Four measurements for assessing facial deformity

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SUMMARY Four lateral cephalometric measurements which localize the anterior maxilla and chin in the horizontal and vertical planes are presented and evaluated against three control methods, in a pilot study of 40 patients. It was found that in 27 out of 30 comparisons (90%) the frequency of agreement between the proposed and each of the control methods was greater than the agreement between the control methods themselves. In three out of 30 comparisons (10%) it was found that the frequency of agreement between the proposed and the control methods was the same as between the controls themselves.

In addition, there was a greater agreement reached between methods when measurements were related to the cranial base. In view of the close relationship between cranial and facial development, it was considered that measuring ratios should portray the facial deformity not just in relation to the cranial base but to the individual's own cranial base and not to a population norm. The results also confirm the findings of previous work in the literature which demonstrate disagreement between cephalometric methods for localization of a given landmark.

Introduction
Traditional methods of cephalometry are based on the measurement of ratios between selected landmarks (Sassouni, 1955; Sassouni and Nanda, 1964; Moorrees and Lebret, 1962; Broadbent et al., 1975) or on quantitative analysis (Björk, 1947; Downs, 1948; Vohies and Adams, 1951; Reidel, 1952; Margolis, 1953; Steiner, 1953; Enlow, 1990; Enlow et al., 1971). Some current methods of measurement have come under criticism as they were reported to be inconsistent (Järvinen, 1986; Proffit and White, 1991) and also when compared with each other (Wylie et al., 1987). Methods relying on quantitative analysis possess certain disadvantages when compared with those based on ratios; for example, numerical values stated to be average for a given population may not match the average for a given individual. Again, the magnification factor on a lateral cephalometric radiograph could prejudice the quantitative measurement of landmarks which are not in the midsagittal plane, as these may be differentially magnified (Fanibunda, 1983). Enlow et al. (1971) advocated a counterpart analysis method in which cranial and facial structures of an individual were compared with each other rather than with a population norm. However, this was not intended to be used as a routine tool in diagnosis as current treatment is not usually based on correction of the underlying cause of the deformity (Enlow, 1990). Broadbent et al. (1975) in their classical study measured >5000 male and female Caucasian faces which showed optimum facial and dental development and produced a standard Bolton face for each year, from 1 to 18 years of age. It is unlikely that such a classical study will be repeated in view of current guidelines on radiation protection.

The purpose of this pilot study was to investigate how cephalometric ratio measurements could be related to the individual's own cranial base and to probe further into the question of inconsistencies between current methods of analysis. Four measurements constructed on ratios related to the individual's own cranial base are described and evaluated against three methods of cephalometric analysis in routine use, on a series of lateral cephalometric radiographs of 40 individuals.

Materials and methods
The ratios of the proposed method were derived from the 18-year Bolton standard lateral face template (Broadbent et al., 1975) which were
used as the population for the study. The ratios were initially obtained by superimposing an acetate sheet over the 18-year Bolton template and identifying the landmarks for the construction of the hexagonal pattern to be described. In order to analyse the lateral cephalometric radiograph of a given individual according to the proposed method, the profile was traced on the acetate sheet and the hexagonal pattern constructed as described below. Any deviation of the individual’s ratios from those of the standard were then noted.

All landmarks were identified under a powerful fibre-light source (Charles F. Thackray Ltd, Leeds, UK). This facility helped to trace structures clearly and reduced any objection for not using a valuable landmark, such as the anterior nasal spine. Each landmark was identified after taking an average of two readings, in order to minimize operator error. The distance between two points, the posterior clinoid process (P) and the nasion (N), was measured. Point P was taken as the mid-point of a line joining the most superior aspect of the right and left posterior clinoid processes respectively. It will be appreciated that nasion may shift during growth; however, this preliminary study has been confined to the 18-year and over age range.

A hexagon was constructed based on the distance P-N (Figure 1). For convenience, the corners of the hexagon were labelled according to the anatomical structure they opposed, e.g. the posterior clinoid process (P), the nasion (N), the lips (L), the chin (C), the mandibular lower border (M), and the occipital bone (O). The diagonal corners of the hexagon were joined to form the central axes PC, NM, and LO, which intersected at a central point. A point just posterior to the anterior nasal spine was constructed by projecting a line upward through point A, perpendicular to and intersecting the ANS-PNS plane; the mid-point between this intersection and the anterior nasal spine was designated as point J (Figure 2).

A hexagonal pattern was constructed on the Bolton profile, using its PN distance (Figure 1). The aim was to obtain the exact proportion of the Bolton face by means of ratios and the standards mentioned below reflect the measurements of the ideal 18-year old face. In view of the inherent margin of error introduced during tracing of structures, the measurements were

Figure 1  Construction of hexagon based on the PN distance of the 18-year standard Bolton profile. P, N, L, C, M, O are corners of the hexagon; S = centre of sella; pt J = point J; ANS = anterior nasal spine; PNS = posterior nasal spine; pt A = point A; pt B = point B; Pg = pogonion; Gn = gnathion; Me = menton; Go = gonion; FH = Frankfort horizontal plane.
judged to within ±2 mm for a particular landmark.

Standard ratios thus obtained were recorded and compared with the hexagonal pattern ratios of a given individual. As the manual operation required construction of a hexagonal pattern for each individual patient and comparison with standard ratios, a computer program, GELA, was written in 'C', which implements its own geometric language, thus enabling this exercise to be completed automatically and any standard deviations for a given landmark to be identified.

The following structures were measured:

1. Anterior maxilla, horizontal plane.
2. Anterior maxilla, vertical plane.
3. Pogonion, horizontal plane.
4. Gnathion, diagonal, horizontal, and vertical planes.

Reliability of the proposed method

The lateral profile tracings of 40 individuals of Caucasian origin were analysed by the proposed method and the results compared against three methods of cephalometric analysis in routine use. Of these, 30 cases comprised Broadbent's good faces (15 male, 15 female, all 18 years of age), and 10 cases (four male, six female, aged 18–39 years) were patients attending the Royal Victoria Infirmary, Newcastle upon Tyne, UK, whose main feature was mandibular protrusion.

The control methods used for comparison were the Conventional, Ricketts, and Bolton analyses. In addition, the control methods were also compared with each other, so that a base line could be obtained for evaluating the proposed method. Under the 'Conventional method' were grouped a collection of frequently employed cephalometric measurements which are commonly used in teaching institutions (Table 1). Reidel (1952) related the cranial base to the maxilla and mandible, respectively, in the midsagittal plane by using the angle, centre of sella-nasion point A (SNA) and the angle, centre of sella-nasion point B (SNB). The measurements anterior upper face height (AUFH) and anterior lower face height (ALFH) are calculated by assuming that if the distance between N and menton were 100%, then ideally the AUFH from N to a point perpendicular to the maxillary plane should be 45% and the ALFH between the maxillary plane and menton should be 55% (Riolo et al., 1974). Ricketts' measurement included a series of analyses compiled by Gugino (Figure 3), based mainly on Ricketts' studies (Ricketts, 1961, 1975; Gugino, 1977; Ricketts et al., 1979). Bolton's cephalometric analysis was based on the method described by Broadbent et al. (1975) which superimposes the 18-year Bolton standard profile template on each of the tracings under examination, at the Bolton Registration point

Table 1 Measurements used for comparison between Proposed, Conventional, Ricketts, and Bolton methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>Anterior maxilla, horizontal plane</th>
<th>Anterior maxilla, vertical plane</th>
<th>Chin, horizontal plane</th>
<th>Chin, vertical plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed</td>
<td>NC intersects point J</td>
<td>N-J = 3/4 P-N minus ANS-J</td>
<td>i) Pg-N-C = 3.5-4°</td>
<td>Gn-P = 1.75 P-N</td>
</tr>
<tr>
<td></td>
<td>SNA = 81°</td>
<td>AUFH = 45°</td>
<td>ii) Gn-P = 1.75 P-N</td>
<td>vertical component</td>
</tr>
<tr>
<td>Conventional</td>
<td>Maxillary depth = 90° ± 3°</td>
<td>Maxillary height = 56.6° ± 3°</td>
<td>SNB = 79°</td>
<td>ALFH = 55%</td>
</tr>
<tr>
<td>Ricketts</td>
<td>Point J (Proposed)</td>
<td>Point J (Proposed)</td>
<td>Facial depth = 90° ± 3°</td>
<td>Facial axis angle 90° ± 3°</td>
</tr>
<tr>
<td>Bolton*</td>
<td>SNA (Conventional)</td>
<td>AUFH (Conventional)</td>
<td>i) Pg ii) Gn (Proposed)</td>
<td>Gn (Proposed)</td>
</tr>
<tr>
<td>Point A (Ricketts)</td>
<td></td>
<td>SNB (Conventional)</td>
<td>ii) Gn (Ricketts)</td>
<td>ALFH (Conventional)</td>
</tr>
</tbody>
</table>

* The landmarks used for measurement of each method are shown.
Results

The standard ratios obtained following construction of the hexagonal pattern on the PN distance of the 18-year Bolton template are as follows:

1. Anterior maxilla (point J), horizontal plane. Standard: NC intersects point J (Figures 1 and 2). Point J, which represents the anterior maxilla, is assessed in the antero-posterior plane by its deviation from NC (side of the hexagonal pattern). Point J may thus be sited anteriorly to NC in a case of maxillary protrusion, or posterior to NC in case of retrusion.

2. Anterior maxilla (point J), vertical plane. Standard: N-J = \(3/4\) P-N minus distance ANS-J (Figures 1 and 2). The anterior maxilla is localized in the vertical plane by measuring the distance between N and J, which represents the anterior upper face height (AUFH).

3. Pogonion, horizontal plane. Standard: Angle C-N-Pg = 3.5–4° (Figure 1). The standard ratios are an exact reproduction of the proportions of the 18-year Bolton template and, in this instance the actual recording obtained for Pg was 3.75°. This measurement was rounded off to the nearest half a degree to take the working error into account and a range of 3.5–4.0° was given. The angle decreases in cases of mandibular protrusion and increases with mandibular retrusion.

4. Gnathion, diagonal, horizontal, and vertical planes. Standard: P–Gn = 1.75 P-N (Figure 1). It was found that the central axis PC of the hexagon intersected the gnathion on the Bolton template and the distance P–Gn was equivalent to 1.75 P–N. On an individual's lateral profile tracing, when the 'actual' gnathion does not correspond to the standard position, the horizontal and vertical components of this measurement are recorded (Figure 4).

The horizontal component of the gnathion and the angle C-N-Pg, reflects the antero-posterior position of the symphysis. The vertical component of the gnathion reflects the anterior total face height (ATFH) in relation to plane PN.

On each of the 40 profiles, a particular landmark was measured according to the Proposed, Conventional, Ricketts, and Bolton analyses. The measurement of the Proposed method was then compared with that of the Conventional, Ricketts, and Bolton methods respectively and similarly the three control methods were compared between themselves, for each landmark. As five landmarks were actually measured (two for chin horizontal) a total of 2000 readings were recorded (400 readings per landmark) on 40 profiles. Table 2 shows the degree of agreement in percentage figures between the proposed and the three control methods and Table 3, the agreement between the control methods themselves. In order to calculate the overall percentage result, each of the five landmarks were
ASSESSMENT OF FACIAL DEFORMITY

Figure 4 'Standard' and 'actual' gnathion (Gn). Orb = orbitale; Por = porion; Vert C = vertical component extending from 'standard' Gn (calculated by P-Gn = 1.75 P-N) to the 'actual' Gn (in the vertical plane) on a given profile tracing; hor C = horizontal component, extending from 'standard' Gn to the 'actual' Gn (in the horizontal plane) on a given profile tracing.

compared with the results in the six columns presented in Tables 2 and 3, giving a total of 30 comparisons. It was found that in 27 out of 30 comparisons (90.0%) the frequency of agreement between the proposed and each of the control methods, respectively, was greater than the agreement between the control methods themselves. In three out of 30 comparisons (10.0%) it was found that the frequency of agreement between the proposed and each of the control methods was the same as between the control methods themselves.

The results were further investigated to establish whether agreement was more frequent in the average or deformity section in the cases examined. An analysis of the results in Table 4 showed that in 11 instances agreement between the methods was greater in the deformity section than in the average section, and in four instances agreement was greater in the average section than in the deformity section.

Discussion

Traditionally, cephalometric methods have been derived from a population norm, and in this instance the Bolton 18-year standard template

<table>
<thead>
<tr>
<th>Structure</th>
<th>Proposed agrees with Bolton (%)</th>
<th>Proposed agrees with Conventional (%)</th>
<th>Proposed agrees with Ricketts (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior maxilla, horizontal plane</td>
<td>60.0</td>
<td>90.0</td>
<td>42.5</td>
</tr>
<tr>
<td>Anterior maxilla, vertical plane</td>
<td>65.0</td>
<td>62.5</td>
<td>72.5</td>
</tr>
<tr>
<td>Chin, horizontal plane</td>
<td>i) 72.5 (pogonion)</td>
<td>87.5</td>
<td>67.5</td>
</tr>
<tr>
<td></td>
<td>ii) 72.5 (gnathion)</td>
<td>90.0</td>
<td>65.0</td>
</tr>
<tr>
<td>Chin, vertical plane</td>
<td>57.5</td>
<td>50.0</td>
<td>62.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structure</th>
<th>Bolton agrees with Conventional (%)</th>
<th>Bolton agrees with Ricketts (%)</th>
<th>Conventional agrees with Ricketts (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior maxilla, horizontal plane</td>
<td>57.5</td>
<td>27.5</td>
<td>40.0</td>
</tr>
<tr>
<td>Anterior maxilla, vertical plane</td>
<td>50.0</td>
<td>60.0</td>
<td>55.0</td>
</tr>
<tr>
<td>Chin, horizontal plane</td>
<td>i) 72.5 (pogonion)</td>
<td>57.5</td>
<td>60.0</td>
</tr>
<tr>
<td></td>
<td>ii) 72.5 (gnathion)</td>
<td>57.5</td>
<td>60.0</td>
</tr>
<tr>
<td>Chin, vertical plane</td>
<td>50.0</td>
<td>45.0</td>
<td>40.0</td>
</tr>
</tbody>
</table>
Table 4 A comparison of agreements reached between the profile tracings of 30 average Bolton faces (aver) compared with 10 facial deformity cases (def).

<table>
<thead>
<tr>
<th>Method</th>
<th>Proposed agrees with Bolton (%)</th>
<th>Proposed agrees with Conventional (%)</th>
<th>Proposed agrees with Ricketts (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aver</td>
<td>Def</td>
<td>Aver</td>
</tr>
<tr>
<td>Anterior maxilla, horizontal plane</td>
<td>56.7</td>
<td>70.0</td>
<td>86.0</td>
</tr>
<tr>
<td>Anterior maxilla, vertical plane</td>
<td>66.7</td>
<td>60.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Chin, horizontal plane</td>
<td>i)  63.3 (pogonion)</td>
<td>100.0</td>
<td>83.0</td>
</tr>
<tr>
<td></td>
<td>ii) 63.3 (gnathion)</td>
<td>100.0</td>
<td>86.7</td>
</tr>
<tr>
<td>Chin, vertical plane</td>
<td>56.7</td>
<td>60.0</td>
<td>56.7</td>
</tr>
</tbody>
</table>

which was based on Broadbent's good faces was used. The ratios of the proposed method are based on the proportions of the Bolton standard face, but otherwise the method is completely unrelated to Bolton's method of cephalometric analysis. Historically, it is not uncommon for researchers to base their cephalometric methods on the good faces of previous studies. For example, Vorhies and Adams (1951) described their facial types based on Downs' (1948) findings and these measurements were later modified by Wylie and Johnson (1952). Steiner's analysis (1953) also relied on norms based on Downs' good cases (1948). Ricketts (1960a,b, 1961) described measurements based on Downs' (1948) as well as his own research. The geometric pattern of the hexagon was chosen as it follows the gross configuration of the facial structures; however, any other suitable pattern would have sufficed, provided the ratios were adequately expressed.

The Conventional method shows good agreement with the proposed method. In horizontal plane measurements, however, its consistency is questioned when compared with the Ricketts and Bolton methods of analysis. On the other hand, the results of the proposed method were found to be generally more in agreement with all the control methods collectively. A greater frequency of agreement between methods does not necessarily imply a greater degree of accuracy; however, it does denote a degree of consistency and thus reliability.

When the Bolton method was compared with the other methods, it was found that if the distances between the Bolton registration point and nasion were similar to the 18-year Bolton standard profile and the profile under analysis, then the frequency of agreement between the methods examined was high, and conversely, if the distance was dissimilar, then the frequency of agreement was low. For this reason, the current practice of superimposing the Bolton standard profile at the nasion or sella point for comparison with a patient's tracing should be interpreted with caution.

The most likely reason for the greater degree of agreement between methods in the deformity section compared with the average section could be that the abnormal jaw relationship was so gross or obvious in the deformity cases examined that there was positive agreement between the different methods in the majority of cases in that section.

The reliability of the proposed method was investigated by matching its results against three control methods and then in turn the results of the control methods were compared against each other. Testing reliability in this manner is considered to be more scientific than undertaking a series of operative procedures on groups of patients with facial deformity in the hope of comparing different methods of analysis. When more than one group of patients are thus matched, a host of variables caused by surgical complications or biological variations prevents the use of such a method for accurate comparison; this problem of reproducibility of the variable factors when attempting to make comparisons to a fine degree has been previously recognized (Paulus, 1977; Music et al., 1989; Fine and Lavelle, 1992). Moreover, as only one method of analysis can be tested per surgical procedure, it would be impossible to predict the
outcome had another method of analysis been used. Wylie et al. (1987) compared five methods of analysis with each other and also to the surgical treatment undertaken for facial deformity, both on a blind basis. When compared with each other, the analyses showed considerable inconsistencies and in addition they also found that no single analysis agreed with the actual surgical treatment more than 60% of the time. Generally, in cases of gross deformity, the postoperative appearance to a large extent would be more pleasing whichever method of analysis had been employed. Therefore the real test of assessment comes into play in the not so obvious or borderline deformity cases, which may or may not require surgical treatment. Hence, the reliability of a new method should be tested on average as well as deformity cases.

The vast majority of the adult skull width and length is achieved by 3 years of age (Enlow, 1990). The cranial base thus develops much faster and at an earlier age than the facial bones, which continue to enlarge for many years. This differential growth between the cranial base and the facial skeleton means that from the point of view of measurement, reference points in the cranial base would be considered to be relatively more stable than those on variable parts of the facial skeleton. Dolci et al. (1991) in a study of 60 adults also confirmed that midfacial sagittal growth in patients affected by mandibular prognathism is impaired by altered cranial base growth. The strong association between cranial and facial development implies that, during assessment of deformity, the measuring ratios should be linked not only to reference points in the cranial base but also to the cranial base of the patient under examination and not just to a population norm. Population norms are important; however, an ideal cephalometric analysis should mean something more than just measurement against an average range. A major advantage of the Hexagonal method is that it not only permits the comparison of a given facial structure against its own cranial base, as nature intended, but also provides simultaneous comparison against a population norm, in the shape of Broadbent's good faces. This dual objective helps the operator to achieve a better understanding of what surgical treatment is required to change the facial appearance in relation to the cranial base of that particular patient, using the proposed method as a guide.

The posterior clinoid process and nasion were chosen as they were natural anatomical landmarks, easily identifiable on a lateral cephalometric radiograph. Inherent problems in recognising landmarks on underexposed lateral cephalometric films were overcome by the use of a powerful fibrelight source. A specially designed computer software program facilitates a quick and user friendly assessment of structures. The operator keys in the relevant landmarks of a patient's lateral profile on the digitizer and the deviation from the prescribed standard in terms of length or angle (including construction of the hexagonal pattern and point J) for that individual is printed. As the described ratios were based on the 18-year Bolton standard lateral profile, the results apply strictly to the population from which the Bolton measurements were derived. As with any pilot study, the results of the Hexagonal method will be investigated by means of randomized clinical trials in order to provide further evidence of its usefulness.

In conclusion, the strength of the proposed method lies in the fact that its ratios are related to the individual's own cranial base rather than a population norm; its results are not dependent on the similarities of distances between reference points on the patient's profile and perhaps a template it may be measured against; it informs the operator of any deviation from the proportions of the ideal 18-year lateral Bolton standard profile; and finally, its results were shown to be more consistent than those of the three control methods against which it was compared. It is envisaged that the proposed measurements would serve as a valuable guide, amongst other investigations for the assessment of facial deformity.

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References

Björk A 1947 The face in profile. Svensk Tandläkar- Tidskrift 40 (part 5b): 1–180


Gugino C F 1977 An orthodontic philosophy (11th edn). R/M Communicators, USA, Division of Rocky Mountain/Associates International Inc.


Reidel R R 1952 The relationship of the maxillary structures to the cranium in malocclusion and in normal occlusion. Angle Orthodontist 22: 142–145


