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Cephalometric correction factors for bite opening—a dry skull study

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SUMMARY The lateral cephalometric radiograph supplies the clinician with valuable information regarding the facial skeletal morphology of the patient, provided that it is taken correctly. These radiographs should be taken while the patient is occluding in maximum intercuspation, failing which the exposure is often repeated, leading to an increase in patient radiation dose as well as added cost in time and materials. This study investigated the relationship between limited bite opening and selected cephalometric variables. Thirty-one dry skulls were used and five splints were constructed for each skull giving increments of bite opening from 0 to 5 mm. Six lateral radiographs per skull were taken at each increment of bite opening. The radiographs were traced and the points plotted using a reflex metrograph.

A linear relationship was found between bite opening and SNB, ANB, SN–mandibular plane, and SN–*Y*-axis angles. Errors in digitization, superimposition, and landmark identification were determined and found to be acceptable. Regression analysis produced a highly significant ($P < 0.001$) gradient for each of these angular relationships, allowing a set of correction factors to be produced, which can be applied to bite openings up to 5 mm.

Introduction

Ever since the introduction of the cephalostat by Broadbent (1931) and Hofrath (1931), the lateral cephalogram head film has become an integral part of orthodontic diagnosis and treatment planning. It is recommended that these radiographs be taken with the teeth together in centric occlusion (Viteporn, 1995; Weems, 1995) in order that an accurate representation of the jaw base relationship can be obtained. Centric occlusion is sometimes difficult to achieve and requires thought and effort for a patient to remain in this position while the radiograph is being taken. Not all patients are able to comply with these instructions, or there is occasionally mandibular opening during the time of exposure. This has often required that the exposure be repeated.

A thorough search of electronic medical and dental databases have revealed no previous publication on the effect of bite opening on cephalometric variables. Due to the growing awareness of health hazards associated with diagnostic radiography, the need to retake high-dose radiographs is being placed under greater scrutiny. The average effective dose averaged across the population is estimated to be about 520 μSv/year, with the majority of the exposure from diagnostic X-ray procedures (McEwan, 1998). On average, a single lateral cephalometric radiograph produces an effective dose of 1–3 μSv, equivalent to approximately 1–3 days of background radiation (Isaacson and Thom, 2001). The recommended effective dose limit for an adult is 1 mSv/year (Frederiksen, 1994). Limiting the need to repeat lateral cephalograms is clearly in the best interest of both the patient and the practitioner, to minimize any unnecessary radiation exposure and cost. The aim of this study was to determine the relationship between limited bite opening and selected cephalometric variables in order to reduce the need to repeat X-ray exposure based on non-occlusion.

Materials and methods

Thirty-one human skulls with sufficient intact dentition to establish maximum intercuspation were selected for this study. Any missing central incisor teeth were replaced using acrylic teeth (Nissin Melamin A5A-500 single colour, Kyoto, Japan) that were prepared to the approximate correct size and held in position with sticky wax. Orthodontic brackets (Ormesh, Ormco Corporation, Glendora, California, USA) were bonded onto the upper and lower left central incisor teeth using Transbond light cure adhesive (3M Unitek, Monrovia, California, USA). The brackets acted as radiographic and clinical reference points for all bite opening measurements. An artificial temporomandibular joint was created for each skull using vinyl polysiloxane impression material putty (3M Express STD firmer set). The putty was mixed according to the manufacturers' instructions and a layer placed into the glenoid fossae of the skull. The mandibular condyles were lightly coated with petroleum jelly and seated into the fossae such that the teeth occluded in maximum intercuspation. Excess putty material was trimmed, and the remaining material in the fossae, once set, functioned as an artificial disc that preserved condylar height on opening. The antero–posterior curvature of the artificial disc limited the mandibular movement (within the maximum opening limit of 5 mm between the incisor teeth) to rotation only, without any sagittal displacement.

Occlusal splints were constructed for each skull using the same impression putty. The splints were constructed to allow bite opening at the brackets of approximately 1, 2, 3, 4, and 5 mm. The exact opening was not critical as the actual amount of bite opening was determined from the cephalogram. Freeway space, on average, is 2–3 mm in humans (MacEntee, 1999; Woda *et al.*, 2001), and the assumption was made that the majority of open mouth positions found on lateral cephalograms would encompass values around the average freeway space value. To account for variation, values of up to 5 mm were selected. The assumption was also made that bite opening up to this value would entail rotational movement of the condyle only, without any translational component, in other words, terminal hinge movement of the mandible (Posselt, 2001). To facilitate landmark identification on the radiographs, 25 of the skulls had 1 mm steel ball bearings placed at the cephalometric landmark sites on the skull and held in position using sticky wax. The remaining six skulls used in the calibration of the cephalostat (AMRAD Craig 1 Cephalometric Unit, B F Wehmer, Addison, Illinois, USA) were found to have easily identifiable landmarks. The use of steel ball bearings helped to eliminate the geometric effect on landmark localization when a curved surface such as the supra-menton area (point B) is rotated (Tng *et al.*, 1993). The ball bearing markers were located on the surface of the skull, and served to assist in identification of the true anatomical landmark, so that both radiographs with and without bearings could be used in the study. The centre of the metal markers was not used to identify points.

The skulls were mounted upside down in the cephalostat and radiographs taken at an exposure of 100 mA at 60 kVp for either 0.04 or 0.05 seconds depending on the thickness of the skull. An opaque ruler was included during all exposures to determine the magnification at a later stage. Six radiographs of each skull were taken with different degrees of bite opening: at 0 mm and each of the five approximate 1 mm increments. The skull was maintained in the cephalostat while the splints were changed to minimize positional and projection errors. Measurement of the vertical interbracket distance was undertaken for each of the six settings using a dial vernier calliper (Mitutoyo, Kawasaki, Japan) to determine the interbracket distance.

Twenty of the 0 mm opening (initial) radiographs were randomly chosen and marked with a set of *X*- and *Y*-axes to be used later as part of the error analysis. This was achieved by placing an accurate square over the radiograph, and small pinpricks made at the origin and along the *X*- and *Y*-axes. The orientation of the axes relative to the image was of no consequence. All radiographs were then hand traced onto acetate paper (3M Unitek) by one operator (EL) using a 0.3 mm 3H mechanical pencil. For each skull, the 0 mm opening was traced first, and the following points were marked, according to the definitions given by Viteporn and Athanasiou (1995): sella (S), nasion (N), point A (A), point B (B), gnathion (Gn), gonion (Go), basion (Ba), and menton (Me), as well as stable metal markers within the skull (metal mountings, clips, and hinges). Tracings of the same skull at subsequent openings were superimposed onto the initial tracing (at 0 mm opening) and the landmarks transferred to each of the tracings. This was undertaken to minimize landmark identification error that may have occurred as a result of minor shifts of the skull position in the cephalostat between exposures.

The landmarks were digitized using a reflex metrograph plotter (Butcher and Stephens, 1981) and a custom-designed software program that calculated the angular and linear measurements. The horizontal distance between the brackets on the upper and lower incisor teeth will vary according to the skeletal jaw base relationship, and in order to compensate for this, vertical measurements were used. This was achieved by drawing the S–N line, then a second line from nasion at 5 degrees cranial to the S–N line to establish a horizontal reference plane. Two parallel lines through the upper and lower brackets were drawn, and their vertical separation gave a representation of bite opening. This linear measurement had to be further adjusted for radiographic magnification. All bite opening values are therefore given as vertically adjusted, absolute (true) bite opening.

Regression analysis, using the mixed model procedure in Stata V8 (College Station, Texas, USA), was performed to examine the relationship between the SNA, SNB, ANB, SN–mandibular plane, and SN–*Y*-axis angle and the amount of bite opening. Each regression was forced to go through the origin (regression analysis without forcing through the origin had shown that the greatest variation of the *Y*-intercept from the origin did not exceed 0.14 degrees). Mixed models were used as they allowed different levels of correlation within measurements on one skull and the measurements taken on different skulls. In addition, the skulls were categorized according to skeletal (antero-posterior) and vertical classification to determine whether skull morphology had any influence on the effect of bite opening on the four selected angles. Skeletal Class was categorized as follows: Class I with an ANB angle between 0 and 4 degrees, Class II above 4 degrees, and Class III below 0 degrees. Vertically, normofacial was arbitrarily selected as those skulls with SN–mandibular plane angle values between 28 and 38 degrees, dolicofacial with angles greater than 38 degrees, and brachyfacial with values less than 28 degrees.

Error analysis

Ten radiographs that had *X*- and *Y*-axes marked on them were retraced 1 week later and digitized (Stabrun and

Danielsen 1982). Error variance in the X- and Y-co-ordinates of the landmarks were calculated using the formula proposed by Dahlberg (1940),

$$S = \sqrt{\frac{\sum d^2}{2n}},$$

where S is the error, d is the difference between the two measurements, and n is the number in the sample. The result gave a combined error of landmark identification and error of digitization. Error of digitization was calculated separately by re-digitizing a fixed 'zero' point on the 10 radiographs and applying the same formula. Error of superimposition was determined by superimposing the 5 mm opening tracing onto the 0 mm opening tracing for each of the 10 skulls using the fixed intra-skull markers and best-fit cranial outline. The relative displacement of the most distant ball bearing markers on the nasomaxillary complex and skull base (N, Ba, and point A) of the two superimposed tracings was determined by digitizing and calculating the linear distance between them. The mean difference between the points and the standard deviation (SD) were calculated, which represented the combination of error of superimposition and error of digitization.

Results

The effect of bite opening on the SNB, ANB, SN–mandibular plane, and SN–Y-axis angles are shown in Figure 1a–d. There was a highly significant relationship between bite opening and the four angles measured after adjustment for within- and between-skull differences ($P < 0.001$). Even though the SNA angle was not expected to change with bite opening, its measurement was included in the analysis as a further control in the study. The regression equation for the SNA angle approximated a horizontal line, and the gradient was not significant (data not shown).

The influence of skull morphology (skeletal classification and SN–mandibular plane angle) on the relationship between bite opening and the four cephalometric angles failed to show any significant effect.

Landmark error analysis in the X- and Y-directions is presented in Table 1. The mean difference in superimposition and SD is presented in Table 2. The mean error variance of digitization in the X-direction was 0.02 mm (SD 0.07) and in the Y-direction 0.05 mm (SD 0.1)

Discussion

Changes in the SNB, ANB, SN–mandibular plane, and SN–Y-axis angles were all significantly correlated with bite opening in a linear fashion. This has enabled a set of correction factors for these angles to be determined for every millimetre of bite opening (Table 3), and will allow the clinician to correct for rotational bite opening by

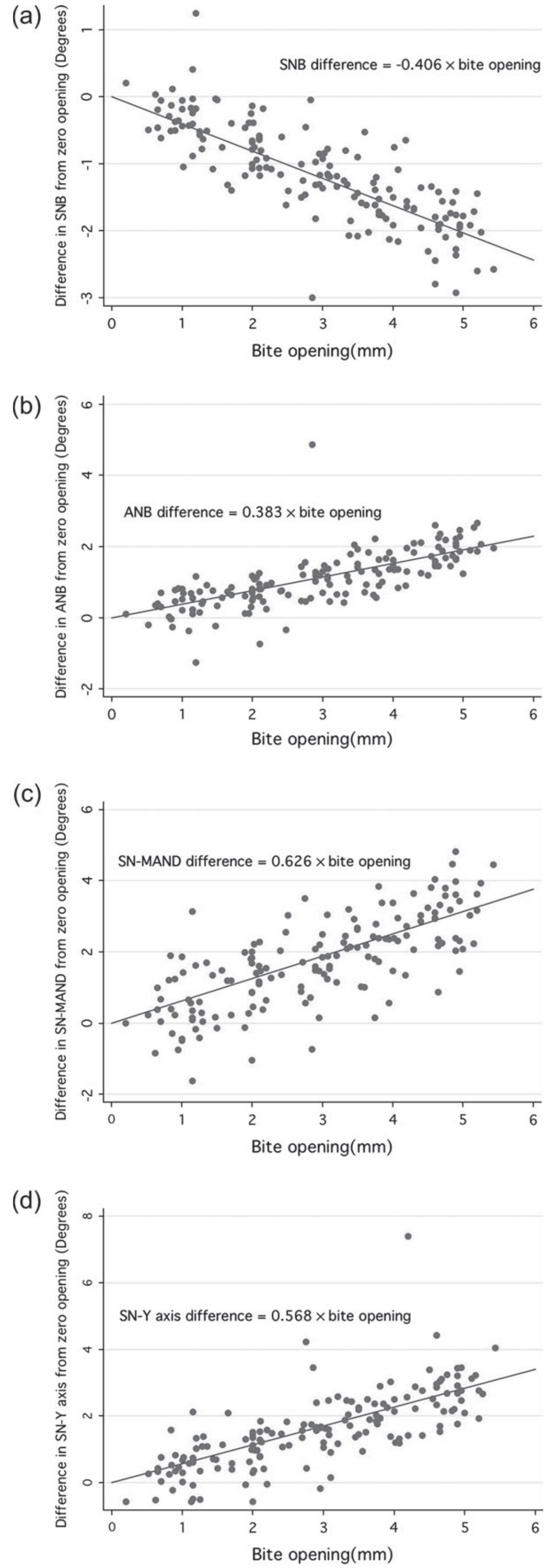

Figure 1 Bite opening versus changes in (a) SNB, (b) ANB, (c) SN–mandibular plane, and (d) SN–Y-axis.

Table 1 Error variance of landmark identification in the *X*- and *Y*-direction (mm).

Cephalometric variable	*X*	*Y*
S	0.31	0.29
N	0.37	0.37
A	0.22	0.45
B	0.22	0.22
Me	0.42	0.37
Gn	0.29	0.23
Go	0.55	0.41

Table 2 Error of superimposition (mm).

	Basion	Nasion	Point A
Mean	0.26	0.22	0.32
Standard deviation	0.21	0.12	0.13

Table 3 Summary of correction factors for cephalometric variables.

Cephalometric variable	Correction factor in degrees per millimetre of bite opening
SNB	Add 0.41
ANB	Minus 0.38
SN–mandibular plane	Minus 0.63
SN–*Y*-axis	Minus 0.57

Note: millimetric bite opening values are corrected for enlargement, and adjusted to the vertical.

comparing the vertical overbite on the lateral cephalogram (corrected for magnification) and the overbite on the models. The discrepancy, in millimetres, would then allow the correction factors to be applied to the angular measurements presented in the table without the need for repeating the radiograph. The assumption was made in this study that subjects who did not keep their teeth in occlusion during the radiographic procedure would most likely be in their rest position and that is, on average, under 5 mm opening. Furthermore, it was also assumed that jaw opening up to 5 mm entailed a simple mechanical rotation of the condyles, which may not truly reflect the natural opening movement (Posselt, 1952, 2001). The correction factors determined in this study may not be valid should there be any antero-posterior shift (functional or muscular habitual positioning) of the mandible during the exposure.

Several outlying values can be observed in Figure 1a,b,d. It could not be established with any certainty that these values were as a result of methodological error, and so they were included in the results. In addition, the power of these values in distorting the overall gradient was considered to be low.

It may be argued that minimal bite opening detected on a lateral cephalogram may be adequately compensated for by tracing a separate template of the lower jaw and rotating it around an axis centred in the condyle head until occlusal contact is made. This technique may be prone to several errors due to lack of radiographic clarity of the condyle area, bilateral radiographic distortion of the condyle heads, as well as difficulty in distinguishing the true occlusal plane. Combined, these errors may exceed the error of the simple correction factors determined in this study.

Variation in the vertical and antero-posterior skull morphology did not appear to make any significant difference to the effect of bite opening on the variables measured, although numbers in each category were small, and the distribution was uneven. Error measurements appeared to be similar to previously published studies (Baumrind and Frantz, 1971; Hägg *et al.*, 1998). Furthermore, error analysis was discriminated into error of landmark identification, error of digitizing, and error of superimposition.

Conclusions

This study has shown the following.

1. Bite opening up to 5 mm at the incisal edge significantly affects SNB, ANB, SN–mandibular plane, and SN–*Y*-axis angles in a linear fashion.
2. The linear relationship has allowed the production of a set of correction factors that can be conveniently employed in situations of limited bite opening without the need to repeat the radiograph.
3. Skull morphology does not appear to have a significant influence on the changes in angular measurements for limited bite opening.

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