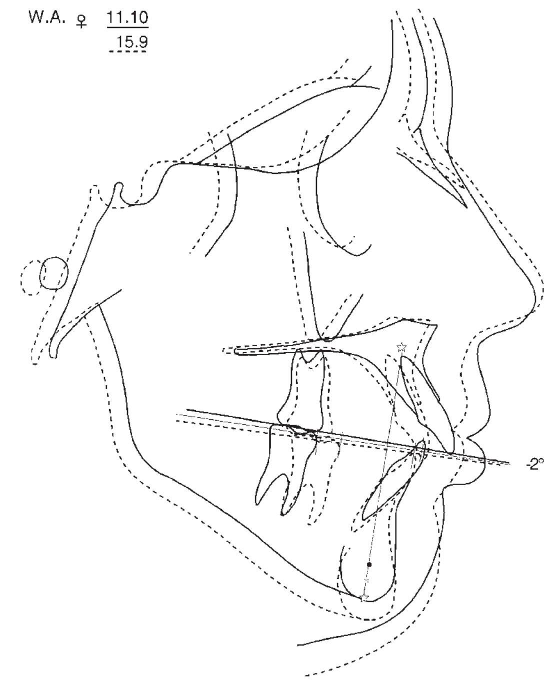

Figure 3 Subject 1: pitchfork superimposition II. The tracings are displaced along the MFOP until the D-points are lying on a common perpendicular line (open asterisks) to MFOP. Again all measurements are undertaken parallel to MFOP. Lower molar change is measured at the mesial contact points and incisor change at the incisal edges. In addition, the tipping angle of the lower molars can be evaluated.

cribriform plate and greater wing of the sphenoid bone (point SE), parallel to the MFOP. A backward movement of point SE corresponds to a forward movement of the maxilla, which is expressed in negative values.

The apical base change (ABCH, Figure 1) was measured in the same way at point D, which is the geometric centre of the symphysis, transferred from the pre- to the post-treatment radiograph by a local structural superimposition of the mandible. The mandibular skeletal change (Mand, Figure 1) was obtained by subtracting the value of Max from that of ABCH.

For *dental measurements*, the change for the upper molars (Figure 2) was measured at their mesial contact points and the change of the upper incisors at their incisal edges. The shift in axial inclination of the molars (Θ) was not registered in this study. Thereafter, the tracings were displaced along the MFOP until the D-points were lying on the same perpendicular line to MFOP (Figure 3). The changes for the lower molars and incisors were then recorded. The molar intercuspation change could be calculated by the addition of ABCH, and upper and lower molar measurements. The overjet change was derived by summing of the values of ABCH, and upper and lower incisor recordings.

The accuracy of the calculated values was tested by comparing these with direct measurements on the tracings. For this, the tracings were realigned so that the mesial contact points of the upper molars were positioned on a common perpendicular line to the MFOP (Figure 4). The direct measurement data of the molar intercuspation change was obtained by gauging

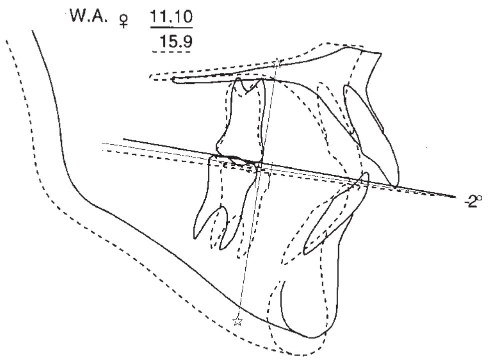

Figure 4 Subject 1: pitchfork superimposition III. The tracings are displaced again until the mesial contact points of the upper molars are lying on a common perpendicular line (open asterisks) to MFOP. The molar intercuspation change is measured at the mesial contact points of the lower molars. This measurement can be compared with the calculated intercuspation change. The difference should not exceed 0.2 mm.

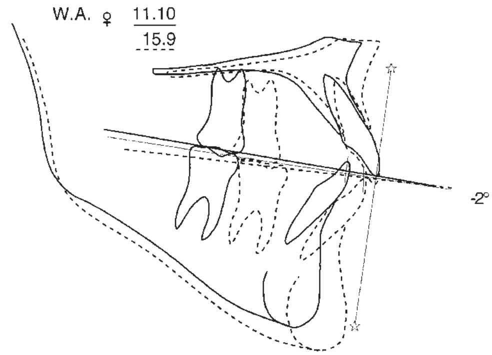

Figure 5 Subject 1: pitchfork superimposition IV. The tracings are displaced again until the incisal edges of the upper incisors are lying on a common perpendicular line (open asterisks) to MFOP. The overjet change is measured at the incisal edges of the lower incisors. This measurement can also be compared with the calculated overjet change. The difference should not exceed 0.2 mm.

the shift of the lower molar mesial contact point parallel to the MFOP. If the difference between the calculated (6/6, Figure 1) and the directly measured values exceeded 0.2 mm, then the recordings were remeasured. The overjet change was recorded and compared with that of the calculated value (1/1, Figure 1) after superimposing on the incisal edges of the upper central incisors (Figure 5). The anterior wall of sella was used instead of point SE for the Teuscher-group as point SE was not available from Teuscher's data. This change is not assumed to affect the results as the distance between the anterior wall of the sella and point SE is constant from the age of about 8 years.

The results obtained were entered in the pitchfork diagram (Figure 6).

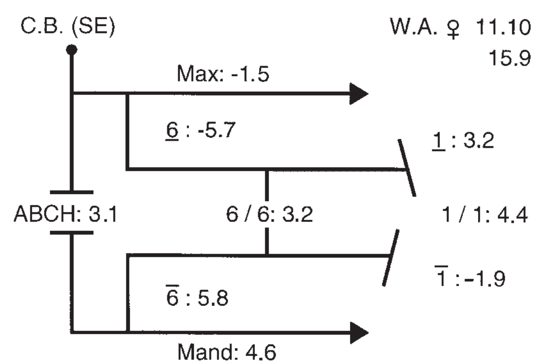

Figure 6 Subject 1: pitchfork-diagram.

Structural superimposition of Björk

The superimpositions were carried out as described in detail by Björk and Skieller (1983). At the present time, *local superimpositions* based on the described structural criteria are the closest methodological approach to implant superimposition (Baumrind *et al.*, 1987a,b; Nielsen, 1989). For the maxilla, the criteria for approximation to an implant-based superimposition are the following: superimposition on (i) the anterior contour of the keyridge and (ii) identical trabecular structures, (iii) height gain equally in a cranial and caudal direction and (iv) the anterior nasal spine translating mainly caudally (Figure 7). For the mandible, the structures for superimposition are (i) the anterior and inferior part of the inner contour of the symphysis, (ii) the mandibular canal, (iii) the cortical base of the wisdom tooth-germs prior to root development and (iv) identical trabecular structures (Figure 7).

For this investigation, additional landmarks were established which were not subjected to local remodelling as they were transferred from

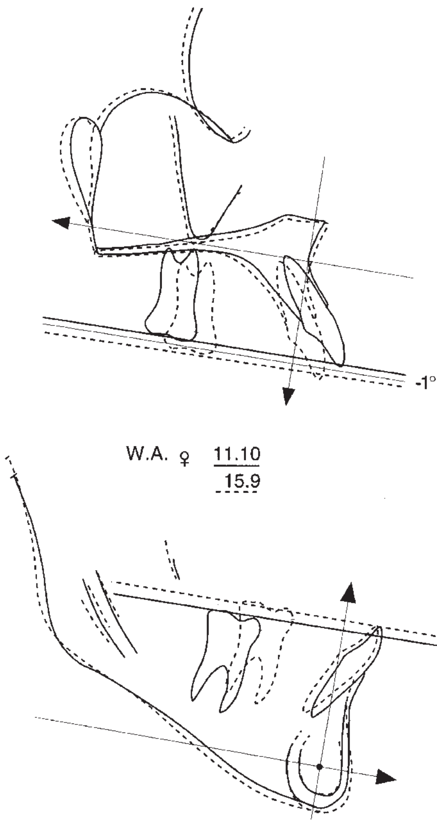

Figure 7 Subject 1: local structural superimpositions of Björk. The co-ordinate system is orientated parallel and rectangular to the mean occlusal plane, drawn at points A and D of the first radiograph. The changes of the mesial contact points of the molars and those of the incisal edges are measured. The occlusal plane angulation changes are also measured.

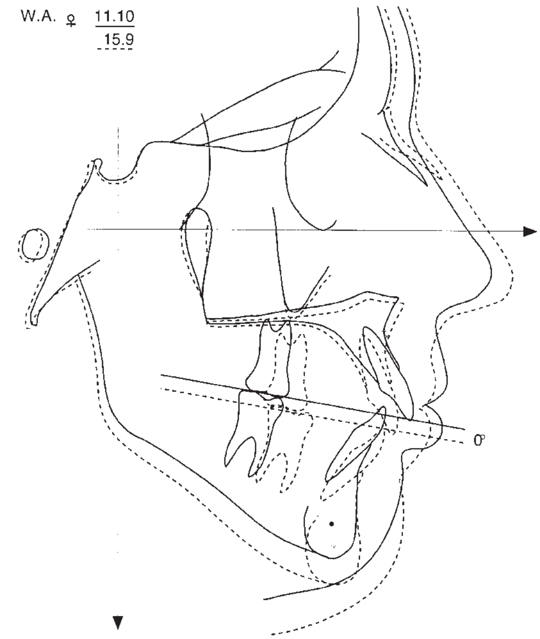

Figure 8 Subject 1: structural superimposition of Björk at the cranial base. The Frankfort Horizontal (FH) of the first radiograph is chosen as the *x*-axis. The *y*-axis is the perpendicular line to FH through sella. The maxillary change is measured at point A. To compensate for remodelling, point A of the first radiograph is transferred to the second by a local structural superimposition (Figure 7) of the maxilla (point A'). The same is undertaken for point D. The change of occlusal plane angulation is also measured and usually differs from the changes in local superimpositions.

the first to the second radiograph by the use of local structural superimposition. Because of this, the local superimpositions were undertaken first. For the maxilla, the most concave point of the anterior contour (point A) of the initial radiograph was transferred to the second and labelled A'. For the mandible, the geometric centre of the symphysis, point D, was established accordingly.

Coordinate systems with the *x*-axis orientated parallel to the MFOP were established in each jaw in order to obtain data directly comparable to those of Johnston's procedure. It has to be emphasised that the superimpositions were performed using the structural criteria of Björk and that only the coordinate systems were orientated along the MFOP. The *y*-axes were established as lines perpendicular to the MFOP, passing through A' for the maxilla and D for the mandible. The sagittal changes of the mesial contact points of the molars and those of the incisal edges were recorded to these coordinate systems (Figure 7).

For the *total changes* (Figure 8) the tracings were superimposed on the anterior cranial base (cribriform plate, fronto-ethmoidal crest, orbital roof, anterior wall of the sella, inner corticalis of the frontal bone; Björk and Skieller, 1983). For correct rotational repositioning, care has to be taken, in addition to these criteria, so that the

Table 1 Subject 1: records of the structural superimposition of Björk and comparison with the Pitchfork Analysis*.

Variable	Sagittal	Difference PFA-structural	Difference relative to structural (%)
Skeletal measurements relative to FH			
Point A	–0.3	(–1.2)	—
Point D	0.4	4.2	1050.0
'ABCH'	0.1	(3.0)	—
Point A'	–0.8	–0.7	–87.5
'A'BCH'	–0.4	3.5	875
Nasal line rotation: +2°			
Dental measurements relative to MFOP			
upper 6	–4.7	–1.0	–21.3
lower 6	6.8	–1.0	–14.7
upper 1	4.3	–1.1	–25.6
lower 1	–0.8	–1.1	–137.5

* Positive values indicate Class II correction; negative values indicate Class II aggravation.

changes of all structures (cranial vault, nasal bone, occipital bone) are the logical outcome of growth: the bone-translocation must always be in an expanding direction. A coordinate system with the Frankfort Horizontal (FH) of the first cephalogram as x-axis was drawn. The FH was preferred to the nasion–sella–line because changes in profile are expressed closer to the facial development as it is perceived clinically. The sella–vertical was established as the y-axis perpendicular to FH.

As a modification to the usual procedure, the positional changes of the maxilla were also analysed after transferring point A of the first radiograph to the second (point A') by local structural superimposition. Thereby, the remodelling activity at the point A region, which can cause significant errors in interpreting maxillary displacement, was excluded. An analogous procedure was applied to the mandible, where point D was chosen.

The *sign convention* for the structural analysis is the same as that of the PFA, namely, maxillary, mandibular, and dental values in a Class II corrective direction are positive, but negative in a Class II aggravating direction. This enabled a direct comparison of the data obtained by Björk's and Johnston's methods.

Rotations were also recorded in the overall superimposition. Posterior (or clockwise) rotations of the nasal line and occlusal plane were labelled positive, and anterior (or anti-clockwise) rotations negative. The apical base changes were calculated by the addition of the sagittal changes for D, and A or A' values.

Comparison of the two methods

The data of the structural superimpositions of Björk were compared with those of the PFA so as to arrive at quantitative differences between the two procedures. Changes of the A- or A'-, and D-points (Table 1) correspond to Max and Mand (Figure 6), sagittal ABCH or A'BCH and dental changes (Table 1) correspond to ABCH and dental changes in the PFA-diagram (Figure 6).

Results

The superimpositions of the PFA for the two individual cases and for Teuscher's 1988 sample are shown in Figures 2–5, 9, and 13, respectively. Those for the Björk's analysis are presented in Figures 7–8, 11, 12, and 15. The quantitative sagittal results derived from the PFA are charted in Figures 6, 10, 14, and those of the structural analysis are summarised in the Tables 1, 2 and 3. The tables also include the differences in the sagittal results obtained by the two methods ('Difference PFA–structural') and as percentage

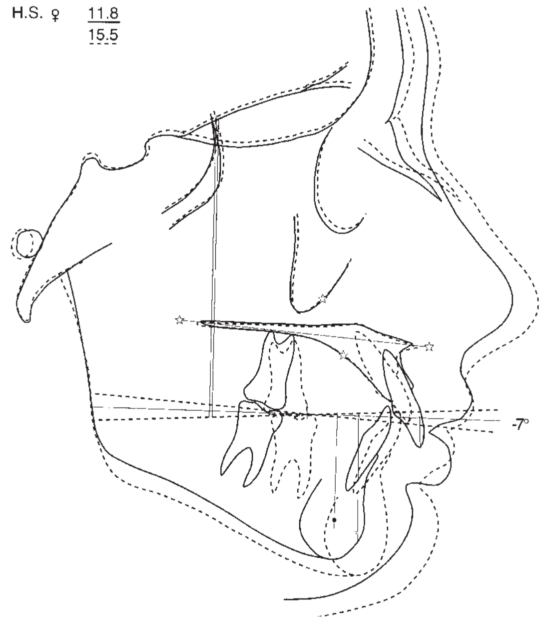

Figure 9 Subject 2: pitchfork superimposition I.

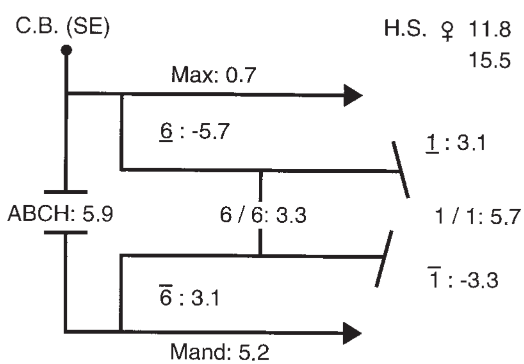

Figure 10 Subject 2: pitchfork-diagram.

deviations from the absolute structural measurement ('Difference relative to structural [%]'). If the structural measurements were smaller than 0.4 mm, the percentage deviations would have become meaninglessly large and were, therefore, not calculated (hyphen, Tables 1–3). Measurements, which included point A were placed in parentheses because the influence of remodelling on this landmark permitted comparisons with certain reservations only.

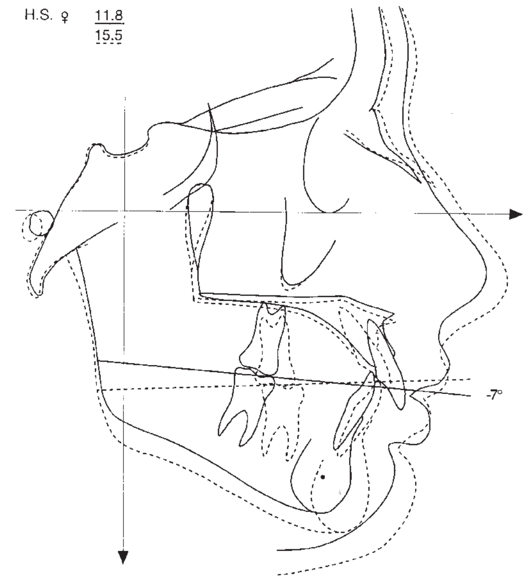

Figure 11 Subject 2: structural superimposition of Björk at the cranial base.

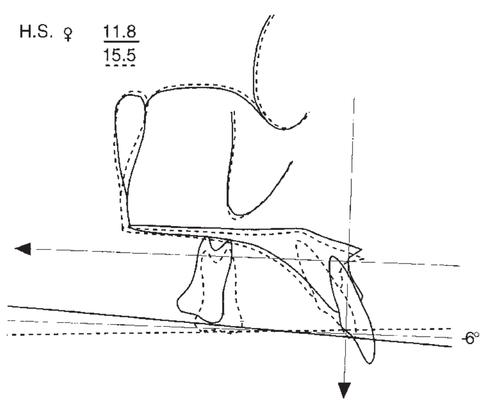

Figure 12 Subject 2: local structural superimposition of Björk. Note significant remodelling of the point A region.

Case 1

A female patient who was treated between the age of 11 years 10 months and 15 years 9 months. The patient received orthodontic treatment following extraction of the upper first and lower second premolars because of the skeletal high angle pattern and severe crowding in the lower arch. As there was almost no sagittal growth

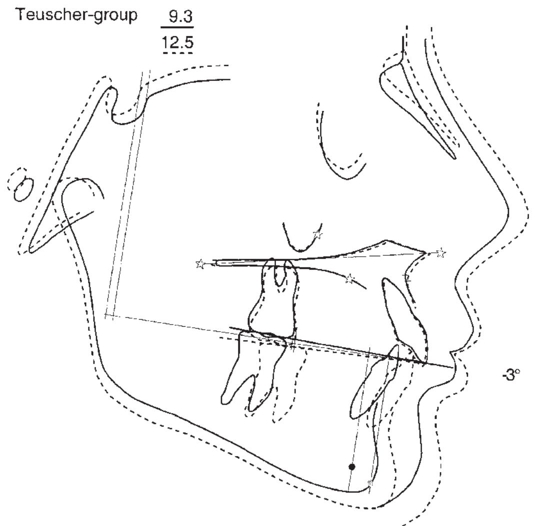

Figure 13 Teuscher's group: pitchfork superimposition I. The anterior wall of the sella was used instead of point SE.

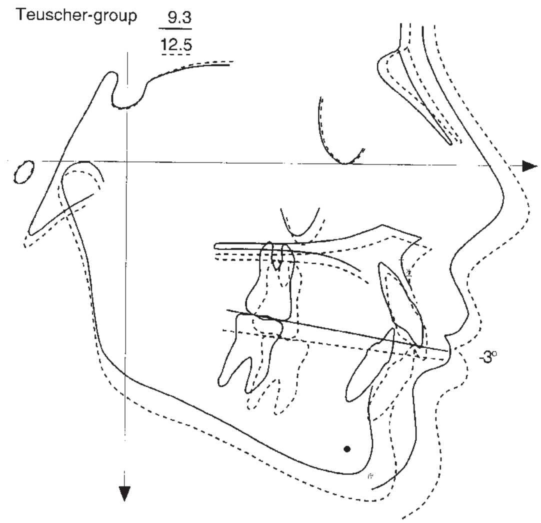

Figure 15 Teuscher's group: structural superimposition of Björk at the cranial base.

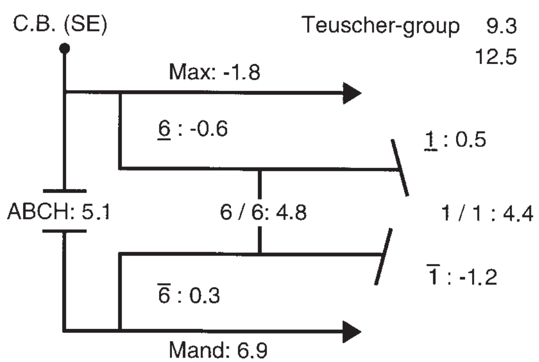

Figure 14 Teuscher's group: pitchfork-diagram.

of the mandible and as the overbite became negative during treatment, it was decided to use simultaneously a Jasper Jumper and a posteriorly rotating high-pull headgear fixed to the upper second molars. This was intended to cause a posterior rotation of the upper dentition that would result in closure of the bite.

Forward mandibular displacement amounted to 4.6 mm by the PFA (Figures 2 and 6). In the structural superimposition, however, the chin (point D) almost exclusively moved downward (Figure 8); the sagittal change of point D was only 0.4 mm (Table 1). The difference of 4.2 mm represents 1050 per cent of the structural measurement. The maxillary forward translation observed by the PFA appeared twice as much as that recorded by the structural analysis. The ABCH was 3.1 mm with the PFA as against a value of nearly zero in the structural analysis. When point A' was chosen, the structural analysis even gave negative values for A'BCH. On the other hand, the values for the dental components using the PFA were smaller than those obtained by the structural analysis (Figure 6, Table 1). In comparison with the PFA, a difference of 15–25 per cent of the structural measurements could be observed for the molars and upper incisors and 138 per cent for the lower incisors.

The structural overall superimposition exhibited a posterior rotation of the nasal line (ANS–PNS) of 2 degrees (Figure 8, Table 1). Accordingly, the maxillary superimposition with the PFA resulted in an anterior rotation of the second tracing by –2 degrees (Figure 2).

Case 2

This female adolescent patient with a tendency for a hypodivergent facial pattern was treated between the age of 11 years 8 months and

Table 2 Subject 2: records of the structural superimposition of Björk and comparison with the Pitchfork Analysis*.

Variable	Sagittal	Difference PFA-structural	Difference relative to structural (%)
Skeletal measurements relative to FH			
Point A	1.8	(–1.1)	(–61.1)
Point D	5.1	0.1	2.0
‘ABCH’	6.9	(–1.0)	(–14.5)
Point A’	0.1	0.6	—
‘A’BCH’	5.2	0.7	13.5
Nasal line rotation: –1°			
Dental measurements relative to MFOP			
upper 6	–4.8	–0.9	–18.8
lower 6	4.6	–1.5	–32.6
upper 1	4.3	–1.2	–27.9
lower 1	–1.8	–1.5	–83.3

* Positive values indicate Class II correction; negative values indicate Class II aggravation.

Table 3 Teuscher’s group: records of the structural superimposition of Björk and comparison with the Pitchfork Analysis*.

Variable	Sagittal	Difference PFA-structural	Difference relative to structural (%)
Skeletal measurements relative to FH			
Point A	–1.9	(0.1)	(5.3)
Point D	5.8	1.1	19.0
‘ABCH’	3.9	(1.2)	(30.7)
Point A’	–1.7	–0.1	–5.9
‘A’BCH’	4.1	1.0	24.4
Nasal line rotation: 0°			
Dental measurements relative to MFOP			
upper 6	–0.4	–0.2	–50.0
lower 6	1.2	–0.9	–75.0
upper 1	0.8	–0.3	–37.5
lower 1	–0.3	–0.9	—

* Positive values indicate Class II correction; negative values indicate Class II aggravation.

15 years 5 months. The patient had a starting clinical situation of a cusp-to-cusp molar relationship with severe crowding in the lower arch requiring the removal of the lower second and upper first premolars. In addition, the patient wore a high-pull headgear. As no sagittal displacement of the maxilla could be observed, the compliance of the patient must have been excellent. Consequently, the patient developed a Class III tendency. In order to compensate and to avoid an eventual surgical intervention, it was decided to rotate the occlusal plane in the anti-clockwise direction by using a cervical headgear with an anterior rotational effect and Class III elastics.

The occlusal plane was markedly rotated in an anterior direction (anti-clockwise; Figure 9). Since significant remodelling in the point A region occurred (Figure 12), a large difference between displacement of cephalometric A- and structural A'-point (1.8 versus 0.1 mm, Table 2) could be observed. The PFA resulted in data suggesting a backward movement of the maxilla by 0.7 mm, but the structural superimposition revealed stability of the upper arch. The translation of the symphysis was almost identically recorded in both superimposition procedures. The difference for the A'BCH between the two methods was thus identical to the difference in maxillary displacement. The estimates of the dental changes by the PFA were consistently smaller than with Björk's analysis and ranged from –0.9 to –1.5 mm (–19 to –83 per cent of the structural measurements).

Mean group results

This group of 26 patients were treated with an activator-headgear-appliance by Teuscher (Teuscher, 1978, 1988; Stöckli and Teuscher, 1994) between the mean ages of 9 years 3 months and 12 years 5 months. The treatment was carried out without extraction of permanent teeth. The appliance consisted of an acrylic monobloc with sagittal pre-activation and torquing springs for the upper incisors and a high-pull headgear counteracting the anti-clockwise rotation of the upper dentition and jaw caused by the monobloc. Therefore, the group-average nasal line angulation was found to be identical before and after treatment (Figure 15, Table 3). The maxillary skeletal measurements did not differ between the two methods (Figure 14, Table 3). Point D was transferred 6.9 mm sagittally and the ABCH amounted to 5.1 mm with the PFA. These measurements were approximately 1 mm larger than those derived by the structural analysis (19 and 24 per cent deviations). The differences for the upper dentition were quite small, although the percentage deviation was quite impressive as the structural measurements were only –0.4 and 0.8 mm. The lower dental measurements were approximately 1 mm smaller with the PFA than those obtained by the structural analysis.

In general, for all cases, there was a tendency for larger skeletal and smaller dental changes with the PFA when compared with Björk's analysis.

Discussion

This study sought an objective evaluation of the PFA against the more established structural analysis of Björk. The results revealed important differences between the methods, essentially stemming from two geometric effects.

Maxillary skeletal rotation

Skeletal changes. The practice of local maxillary superimposition in the PFA to interpret skeletal changes of the maxilla and mandible in relation to the cranial base appears to have misleading consequences. It must be pointed out that the PFA does not take into account the impact of maxillary rotations that may occur during treatment as is evident from the statement: 'On average, however, maxillary basal rotation is minimal and thus, its effect on the analysis is probably neglible' (Johnston, 1996). On the other hand, Björk and Skieller's (1976, 1977a,b) implant studies have clearly shown that there is an average maxillary skeletal rotation of –2.5 degrees. A rotation of –1.5 degrees was reported for the maxilla in adolescent girls by Iseri and Solow (1990). As there is greater resorption in the anterior part of the nasal floor, this maxillary rotation is generally obscured. However, quite marked rotation of the nasal line can occur in certain cases during the active treatment phase if eccentric force vectors are applied with particular designs of headgears (Teuscher, 1986) or with highly efficient appliances such as the Herbst (Pancherz, 1982, 1984) or Jasper Jumper (Blackwood, 1991; Cash, 1991; Cope *et al.*, 1994).

In this study, the effect of a pure maxillary rotation of 4 degrees in an otherwise identical situation was investigated (Figures 16 and 17). If an anterior rotation of the maxilla occurs (Figure 16), the second radiograph must be rotated in a clockwise direction to superimpose on the nasal line. Consequently, all other landmarks such as points SE, A and D are also rotated in the same direction, thereby causing 'skeletal translatory effects' in the PFA. Maxillary 'retrusion' and a quite significant negative ABCH are revealed, although there was no biological change, but a pure rotation of the nasal line. This effect is the

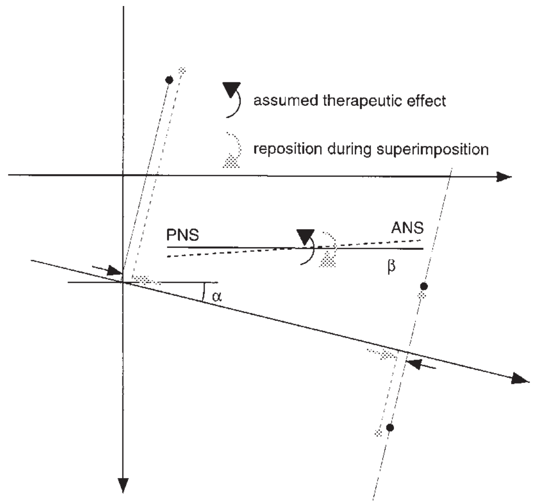

Figure 16 Influence of a pure anterior rotation of the nasal line on the skeletal measurements. It is assumed that the only therapeutic effect was an anterior rotation of the nasal line of –4 degrees (black). In PFA superimposition I, the second radiograph is rotated in a clockwise direction (grey) to superimpose the nasal line. All the other landmarks (points SE, A, and D) are also rotated, thereby giving the erroneous impression that the maxilla and the mandible have been forced back.

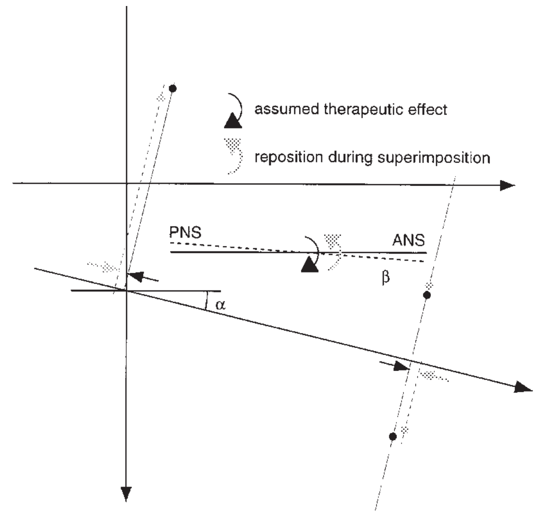

Figure 17 Influence of a pure posterior rotation of the nasal line on the skeletal measurements. It is assumed that the only therapeutic effect was a posterior rotation of the nasal line by 4 degrees (black). The second radiograph is rotated in an anti-clockwise direction (grey) to superimpose the nasal line. All the other landmarks are rotated in the same direction thereby giving the wrong impression, that the maxilla has 'grown forward' and the mandible 'has grown even more'.

main cause for the differences found in subject 2 (Figures 9–12, Table 2), where a backward movement of the maxilla by 0.7 mm with the PFA, but stability of the upper arch with Björk's method were observed. Even with very good patient compliance, blockage of anterior maxillary displacement was not anticipated at this age, but absolute backward movement of the maxilla was never observed by this investigator. This suggests that the PFA does not reflect the real biological effects.

If the maxilla has rotated in a clockwise direction (Figure 17), the opposite would occur with the result that the upper jaw would appear to have 'grown forward', thereby eliminating headgear effects and the mandible would seem to have 'grown forward', even more. This situation was observed in subject 1 (Figures 2–8, Table 1), in which the nasal line was rotated by 2 degrees (clockwise rotation). With the PFA, the maxillary forward movement was observed to be twice as large as that with the structural analysis, although a high-pull headgear with a force-vector below the centres of resistance and a Jasper Jumper had been used. The inhibitory effect of the appliances on the maxilla may have partly been hidden by the PFA. The ABCH and mandibular advancement have been enhanced when compared with the data obtained by the structural analysis, although the facial profile did not improve. This means that the skeletal Class II correction was substantial when the interpretation was based on the PFA, but non-existent with Björk's analysis. These PFA effects give the impression that the treatment resulted in substantial and desirable skeletal changes although those changes were only rotational compensational effects.

Dental changes. Local superimposition of the maxilla, orientated to the nasal line, is quite reliable for evaluating the sagittal dental changes in the upper arch. However, for long-term observation, the structural method is preferable to the nasal-line-superimposition because of uneven remodelling at the nasal floor (Björk and Skieller, 1956; Iseri and Solow, 1990) and the true appearance of the vertical development of the

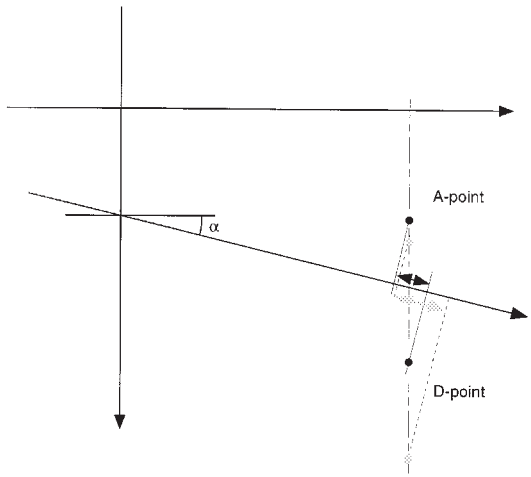

Figure 18 Influence of pure vertical growth on the skeletal measurement of the ABCH. It is assumed, that the only effect was vertical growth of maxilla and mandible. As the mean functional occlusal plane is usually not parallel to FH, with the pitchfork analysis, a significant apical base change is recorded.

dentoalveolar structures. For the lower dentition, sagittal superimposition of the mandible with the nasal lines orientated parallel to each other is absolutely unreliable, even when registered on point D, because both the maxilla and the mandible can undergo rotation during treatment, which may have vertical and sagittal consequences. Therefore, dental changes in the lower arch must be evaluated by structural superimposition of the mandible itself. This local structural superimposition is essential for the PFA just to define point D, but not to analyse the dental changes as it does not fit the mathematical procedure.

Measuring parallel to the occlusal plane

The problem of using the occlusal plane to interpret skeletal changes should be considered. The occlusal plane is highly individual for every patient. If there is a high-angle situation with a steep occlusal plane, pure vertical growth is partly interpreted as sagittal changes (Figure 18). Furthermore, there may not be any change in profile, particularly of the chin area. Even if there is no rotation of the maxilla, mandible and occlusal plane, this effect would give the illusionary impression that the skeletal pattern of high-angle cases can be changed quite markedly. This appears to have been the situation with respect to subject 1 (Figure 2–8, Table 1), where the PFA indicates a sagittal skeletal gain of 3.1 mm (ABCH, Figure 6), as against a loss of 0.4 mm in reality (A'BCH, Table 1).

If the occlusal plane were rotated during treatment, the reference system (MFOP) would also rotate by half of the measurement unit in the same direction. A rotation in the posterior direction (clockwise) would result in the occlusal plane becoming steeper and the reference system gaining a more favourable position to suggest positive skeletal changes in Class II cases. This is because a certain amount of the vertical change is interpreted as sagittal effect (Figure 18). An anti-clockwise rotation of the occlusal plane would result in less vertical changes being interpreted as sagittal improvement, as the occlusal plane is almost parallel to FH. Such anterior rotation of the occlusal plane is rather rare following treatment of Class II cases, but occurred in subject 2. That is why the outcomes of the two systems of analysis did not reveal extreme differences (Figure 10, Table 2). This point is highlighted in the evaluation of the Teuscher group where, no maxillary rotation but minor anterior occlusal rotation occurred. The differences were more obvious in the mandibular skeletal aspects and smaller in the dental components (Figure 14, Table 3). The levelling of the individual data was not the cause for the small differences. It can be attributed to the fact that, on average, there was no rotation of the nasal line nor a significant steepness of the occlusal plane.

Only in the absence of maxillary, mandibular, and occlusal plane rotations can the findings of the PFA be of value. It then informs about the skeletal and dental changes in the single dimension of the individual occlusal plane. In order to find out whether rotations occurred, structural superimpositions have to be under-taken in any case, which provide more information than the PFA because they contribute sagittal and vertical dimensions.

In this context, it may be pointed out that Pancherz (1982) also suggested a similar method in which Downs occlusal plane, instead of MFOP and a different mathematical model were used. The basic difference was the use of the cranial base instead of the maxilla for superimposition. Johnston appears to be the initiator of local maxillary superimposition to evaluate skeletal changes for both arches. In most of the classic superimposition methods such as those of Brodie (1941), Steiner (1953), Björk (1955), Björk and Skieller (1956, 1976, 1977a,b, 1983), Broadbent (1935, 1937) and Ricketts (1960, 1979) the cranial base, or FH is used in some way or other as the reference structure to evaluate skeletal changes of the maxilla and mandible, and the differences among those methods are quite minimal (Ghafari *et al.*, 1987).

Taken together, although the PFA is impressive by its mathematical simplicity, the conclusions reached regarding the facial and dental response to treatment differ substantially from Björk's superimposition methods. It must be borne in mind that the PFA is a one-dimensional assessment of two-dimensional recordings of three-dimensional events resulting in limited and possibly inaccurate interpretations. In order to evaluate the percentage contribution of the dental and the skeletal therapeutic effects of any orthodontic appliance, new approaches, combining the mathematical advantages of the PFA with the precision of Björks superimpositions, have to be developed.

Conclusions

The results of the critical evaluation of the PFA in comparison with the structural superimposition of Björk indicate that the PFA is not sufficiently sensitive to differentiate between dental and skeletal changes. This is particularly so if appliances with a potential rotational effect on the upper arch have been used or if the patient has a steep occlusal plane. The visual effects that can be recorded by the classic structural superimpositions of Björk were found to be of greater clinical reliability.

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