Original article

Assessing lower incisor inclination change: a comparison of four cephalometric methods

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Summary

Objective: Cephalometric inclination change of the lower incisors during orthodontics is used to assess treatment outcome. The lower border of the mandible is commonly used for measuring inclination change, despite it being subject to remodelling in growing patients. Superimposition of radiographs using Björk’s ‘stable structures’ is intended to exclude these growth changes. We tested whether there is a significant difference for three commonly used methods to assess inclination change induced by orthodontic treatment (Me–Go, Go–Gn, the tangent to the lower border of the mandible) when comparing it to Björk’s ‘stable structures’.

Methods: Björk’s superimposition does not allow measuring incisor inclination changes directly; hence, one pre- and mid-treatment cephalogram of 39 growing orthodontic patients were superimposed in this retrospective study. The radiographs were taken at least 1 year apart (120 weeks; SD = 34.4). Patients undergoing growth modification treatment were excluded. Standardized cephalograms were hand traced and changes in lower incisor inclination, using the three mandibular planes, were compared to the changes obtained by anatomical superimposition of Björk’s ‘stable structures’.

Results: Linear regression showed good intra-class correlation (ICC) between all methods. ICC was 0.96 for Me–Go, 0.94 for Go–Gn, and 0.92 for the lower border tangent. ICC for operator reliability was 0.99.

Limitations: Measurement errors affect all investigations of both analogue and digital radiographs, but movement artefacts particularly apply to the latter. Cephalometry uses two-dimensional measurements of a three-dimensional subject, which can lead to further inaccuracies. These limitations have to be taken into account when interpreting the results of our investigation.

Conclusion: Data obtained from Björk’s superimposition did not vary significantly from the other more commonly used techniques (Me–Go, Go–Gn, and the tangent to the lower border of the mandible). Remodelling of the lower border of the mandible was insignificant for the time period investigated.

Introduction

Accurate inclination measurements of the position of the lower labial segment are important in orthodontics as they can influence treatment planning and are a prognostic indicator of stability following orthodontic treatment (1). Orthodontic treatment can force the lower incisors anteriorly or posteriorly both bodily and in tipping motion and this is monitored by comparing lower incisor angulation to the mandibular border using consecutive lateral cephalometric radiographs.
The lower incisors have only limited antero-posterior movement capability due to alveolar bone thickness; most of the lower incisor movement observed during orthodontic treatment is angular. The amount of incisor tipping should be limited so the root surface does not contact cortical bone and detrimental effects, such as root resorption (2). Other unwanted side-effects such as fenestration and/or gingival recession can also be caused by incisor movement (3). The lower incisor position should ideally be kept unchanged during orthodontic treatment for stability unless specific treatment aims dictate otherwise (1, 4, 5).

Pre- and mid-treatment cephalograms are used to quantify change in incisor inclination and the lower incisor to mandibular plane (LIMP) angle is most commonly used. The LIMP angle can be recorded using any one of three different mandibular planes (Figure 1): Mills (Eastman analysis) used a line drawn from menton to gonion (1). The line drawn from gnathion to the gonion was used in Steiners’ and Ricketts’ analysis (6, 7). The tangent to the lower border of the mandible is assessed by superimposing mandibular images at two different time points during treatment and then measuring the angle between them. This method allows measuring the magnitude of the change, but not a comparison against a norm value. Björk’s method of superimposition uses ‘stable structures’ in both the anterior and posterior mandible. In the anterior mandible, these are the lower and outer border of the mandibular symphysis, the inner border of the cortex in the mandibular symphysis region, and any prominent trabeculae. Posterior structures include the inner cortical outline of the inferior dental nerve and the lower border of the germ of the third permanent molar before root formation (14).

All methods of measuring incisor inclination are subject to cephalometric tracing and measurement error, inconsistencies with radiographic equipment, patient positioning, or distortion. This error is usually around 1 degree and is thought to be clinically insignificant (15, 16). Cephalometric landmark validity is another consideration; this is the estimation of the point on a cephalogram compared by the actual position on the skull. LIMP was shown to be inaccurate by up to 3.8 degrees, which is large compared to other angles measured (17). Other investigators found poor accuracy in locating other points such as gonion and lower incisor apex (15, 17). The apex was shown to have particularly poor reproducibility of only 75 per cent (18). Usually only small inclination changes occur in the lower incisor region during orthodontic treatment; however, imprecision of measurements can have a significant impact on presumed treatment effects.

The validity of Björk’s ‘stable structures’ has also been criticized and it has been proposed that no completely universal ‘stable structures’ can be seen in the mandible. However, Björk’s structures are possibly least prone to error (19). When Bork’s structures were analysed by the above authors, they noted that the posterior structures were more variable than the anterior midline structures, with the inferior dental canal performing the worst. The authors speculated that the mandibular plane itself could possibly be more accurate than the superimposition on Björk’s ‘stable structures’ itself; however, their techniques compared the tracings of mandibular outlines as well as the superimposition techniques and they finally concluded that for long-term growth predictions, techniques using ‘stable structures’ were better.

Superimposition techniques have their own inherent error that has been outlined by several studies (20, 21). Some superimposition techniques may show a completely different direction of growth or emphasize one growth vector more than another as shown on some craniofacial superimposition techniques using non-conventional points (20). This also indicated that some techniques may conceal a pattern seen on more conventional superimposition techniques (22, 23). On comparison of Björk’s superimposition techniques of the mandible with the Ricketts’ method (7), it was shown that the former is more appropriate for growing individuals and replicates normal changes expected during growth (13). The authors used data from the implant research files of the University of Washington, Seattle. The two techniques were compared to implant superimposition and the difference was thought to be clinically relevant; the authors added that caution must be exercised when conclusions are drawn using any superimposition technique.

Growth of the mandible primarily occurs in the condylar region and is generally in a downward and forward direction; however, mandibular remodelling alone can often be considerable. Surface remodelling occurs in the ramal region and body. Previous studies have shown extensive remodelling of the lower border of the mandible (24).

Mandibular border remodelling is part of normal development and can be highly variable (13). Gonion itself was shown to have a great remodelling capability surpassed only by condyolar points (25).

This retrospective study was undertaken to assess congruency of different methods of assessing lower incisor inclination change.
for patients who grew actively and underwent orthodontic treatment. Incisor inclination change is important for planning treatment mechanics in orthodontics as well as retention. The null hypothesis was that growth has no effect on the methods used to measure the lower incisor inclination change during orthodontic treatment and that hence no difference exists between the four methods tested.

Materials and methods

Inclusion criteria were 1. fixed appliance treatment, 2. age between 12 and 16 years at the start of treatment, 3. orthodontic treatment for at least a year between the pre- and mid-treatment radiographs, and 4. no lower incisor extraction.

For the present investigation, a reproducibility study was performed with 10 cases randomly selected and the cephalograms were traced for sample size calculation. A sample size of 39 was calculated to have 80 per cent power at 5 per cent significance level to detect correlations deviating from 0.5 degrees and above.

Tracing technique

All radiographs were taken using the same digital cephalostat (Planmeca, Dimax3, Helsinki, Finland). Radiographs were standardized by equilibrating their magnification digitally, printed (AGFA Drystar 4500, Morstel, Belgium) and then manually traced on a light box in a darkened room using a 2H pencil on acetate. All tracings were carried out by the same operator (AJ). Pre- and mid-treatment lower incisor inclination was measured and the change evaluated for each pair of radiographs using three separately constructed mandibular planes: 1. menton–gonion, 2. gnathion–gonion, and 3. tangent to the lower border of the mandible (Figure 1).

Mandibular superimposition

Pre- and mid-treatment lower incisor inclination change was also recorded using superimposition of cephalometric radiographs on the ‘stable mandibular structures’ (11). Mandibular superimposition was carried out for each pair of radiographs using the following technique: the entire mandibular outline was traced, including that of the most prominent lower incisor, and the ‘stable mandibular structures’ were traced to superimpose the radiographs according to the method of Björk: 1. outer surface of the mandibular symphysis, 2. inner surface of the cortex of the same region, 3. any prominent trabaculae present within the symphyseal cortex, 4. internal cortical margin of the inferior dental nerve, and 5. the lower border of the third molar tooth germ prior to root formation (11–13). Anterior structures were aligned before posterior and the measured incisor inclination change was recorded for each pair of radiographs (26).

Statistical analysis

Multivariate analysis of the amount of inclination change, the treatment time, and the age during treatment was undertaken.

Repeatability study

For the repeatability study, the LIMP was measured for 10 randomly treated orthodontic patients at two instances. The cephalograms were traced separately for both instances. The between-subject variability was highly significant: \( F(9, 10) = 154, P < 0.0001 \), and the intra-class correlation (ICC) was 0.99 (95 per cent confidence interval (95 per cent CI): 0.98–1), indicating excellent reproducibility between the two measurements. Repeatability was similar to other investigations (15, 16). The between-subject variability was highly significant: \( F(9, 10) = 154, P < 0.0001 \), and the ICC was 0.99 (95 per cent CI: 0.98–1) indicating excellent reproducibility. Single operator reproducibility using highly significant subject variability showed a 0.99 ICC, indicating excellent reproducibility between replicated measurements of anatomical points.

Results

Cephalometric radiographs of 26 female and 13 male patients with a mean age of 13.7 (SD = 1.24) years were used. All had been treated with fixed appliances over a period of 18–36 months. The mean time between the taking of pre- and mid-treatment cephalograms was 120 (SD = 34.4) weeks.

Mean changes in lower incisor inclination measured by the four different methods along with their standard deviations are shown in Table 1. All techniques showed a change below 1 degree but with slight variation, from 0.26 degrees using the Me–Go plane and 0.64 degrees using tangent to the lower border of the mandible. Björk’s superimposition method produced values closest to those of tangent to the lower border of the mandible and the mean values of the Me–Go and Go–Gn techniques were also similar. The correlations between Me–Go and Go–Gn were good at 0.31 and 0.26 degrees, respectively. The median range was 0.33 degrees between the highest and lowest values indicating good accuracy. The correlations between Me–Go and Go–Gn techniques were good at 0.31 and 0.26 degrees, respectively; the mandibular tangent agreed best compared to the Björk superimposition technique values. The changes in the LIMP show very similar correlation to each other, and the values are all within 1 degree.

Björk’s superimposition technique was used as a reference for calculating the ICC; subsequently, the other techniques were compared. The ICC benchmarks were (27):

<table>
<thead>
<tr>
<th>Agreement</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor agreement</td>
<td>0.20</td>
</tr>
<tr>
<td>Fair agreement</td>
<td>0.40</td>
</tr>
<tr>
<td>Moderate agreement</td>
<td>0.60</td>
</tr>
<tr>
<td>Good agreement</td>
<td>0.80</td>
</tr>
<tr>
<td>Excellent agreement</td>
<td>1.00</td>
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</table>

Comparison of the changes measured in incisor inclination between pre- and mid-treatment cephalograms using the three different methods were compared to each other using a linear regression model. A univariate model was used first, followed by multivariate analysis adjusting for age and length of treatment. Me–Go plane and Björk’s superimposition were in excellent agreement (ICC of 0.96; 95 per cent CI). The multivariate regression model showed \( P \) values of 0.91 if the age and 0.55 if the length of treatment time were taken into account along with the age.

Agreement of Go–Gn change to the Björk’s superimposition technique was also excellent: the ICC was 0.94 in a 95 per cent CI. The multivariate regression model showed \( P \) values of 0.95 with regards to the age and 0.51 with regards to the age and length of treatment time.

Table 1. Mean changes in the lower incisor inclination with each method used and their corresponding standard deviations.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Mean (°)</th>
<th>SD (°)</th>
</tr>
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<tbody>
<tr>
<td>Me–Go</td>
<td>0.31</td>
<td>7.73</td>
</tr>
<tr>
<td>Go–Gn</td>
<td>0.26</td>
<td>7.73</td>
</tr>
<tr>
<td>Tangent</td>
<td>0.64</td>
<td>7.91</td>
</tr>
<tr>
<td>Björk</td>
<td>0.51</td>
<td>7.69</td>
</tr>
</tbody>
</table>
When the mandibular tangent was compared to the Björk’s superimposition technique, the results were very similar to the above with an ICC of 0.92 and a CI of 0.95 per cent. The multivariate analysis was 1.00 when compared to age and 0.57 when compared to age and treatment time. Comparing Me–Go plane with Go–Gn plane, there was again excellent agreement: the ICC was 0.98 with a 95 per cent CI and the multivariate analysis showed a good correlation (0.70) with age and 0.57 with age and elapsed treatment time between two radiographs. Comparing the Me–Go plane with the tangent showed an ICC of similar value: 0.96 (excellent agreement) and 95 per cent CI and the multivariate regression model showed P values of 0.76 with age alone and 0.63 with both age and treatment time elapsed. Finally, when comparing the Go–Gn with the tangent of the mandible, the ICC was again very high, at 0.97 (95 per cent CI), showing excellent agreement. The multivariate regression model showed that age was at a P value of 0.80 and along with treatment time was 0.59. Figure 2 shows a forest plot based on median values of each of the techniques used. The highest and lowest values in each technique were shown, the interquartile range was relatively stable in all the techniques, and the median values were similar as well. Repeatability was similar to previous investigations (Table 2) (15, 16).

### Discussion

Different techniques to measure the lower labial segment inclination have been scrutinized in detail before, particularly comparing techniques using the lower border of the mandible (28, 29, 30). However, to our knowledge, linear measurements have not been compared to Björk’s superimposition techniques.

The studies investigating radiographic error have shown that location of particular cephalometric points, such as incisor apex, is often challenging and some points can be identified more accurately than others (15). Points located in the anterior mandible, such as the lower incisor apex and gonion, are particularly prone to those errors (15, 16). Repeatability and reproducibility can be weak when those landmarks are used as part of an investigation; however, the data from our study were in line with those of other investigators (15, 16).

There are a number of techniques to superimpose the mandible (1, 5–10). Our study used the Björk’s superimposition technique, which was developed in the 1960s as the ‘gold standard’ for comparison with the abovementioned three techniques. Björk’s superimposition has been used for a long time and various investigators found that Björk’s superimposition method is the most accurate technique for superimposition of skeletal cranial structures over time. A recent study investigated angular changes of the lower incisor position and remodelling of the lower border of the mandible, especially in the anterior region, was considered (31). Superimpositions are mostly used in education and research although they could be part of the cephalometric investigation during routine orthodontics.

One of the reasons why investigating incisor inclination change by means of superimposition is not popular could be poor identifiability of the inferior apex of the lower incisors (15, 18). However, one of the most cited studies in orthodontics uses inclination change and the methodology has been generally accepted (32).

In order to assess the impact on remodelling of the lower border of the mandible on incisor inclination, only growing patients were admitted to this study. We excluded use of functional appliances; admission of this patient group could have changed the outcome of our investigation because use of growth modification treatment may have an effect on shape change of the mandible by interfering with normal growth. This in turn may have an influence on measurements relying on the mandibular border as a reference (33–36). Although inter-arch elastics (Class II or III) may have a myofunctional role, particularly if the elastics are heavy and are worn over longer periods of time, their clinical use is usually of limited duration and their use was hence not chosen as exclusion criteria.

It is not inconceivable that different methods for assessing lower incisor inclination could lead to poor comparability of studies using different methods. Our investigation, however, showed excellent consistency between the techniques used when assessing lower incisor inclination change. This means that either the period of treatment is too small to allow for a clinically significant change of the lower border of the mandible or that the studies on the changes of the lower mandible on incisor inclination, only growing patients were admitted to this study. We excluded use of functional appliances; admission of this patient group could have changed the outcome of our investigation because use of growth modification treatment may have an effect on shape change of the mandible by interfering with normal growth. This in turn may have an influence on measurements relying on the mandibular border as a reference (33–36). Although inter-arch elastics (Class II or III) may have a myofunctional role, particularly if the elastics are heavy and are worn over longer periods of time, their clinical use is usually of limited duration and their use was hence not chosen as exclusion criteria.

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**Table 2.** The intra-class correlation (ICC) values for individual comparisons between the methods.

<table>
<thead>
<tr>
<th></th>
<th>Go–Gn</th>
<th>Tangent</th>
<th>Björk</th>
</tr>
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<tbody>
<tr>
<td>Me–Go</td>
<td>0.98</td>
<td>0.96</td>
<td>0.96</td>
</tr>
<tr>
<td>Go–Gn</td>
<td>0.97</td>
<td>0.94</td>
<td>0.92</td>
</tr>
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All the ICC values were above 0.80 and hence were in excellent agreement.

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**Figure 2.** Forest plot showing median changes in the lower incisor inclination with each method used.
border of the mandible are not variable enough to be significant, unless in rare cases. One of the limitations in our study is caused by the inaccuracies even when superimposing Björk’s ‘stable structures’. Recording smaller angles using a geometrical technique is difficult and it has been proposed that digitizing points and using computers may improve accuracy. However, computerized techniques have been shown to entail their own inaccuracies (37) and a number of investigations have shown that there is little difference in the accuracy in the two techniques: some researchers have showed no significant differences between the two methods in the measurement of treatment changes when using commercially available software (30). Others also found no statistical significance between digitizing cephalograms and hand tracings; however, this study was undertaken when technologies were less advanced than they are now (38).

The Björk’s superimposition technique is mainly used for assessing skeletal and dentoalveolar treatment changes in the mandible and maxilla, and it could also be used for measuring incisor inclination change. Superimposition techniques are, however, somewhat more time consuming and possibly require better operator skills compared to using the lower border for assessment of incisor inclination changes. Superimpositions do not easily lend themselves to computerization as they are generally qualitative and not quantitative. Another disadvantage of using a superimposition for inclination change is the difficulty in comparing studies with current norms of the lower incisor inclination; superimpositions only allow for assessment of inclination change, but population norms cannot be established using this technique.

Since all the techniques using the mandibular plane angle for measuring the lower incisor inclination change and Björk’s superimposition method produced similar results, any of the above technique may be used at the age when growth occurs; all techniques were very similar to each other and the impact of growth during the treatment time appeared negligible in our study. We can only speculate that the lower border of the mandible either remodels insignificantly or that the ‘stable structures’ described by Björk remodel concomitantly with the lower border of the mandible and that hence there is little appreciable difference between the methods.

Limitations

Cephalometric studies are subject to a number of general limitations such as measurement errors and movement artefacts, which have been described in detail before (15, 16). Digital radiographs are prone to the latter error because of longer exposure times (18, 39, 40).

Cephalometric studies take two-dimensional measurements of a three-dimensional subject, particularly when assessing the lower border of the mandible. In our investigation, we ‘averaged’ the lower border when two outlines were visible and this may have introduced operator bias.

Measuring inclination change, as undertaken in our study, does not always imply a change of incisor crown position in the anterior–posterior direction (41); inclination change relative to the mandibular border could theoretically be introduced by changing incisor torque without a change of crown position. This, however, would not have had any impact on the results of our investigation as the inclination change would have been affected equally by growth changes of the lower border (42, 43).

Conclusion

1. The use of any of the 3 commonly used mandibular planes (Go–Gn, Me–Go, and tangent to the lower border of the mandible) appears equally valid when measuring lower incisor inclination change and they are in excellent agreement with each other for growing orthodontic patients from the age of 12–16.
2. Björk’s superimposition technique can also be used to detect lower incisor inclination change during orthodontic treatment and it was in excellent agreement compared to the three techniques conventionally used.
3. Growth changes of the lower border of the mandible appeared too minor to have an effect on incisor inclination measurements during the time period investigated (120 weeks, SD = 34.4 weeks).

References