Overbite depth and anteroposterior dysplasia indicators: the relationship between occlusal and skeletal patterns using the receiver operating characteristic (ROC) analysis

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SUMMARY This study was carried out to investigate the validity of the overbite depth indicator (ODI) and the anteroposterior dysplasia indicator (APDI), based on the cephalometric analysis of 122 Caucasians selected at random for assessment of vertical and sagittal relationships. Considering the occlusion, the sample was divided into three classifications in the sagittal component: 36 cases of neutrocclusion, 54 cases of distocclusion, and 34 cases of mesiocclusion. The sample was also categorized according to the overbite relationship: 54 cases of normal overbite, 34 cases of open bite, and 34 cases of deep overbite.

In the sagittal component analysis, the APDI measurement resulted in significant differences between the neutrocclusion, distocclusion, and mesiocclusion groups. In the vertical component analysis, the ODI significantly distinguished between the normal and deep overbite groups, and the open bite and deep overbite groups, but not between the normal overbite and the open bite groups. A receiver operating characteristic (ROC) analysis showed that the APDI matched the anteroposterior molar relationship in 88 per cent, and the ODI matched the amount of incisor overbite in 81 per cent.

Introduction

A lateral cephalometric radiograph reveals details of skeletal and dental relationships that are not observed on clinical examination (Graber and Vanarsdall, 1994). Differential diagnosis is essential because similar malocclusions may be analogous, but not homologous due to different skeletal patterns (Graber and Vanarsdall, 1994). While the angle ANB or the denture base relationship (Wits appraisal) were devised to determine the sagittal jaw discrepancies, some authors question the ability of these measurements to describe these relationships (Oktay, 1991; Foley et al., 1997; Čelar et al., 1998). The same controversy exists with the vertical dimension (Frost et al., 1980; Fields et al., 1984; Graber and Vanarsdall, 1994). No single cephalometric measurement separates normal from vertically abnormal patients (Fields et al., 1984). A combination of cephalometric measurements could provide more information as the sum of inter-planar angles is more appropriate for the comprehension of skeletal features (Kim and Vietas, 1978; Han and Kim, 1998).

In the past, two component cephalometric measurements were introduced for the differential diagnosis of malocclusions: the overbite depth indicator (ODI; Kim, 1974) and the anteroposterior dysplasia indicator (APDI; Kim and Vietas, 1978). Consisting of two angular measurements, the ODI describes the tendency
of an existing dentoskeletal pattern towards open or deep bite. The APDI consists of three angles and is used to assess a given sagittal relationship. Former studies on the ODI and APDI only applied global tests, and did not test each study group against the other (Kim, 1974, 1979; Kim and Vietas, 1978).

The purpose of the present investigation was to answer the following questions: Do significant differences exist for the ODI and its components in subjects assigned to study groups according to the incisor overbite? Do significant differences exist for the APDI and its components when the subjects are assigned to groups according to the Angle classification?

Subjects and methods

This study evaluated clinical and cephalometric data of 122 Caucasians selected at random. The sample consisted of 44 males and 78 females aged from 7 to 33 years (mean 13 ± 5.8 years; median and mode, 12 years). The subjects were first-time patients from two private orthodontic offices and five public dental centres in Vienna, Austria. The offices were chosen according to demographic data and informed consent was obtained.

Each patient examined had the following records taken: a clinical examination, a lateral cephalometric headfilm, and mounted dental casts. The patients were assigned to three groups according to the overbite and the Angle classification measured on the dental cast:

1. The overbite was measured on the cast in millimetres with dial callipers accurate to 0.1 mm. For evaluation of the ODI, the patient’s overbite placed him/her in one of three test groups: the open bite group (zero or plus mm open bite, \( n = 34 \)), the deep bite group (overbite > 3 mm, \( n = 34 \)), and the normal overbite group (overbite between 0.1 and 3 mm, \( n = 54 \)).
2. For evaluation of the APDI, the molar relationship placed the patient into one of three sagittal test groups: the neutrocclusion group \( (n = 36) \), the mesiocclusion group \( (n = 32) \), the distocclusion group \( (n = 54) \).

Further criteria used for the assignment included the incisor overjet and the canine relationship.

Cephalometric measurements

The ODI is the scalar sum of two angles and read without unit: (i) the angle formed by the A–B plane and the mandibular plane (MP), and (ii) the angle formed by the palatal plane (PP) and the Frankfort horizontal plane (FH). When the PP slopes upwards and forwards to the FH, the measurement is read as a negative angle. When the PP slopes downwards and forwards in relation to the FH, the measurement is read as a positive angle (Figure 1).

The APDI is the scalar sum of three angles: (i) the angle formed by the FH and the line connecting nasion and pogonion (N–Pg), (ii) the angle formed by the A–B line and N–Pg, and (iii) the angle formed by the PP and the FH. If the A–B line is rotated clockwise to the N–Pg, the measurement will be read negatively. Conversely, a positive value will result in counter-clockwise rotation of the A–B line (Figure 1).

Each of the four investigators who separately collected the data evaluated a part of the sample (clinical examination, cast analysis, cephalometric tracing). To check for systematic error...
(inter- and intra-examiner), 10 lateral cephalograms were selected randomly. These cephalograms were traced by all four investigators and retraced after 6 months. The mean method errors for all four angles averaged 1 degree according to Dahlberg’s formula (Dahlberg, 1940).

**Statistical evaluation**

Descriptive statistics for ODI and APDI included mean, SD, median, maximum, and minimum values. The Wilk–Shapiro test was applied to check for normal distribution. A one-way analysis of variance was used to compare the mean values for the ODI and the APDI for each study group. *Post hoc* multiple comparisons were carried out using Tukey’s test. Significant difference was considered if \( P < 0.05 \).

As the ODI and the APDI are understood as diagnostic tests, a further statistical evaluation was applied independent of the analysis of variance: the receiver operating characteristic method (ROC). The ROC calculates the association between sensitivity and specificity for each value of interest. Sensitivity is the proportion of positives identified correctly by a diagnostic test, and specificity the proportion of negatives identified correctly (Altman, 1997). In a graph, the sensitivity is plotted on the vertical axis against 1—specificity on the horizontal axis, varying the values of the groups for the parameter of interest (Guggenmoos-Holzmann and Wernecke, 1996; Altman, 1997). The ROC curve represents the true-positive rate versus the false-positive rate. The performance of a diagnostic test can be evaluated by calculating the area under the curve expressed as a proportion of the total possible area. An area of 1 represents a perfect test and an area of 0.5 indicates a test that performs no better than chance. More efficient diagnostic tests are represented by ROC curves, which lie closest to the top left corner of the graph and which therefore occupy a larger percentage of the entire graph area. In other words, the area under the ROC curve is an index of accuracy.

Within the ROC analysis, the ODIs of the open bite group were compared with those of the normal overbite group and those of the deep bite group were compared with the normal overbite group. For the APDI, the distoclusion group was compared with the neutroclusion group and the mesiocclusion group with the neutroclusion group. Further ROC calculations compared the ODIs of the open bite group with those of the deep bite group, and the APDIs of the distoclusion group with the APDIs of the mesiocclusion group. The SAS Statistical Package® (SAS Institute Inc., Cary, NC, USA) was used for all computations.

**Results**

The ODI measurements demonstrated the following means and SD: 65.5 ± 8.8 in the open bite group, 67.7 ± 8 in the normal overbite group, and 75.3 ± 5.5 in the deep bite group. Table 1 shows these results and the mean ± SD of

<table>
<thead>
<tr>
<th></th>
<th>ODI</th>
<th>FH-PP</th>
<th>AB-MP</th>
<th>ROC of ODI</th>
<th>ODI (Kim 1974)</th>
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<tbody>
<tr>
<td>OB (n = 34)</td>
<td>65.5 ± 8.8</td>
<td>−2 ± 4.3</td>
<td>66.7 ± 6.9</td>
<td>65.5 ± 6.1</td>
<td></td>
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<tr>
<td>NB (n = 54)</td>
<td>67.7 ± 8</td>
<td>−2.4 ± 3.2</td>
<td>70.2 ± 7.6</td>
<td>74.5 ± 6.1</td>
<td></td>
</tr>
<tr>
<td>DB (n = 34)</td>
<td>75.3 ± 5.5</td>
<td>−1.7 ± 3.7</td>
<td>76.8 ± 5.5</td>
<td>77.7 ± 6.6</td>
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<tr>
<td>NB versus OB</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>0.6</td>
<td></td>
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<tr>
<td>NB versus DB</td>
<td>*</td>
<td>NS</td>
<td>*</td>
<td>0.78</td>
<td></td>
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<tr>
<td>OB versus DB</td>
<td>*</td>
<td>NS</td>
<td>*</td>
<td>0.81</td>
<td></td>
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OB, open bite group; NB, normal overbite group; DB, deep bite group.
both angular components of the ODI. Further
descriptive statistics for the ODI are shown in
Figure 2 as a box-and-whisker plot for each group.
Testing one group against the other, significant
inter-group differences were found in the ODIs and
angles AB–MP, except between the open and
normal bite groups; the angle FH–PP was
not significantly different between the groups (Table 1; Tukey’s Student test, P < 0.05).

Testing the ODIs of the normal overbite group
against those of the open bite group, the area
under the ROC curve yielded 0.6. For the normal
overbite group compared with the deep bite
group, the area under the ROC curve was 0.78
(Table 1, Figure 3). The ODIs of the open bite
group versus those of the deep bite group resulted in an area under the ROC curve of 0.81. The 95 per cent confidence intervals for the mean differences in ODI are shown in Table 2.

The APDI measurements averaged 78 ± 5.8 in
the distocclusion group, 81.2 ± 6 in the
neutroclusion group, and 88 ± 5.6 in the
mesioclusion group. Mean ± SD of the three
angular components are shown in Table 3. Descriptive
statistics for the APDI are given in Figure 4 as a
box-and-whisker plot. The APDI values were
significantly different between all groups, while
its components did not show consistent significant
difference between the groups (Tukey’s Student test, Table 3).

### Table 2

<table>
<thead>
<tr>
<th>ODI</th>
<th>lcl &lt; dbm &lt; ucl</th>
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<tbody>
<tr>
<td>NB versus OB</td>
<td>1.8 &lt; 2.2 &lt; 6.2</td>
</tr>
<tr>
<td>NB versus DB</td>
<td>3.7 &lt; 7.7 &lt; 11.7</td>
</tr>
<tr>
<td>OB versus DB</td>
<td>5.4 &lt; 9.8 &lt; 14.3</td>
</tr>
</tbody>
</table>

lcl, lower confidence limit; dbm, difference between means; ucl, upper confidence limit; OB, open bite group; NB, normal overbite group; DB, deep bite group.

![Figure 2](image-url) Box-and-whisker plots of descriptive statistics (minimum, maximum, median, and upper and lower quartiles) for the ODI in the open bite group (OB), the normal overbite group (NB), and the deep bite group (DB).

![Figure 3](image-url) (a–c) Receiver operating characteristic curves of the ODI. (a) Open bite group versus normal overbite group (OB–NB). (b) Deep bite group versus normal overbite group (DB–NB). (c) Deep bite group versus open bite group (DB–OB).
The ROC computations for the APDI resulted in an area under the curve of 0.66 when testing the distocclusion group versus the neutrocclusion group, and 0.79 for the mesiocclusion group versus the neutrocclusion group. Testing the mesiocclusion versus the distocclusion group, the area under the ROC curve was 0.88 (Figure 5).

The 95 per cent confidence intervals for the mean differences in APDI are reported in Table 4.

**Discussion**

The work of Sassouni and Nanda (1964) highlighted the necessity of considering anteroposterior and vertical measurements within an analysis of the lateral headfilm. This obligation has been met by the APDI and ODI. In the present study...
the statistical analysis revealed the significant differences between Class I, Class II, and Class III malocclusions in terms of the APDI. For the ODI, the statistical analysis found significant differences between subjects with deep bite and those with an open bite, and also between subjects with normal overbite and those with a deep bite, but no significant difference was found between the normal overbite and open bite groups.

The ODI and APDI means of the present study mostly agree with those published by Kim (1974), and Kim and Vietas (1978). The only gross exception was found between the ODI of the normal overbite groups (Table 1), which was the same as the significance of inter-group difference. While Kim (1974) defined normal overbite as between 0.5 and 4 mm, the present study defined normal overbite from 0.1 to 3 mm, according to the literature (Schwarz, 1951; Posselt and Franzen, 1960; Ai, 1962; Andrews, 1972; Solberg and Clark, 1974; Schulze, 1993; Schmuth and Vardimon, 1994). In the opinion of the authors, it appears reasonable to attribute the 4 mm overbite to a deep rather than to a normal bite group.

Table 4 The 95 per cent confidence intervals for the APDI mean differences, and upper and lower confidence limits between the three anteroposterior groups.

<table>
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<tr>
<th>APDI</th>
<th>lcl &lt; dbm &lt; ucl</th>
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<tbody>
<tr>
<td>N versus D</td>
<td>0.2 &lt; 3.2 &lt; 6.2</td>
</tr>
<tr>
<td>N versus M</td>
<td>3.5 &lt; 6.8 &lt; 10.2</td>
</tr>
<tr>
<td>D versus M</td>
<td>6.9 &lt; 10 &lt; 13.1</td>
</tr>
</tbody>
</table>

lcl, lower confidence limit; dbm, difference between means; ucl, upper confidence limit; D, distocclusion group; N, neutroclusion group; M, mesiocclusion group.

The ODI and APDI means of the present study mostly agree with those published by Kim (1974), and Kim and Vietas (1978). The only gross exception was found between the ODI of the normal overbite groups (Table 1), which was the same as the significance of inter-group difference. While Kim (1974) defined normal overbite as between 0.5 and 4 mm, the present study defined normal overbite from 0.1 to 3 mm, according to the literature (Schwarz, 1951; Posselt and Franzen, 1960; Ai, 1962; Andrews, 1972; Solberg and Clark, 1974; Schulze, 1993; Schmuth and Vardimon, 1994). In the opinion of the authors, it appears reasonable to attribute the 4 mm overbite to a deep rather than to a normal bite group.

Evaluated by ROC curves, a modified ODI had the highest diagnostic value in distinguishing open bite from any positive overbite (Wardlaw et al., 1992). Comparison of that study with the present investigation must consider (i) the modification of the ODI (Frankfort horizontal was replaced by the S–N plane as Wardlaw et al. (1992) intended to avoid an error into the identification of orbitale), and (ii) the assignment of the subjects in only two groups (open and non-open bite). It may be speculated that both studies allow the following conclusion: The ODI is able to distinguish the deep and open bite, but not between an overbite of 0.1–3 mm and open bite.

The ODI as a diagnostic measurement was questioned on the basis of a sample of five subjects in a case report article (Nahoum, 1975). However, other investigators have found the ODI and APDI to have the highest correlation for description of vertical and sagittal relationships among up to 15 commonly used cephalometric measurements (Kim, 1974; Kim and Vietas, 1978; Oktay, 1991; Wardlaw et al., 1992; Han and Kim, 1998).

Previous research on the ODI and APDI and the results of the present study indicate that the judgement of skeletal relationships benefits from component angular measurements (Kim, 1974; Kim and Vietas, 1978; Wardlaw et al., 1992). This is shown for the facial plane angle, the denture plane angle, and the angle FH–PP. For example, mandibular retrognathism may be expressed as a low value to the single angle FH–Np. The more severe the Class II, the greater is the angulation between the A–B line and the N–Pg line, and a low APDI value results (emphasized by a negative angle AB–NPg). Using the APDI, its significant differences between the normo-, disto-, and mesiocclusion groups was superior to some single angular measurements of the APDI (insignificant differences between the normo- and distocclusion, and the disto- and mesiocclusion groups). Thus, the APDI provided more diagnostic evidence than one of its component measurements alone.

Vertical relationships are covered by the ODI within the cephalometric analysis. Regarding the two components of the ODI separately, the angle AB–MP showed significant inter-group differences to the same extent as the ODI in the present study. The orientation of the PP to the FH plane played an important role only in the assessment of the individual malocclusion. In an individual with open bite, a negative FH–PP angle decreases the ODI value and complicates therapy.
In medicine, a diagnostic indicator is used to determine the presence or absence of a sign, a disease, or the probability to be ill. An indicator should differentiate between two conditions (Zweig and Campbell, 1993). For example, the creatine phosphokinase isoenzyme confirms the diagnosis of an acute myocardial infarction. In this instance a so-called ‘cut-off’ value exists on which a diagnosis is based. Demanding such a cut-off value for an orthodontic diagnosis is unworkable since the question of an orthodontic diagnostic is never a faultless ‘Yes’ or ‘No’. Variations in the dentofacial complex are rarely produced by a single factor (Kim and Vietas, 1978; Fields et al., 1984). Wardlaw et al. (1992) demonstrated that a single cut-off value was of little use in orthodontic diagnosis. They found that the calculation with the ROC method was far more useful in discriminating the diagnostic value of various cephalometric measurements.

In order to substantiate a link between skeletal pattern and occlusion in the present study, the results of the ROC analysis expressed the probability that an individual with a low ODI value had a greater chance of an open bite and vice versa for the deep bite. The same held true for the APDI and the Angle classification: the higher the APDI value, the greater the probability of a Class III malocclusion and/or skeletal pattern, and vice versa for the Class II.

If the non-significant difference for the ODI between the normal bite and the open bite group (Tukey’s test), the probability of having a higher value in the normal overbite group was 60 per cent in terms of the ROC. In detail, the ROC calculation showed that the vertical skeletal pattern was consistent with the extent of the overbite in 81 per cent. Nineteen per cent did not show this characteristic. It may be speculated that the alveolar bone and/or the axial inclination of the dentition contribute to this diagnostic confusion if an ODI typical of a skeletal open bite appears with a deep incisal overbite. On the other hand, an individual with a high ODI value, typical of a skeletal deep bite, may present with a dental open bite due to habits or an extremely protruded incisor inclination. Such inconsistencies between the skeletal pattern and the amount of overbite must be taken into account for individual treatment planning: a complex treatment of the malocclusion must be expected. This argument was substantiated by Meyers (1992), who tested the relationship between craniofacial structures and occlusion. He found a higher correlation between the variation in anteroposterior skeletal structure and that in sagittal occlusion than between the variation in vertical skeletal structure and that in vertical occlusion.

In the ROC procedure for the APDI, the consistency of the skeletal pattern with the amount of molar relationship was almost as high as 90 per cent. However, there are still patients with a skeletal Class III pattern and a distocclusion. In these instances, the Angle classification does not match the inherent skeletal morphology. On the other hand, individuals with a Class I molar relationship and a low APDI value may be allocated to a skeletal Class II group. In treating such so-called Class I malocclusions, one should, for example, avoid mechanics that shift the molar Class I to a Class II, for example, by a backward rotation of the mandible. Neglecting such a relationship could produce an unexpected iatrogenic Class II.

Several authors have found evidence of a non-existing homogenous Class I (Nanda, 1990; Harris and Johnson, 1991; Dibbets, 1996; Enlow and Hans, 1996). This Class I could have any of several anterior relationships: deep overbite, open bite, crossbite, rotations, etc., and they are all still Class I molar. To be thorough, these patients need a better distinguishing characteristic, which would relate their malocclusions to their inherent skeletal pattern. Enlow and Hans (1996) stated: ‘This is a clinically most relevant point but it has almost never been a factor in most clinical and research studies’. Their statement was confirmed by the ROC analysis when testing the normal overbite group and the neutroclusion group, respectively, against the other two groups in the present study. Most malocclusions exist because of the variations in the skeletal pattern. In most instances, malocclusions mirror the skeletal pattern in which they are found, i.e. Class II molar relationships exist in Class II skeletal patterns. In those malocclusions that do not mirror their skeletal pattern, component measurements such as the
ODI and the APDI could preclude treatment complications, e.g. a low ODI indicates the risk of opening the bite during treatment.

Another advantage of these component measurements is the use of angles fairly stable during growth. In the longitudinal growth studies of Riolo et al. (1974), Bhatia and Leighton (1993), and Bishara et al. (1997), the angles used for the ODI and the APDI did not show significant changes during growth with the exception of the facial plane angle. Thus, the assessment of malocclusions becomes independent of individual age.

In the present study, mounted casts were used to simulate the intra-oral clinical chairside examination, which is dominated by the molar relationship, and the amount of overjet and overbite. As stated by Han and Kim (1998), there is no cephalometric measurement widely accepted that displays the skeletal configuration of a malocclusion, while occlusal relationships are commonly used diagnostic parameters.

Derived from individuals seeking orthodontic consultation, the data for the neutroclusion and normal overbite groups might be biased in the present study. Further research should be undertaken to establish ‘norm values’ derived from a randomized ideal occlusion sample, matching the six keys of normal occlusion of Andrews (1972). However, such a project might interfere with ethical commitments to radiographic hygiene.

Conclusions

1. In the vertical component analysis, the ODI differentiated significantly between the deep bite and normal overbite groups, and between the deep bite and open bite groups. The normal overbite was defined as being between 0.1 and 3 mm.

2. In the sagittal component analysis, the APDI resulted in significant group differences between all three Angle classes.

3. The lower the ODI value, the greater the chance of a skeletal open bite and vice versa for the deep bite. This was consistent with the incisor overbite in 81 per cent of subjects.

4. A high APDI indicated a skeletal Class III pattern, a low number showed a Class II. This was consistent with the molar relationship in 88 per cent.

5. Lack of agreement between ODI and incisor overbite, or between APDI and molar relationship, may be indicative of a complex treatment of the malocclusion.

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