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A method for defining targets in contemporary incisor inclination correction

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SUMMARY Different craniofacial properties require individual targets in incisor inclination. These requirements are mostly scheduled on the basis of cephalometric diagnosis, but, however, performed using straightwire appliances, which refer to third-order angles and not to cephalometric data. The objective of this study was to analyze the relationship between incisor third-order angles, incisor inclination, and skeletal craniofacial findings in untreated ideal occlusion subjects with natural dentoalveolar compensation of skeletal variation, in order to link the field of cephalometric assessment of incisor inclination with that of contemporary orthodontic incisor inclination correction. This study utilized lateral cephalograms and corresponding dental casts of 69 untreated Caucasians (21 males and 48 females between 12 and 35 years of age) with neutral (Angle Class I) molar and canine relationships and an incisor relationship that was sagittaly and vertically considered as ideal by three orthodontists (i.e. well supported by the antagonistic teeth and without the need for either deep or open bite correction). Upper (U1) and lower (L1) axial incisor inclinations were assessed with reference to the cephalometric lines NA and NL, and NB and ML, respectively. Sagittal and vertical skeletal relationships were classified using SNA (SNB) and NSL-ML (NSL-NL) angles. Third-order angles (U1TA and L1TA) were derived from direct dental cast measurements using an incisor inclination-recording appliance.

The relationships between cephalometric and third-order measurements evaluated by calculating Pearson product-moment correlation coefficients ($\alpha = 0.05$) showed strong correlations between cephalometric axial inclination data (U1NA/deg, L1NB/deg, U1NA/mm, L1NB/mm, U1NL, and L1ML) and sagittal-skeletal data, but no significant relationship between skeletal-vertical findings and incisor inclination. The mean U1TA was 4.9 (standard deviation [SD] 5.85) and the mean L1TA –3.0 (SD 6.9) degrees. Regression analyses were used for axial inclination (ANB angle designated as the independent variable) and for third-order data (U1NA, L1NB, U1NL, and L1ML designated as independent variables). Based on the correlations found in this study, a novel method for defining targets in upper and lower incisor third-order correction according to natural standards is presented. As a consequence, third-order movements can be adapted to cephalometric diagnosis with enhanced accuracy.

Introduction

Good molar and canine occlusion and a satisfactory incisor relationship can be found naturally in a majority of subjects with very differing craniofacial properties (Steiner, 1953). In these untreated ideal occlusion cases, varying incisor inclination plays an essential part in achieving dentoalveolar compensation of skeletal discrepancies (Solow, 1980). Detailed descriptions of this dental compensation mechanism have been provided (Segner and Hasund, 1998), including regression equations for calculating definite incisor positions on the basis of craniofacial properties, such as ANB angle. According to Hasund and Ulstein (1970) and Segner (1989), this compensation mechanism should be used as a guideline for correcting incisor inclination during orthodontic treatment in compliance with naturally occurring standards.

Orthodontic correction of inadequate incisor relationships is usually performed using fixed orthodontic appliances. However, torque or third-order prescriptions of brackets do not refer to cephalometric lines, but to the occlusal. Despite previous studies regarding the natural range of incisor inclination in subjects with ideal occlusal relationships (Bibby, 1980; McNamara, 1984), there is a lack of information in the orthodontic literature regarding how to adjust teeth according to skeletal data using straight wire appliances. Hence, the aim of this study were to link the fields of cephalometric assessment of incisor inclination with that of contemporary orthodontic incisor inclination correction, in order to enhance the applicability of well-accepted cephalometric standards. For this purpose, the correlation between vertical and sagittal craniofacial patterns, incisor inclination, and third-order angles (Figure 1) were investigated initially in an untreated ideal occlusion sample with natural dentoalveolar compensation of skeletal discrepancies. Subsequently, these correlations will provide the basis for the development of a method for determining individual recommendations for third-order corrections based on natural standards.

Subjects

The sample used in the study was obtained from the Center of Dentistry, Department of Orthodontics at the University Hospital Göttingen. This study was carried out following the Helsinki Criteria and approved by the Human Subject Commission of the university.

Sixty-nine Caucasians (21 males and 48 females between 12 and 35 years of age) were selected according to the following exclusion criteria: previous orthodontic therapy, primary teeth, missing teeth, filled incisors, crowned teeth, and morphological tooth anomalies. Inclusion criteria were a neutral (Angle Class I) molar and canine relationship and an incisor relationship which was sagittally and vertically considered as ideal (i.e. well supported by the antagonistic teeth and without the need for either deep or open bite correction) by three orthodontists at the Department of Orthodontics of the University of Göttingen, Germany, with the exception of minor rotations or marginal lower arch crowding which did not affect axial incisor inclination (Miethke, 2000).

The various craniofacial (sagittal and vertical skeletal) properties of the subjects included in the study were expected to reflect a normal variation and were analyzed descriptively as part of the study.

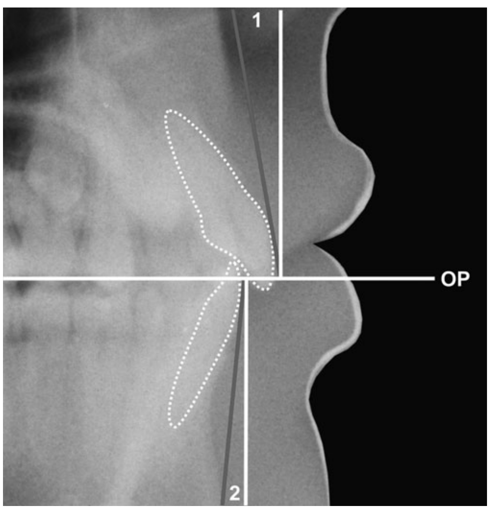

Figure 1 Schematic drawing of third-order angles in the upper (1, U1TA) and lower (2, L1TA) arch.

Method

Cephalometric measurements

Sagittal (SNA, SNB, and ANB) and vertical (NSL-ML/NSL-NL) skeletal structures were analyzed on lateral cephalograms, utilizing 12 landmarks (Figure 2).

Upper (U1) and lower (L1) incisor angulations were assessed with reference to the lines NA and NL (U1NA/deg and U1NL/deg; Figure 2), and NB and ML (L1NB/deg and L1ML/deg), respectively. Each tracing was performed manually by two examiners (MK and LG-R) on two occasions with a 3 week interval, and the respective measurements were subject to error analysis.

Third-order measurements

Third-order angles were derived from pairs of dental casts, created in parallel with the corresponding lateral radiograph. The most proclined upper and lower central incisors were chosen on the lateral radiographs and prepared for third-order assessment by marking the middle of the labial long axis of the incisor clinical crown (LACC). The measurements were performed using an incisor inclination gauge, the reliability of which has been proven in several studies (Richmond *et al.*, 1998; Ghahferokhi *et al.*, 2002; Knösel *et al.*, 2007). The measuring device consisted of a table

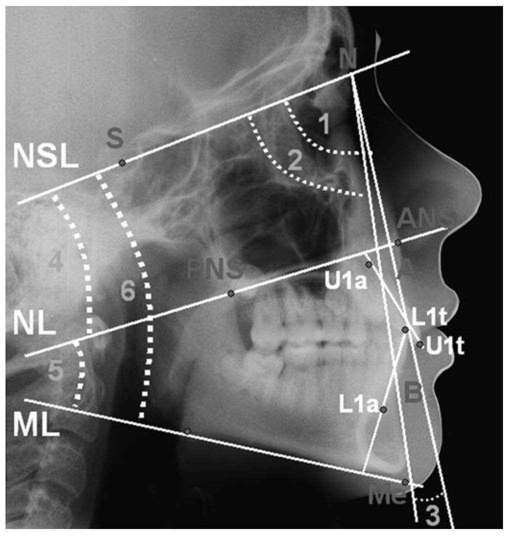

Figure 2 The landmarks used for analysis of skeletal structures and incisor inclination (S, sella; N, nasion; A; B; U1a; U1t [L1a, L1t]; tip and root apex of the most proclined upper and lower central incisor; ANS, anterior nasal spine; PNS, posterior nasal spine; Me, menton; most inferior point on the outline of the mandible at the gonion angle). Cephalometric measurements SNA (angle determined by points S, N, and A), SNB (angle determined by points S, N, and B), ANB (angle determined by points A, N, and B), NSL-NL (angle determined by SN plane and maxillary plane), NSL-ML (angle determined by the SN plane and mandibular plane), ML-NL (angle determined by the maxillary plane and mandibular plane), U1NA (angle determined by U1a-U1t line and NA line), L1NB (angle determined by L1a-L1t line and NB line), U1NL (angle determined by U1a-U1t line and maxillary plane), and L1ML (angle determined by L1a-L1t line and mandibular plane).

(dimension: 270 × 130 × 130 mm) with a centric slot and a 180 degree protractor mounted beneath. The slot was fitted with a rotating brass tube, incorporating a retractable needle (diameter: 0.5 mm) serving as the inclination indicator. For the assessments, the dental casts were mounted on a sliding sledge (dimension: 100 × 100 × 15 mm) which was track guided on the measuring table (Figure 3).

For third-order measurements, the plane of occlusion, used as the reference plane, is of particular importance. It was maintained by positioning the maxillary dental casts on the measuring sledge contacting the molars and premolars. The dental casts were then horizontally adjusted with the edge of the incisor perpendicular to the table's protractor and then guided forward against the needle until contacting the LACC (Figure 4). The excursion of the needle on the protractor then indicated the third-order angle of the incisor (U1TA and L1TA; Figure 1), which is the inclination of the facial surface inclination of the incisor to the occlusal plane. Third-order values were defined as positive if the gingival portion of the facial tangent as marked by the needle was lingual to the incisal portion and negative if the incisal portion was lingual.

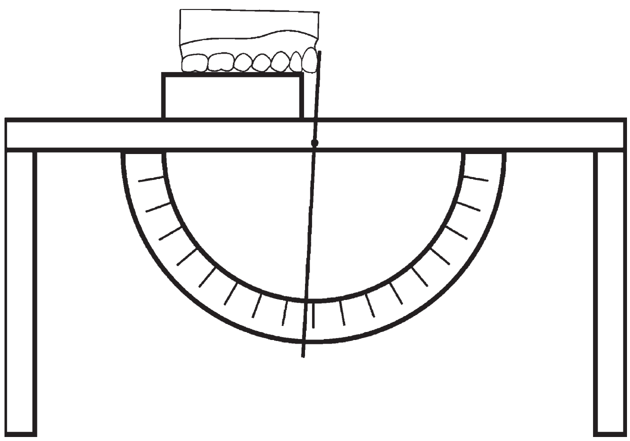

Figure 3 Schematic drawing of the third-order angle-measuring protractor. Dental casts were positioned on a sliding sledge and then guided forward until the indicator needle contacted the labial long axis of the incisor clinical crown.

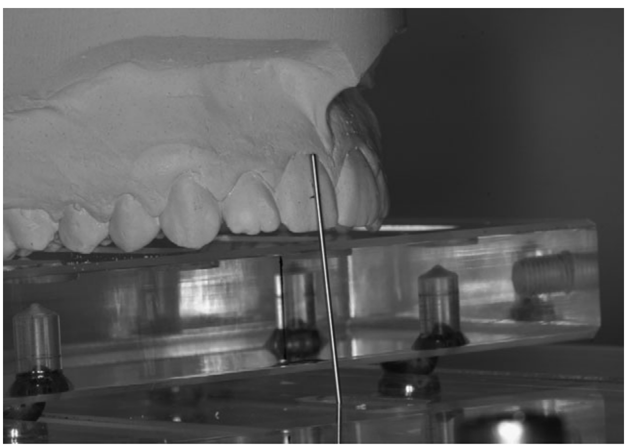

Figure 4 The recording of third-order angles.

Statistical and error analysis

For statistical analysis of the measurement data, the SAS program (StatSoft Inc., Tulsa, Oklahoma, USA) was used. Axial inclination data, third-order angles and skeletal findings were analyzed descriptively, and the relationships between these measurements were evaluated by calculating Pearson product-moment correlation coefficients ($\alpha = 0.05$). Regression analyses were used for axial inclination (ANB designated as the independent variable) and for third-order data (U1NA, L1NB, U1NL, and L1ML designated as independent variables).

Systematic differences between replicate measurements (U1TA, L1TA, U1NA, L1NB, U1NL, and L1ML) performed by two examiners (MK and LG-R) on two occasions with a 3 week interval were tested with a paired Student's *t*-test setting the α error at 0.05. The mean values of both examiners' data were considered in the calculation. Table 1 provides the mean standard deviation (SD) for the two upper and lower 1TA measurements. There were no significant differences ($\alpha = 0.05$) either between the replicate 1TA measurements or the cephalographic assessments. The method error was assessed using the formula:

$$\mathrm{ME} = \left(\sum d^2 / 2n\right)^{1/2},$$

where d is the difference between single measurement and the mean of the single measurements and n the number of measurements (Dahlberg, 1940). The errors were 0.64 degrees for U1TA measurements and 0.89 degrees for lower incisor (L1TA) measurements.

Results

Correlation between radiographic inclination data and skeletal findings

Regarding sagittal-skeletal data as illustrated by ANB, a strong negative correlation with upper axial incisor inclination (U1NA/deg) as well as a positive correlation with lower incisor inclination (L1NB/deg) was found (Table 2), but weaker correlations with cephalometric U1NL, L1ML, and third-order angles (U1TA and L1TA). There were also rather weak correlations between vertical-skeletal structures and axial inclination data (Table 3); the negative correlation (−0.36) between palatal plane inclination (NL-NSL) and U1NA/deg being the highest within this aspect.

Correlation between skeletal-sagittal and skeletal-vertical findings

The geometric influence of upper and lower jaw inclination on the sagittal position of the landmarks A and B can be

Table 1 Third-order measurement error analysis: method error and mean standard deviation between the two investigators (degrees).

	U1TA	L1TA
Mean SD	0.65	0.96
Method error	0.64	0.89

Table 2 Upper and lower incisor axial inclination versus sagittal-skeletal dimension: coefficient of correlation.

	SNA	SNB	ANB
U1TA	−0.12 (*P* = 0.625)	0.036 (*P* = 0.945)	−0.24 (*P* = 0.030)
U1NL	−0.12 (*P* < 0.001)	0.14 (*P* < 0.001)	−0.39 (*P* < 0.001)
U1NA/deg	−0.36 (*P* = 0.400)	0.024 (*P* = 0.087)	−0.6 (*P* < 0.001)
U1NA/mm	−0.34 (*P* = 0.513)	0.035 (*P* = 0.715)	−0.58 (*P* < 0.001)
L1TA	−0.1 (*P* = 0.110)	−0.3 (*P* = 0.031)	0.29 (*P* = 0.019)
L1ML	0.09 (*P* < 0.001)	−0.16 (*P* < 0.001)	0.38 (*P* < 0.001)
L1NB/deg	−0.02 (*P* = 0.006)	−0.3 (*P* = 0.062)	0.48 (*P* < 0.001)
L1NB/mm	−0.08 (*P* = 0.457)	−0.3 (*P* = 0.876)	0.33 (*P* = 0.006)

Table 3 Upper and lower incisor axial inclination versus vertical-skeletal dimension: coefficient of correlation.

	NSL-NL (deg)	NSL-ML (deg)	ML-NL (deg)
U1NA/deg	−0.36 (*P* = 0.261)	0.03 (*P* = 0.264)	0.14 (*P* = 0.071)
U1NL (deg)	0.16 (*P* = 0.046)	0.02 (*P* < 0.001)	−0.07 (*P* = 0.002)
U1TA (deg)	−0.12 (*P* = 0.325)	0.14 (*P* = 0.400)	0.22 (*P* = 0.541)
U1NA/mm	−0.21 (*P* = 0.09)	0.001 (*P* = 0.287)	0.13 (*P* = 0.877)
L1NB/deg	0.14 (*P* = 0.096)	0.25 (*P* = 0.041)	0.19 (*P* = 0.010)
L1ML (deg)	0.035 (*P* = 0.778)	−0.01 (*P* = 0.178)	−0.21 (*P* = 0.028)
L1TA (deg)	−0.04 (*P* = 0.526)	−0.17 (*P* = 0.418)	0.01 (*P* = 0.528)
L1NB/mm	0.034 (*P* = 0.645)	0.21 (*P* = 0.143)	0.21 (*P* = 0.047)

Table 4 Correlations between vertical and sagittal skeletal configurations.

	NL-NSL	ML-NSL	ML-NL
SNA	−0.27 (*P* = 0.433)	−0.52 (*P* = 0.0004)	−0.42 (*P* = 0.014)
SNB	−0.48 (*P* = 0.801)	−0.64 (*P* = 0.009)	−0.43 (*P* = 0.014)
ANB	0.29 (*P* = 0.016)	0.14 (*P* = 0.284)	−0.016 (*P* = 0.611)

seen in Table 4, according to which SNA but mainly SNB were correlated with the vertical position of the mandible (ML-NSL angle), but less to the cant of the palatal plane (NL-NSL angle).

Correlation between radiographic incisor inclination findings and third-order angles

Highly significant coefficients of correlation ($\alpha = 0.05$) were found for third-order angles (U1TA and L1TA) and cephalometrically assessed incisor inclination (Table 5).

The linear regression equations for the cephalographic assessed incisor inclination were

$$U1NA = 25.099 - (2.053 \times ANB), (R = 0.602; \sigma_{est} = 5.779),$$
$$L1NB = 21.268 - (1.433 \times ANB), (R = 0.481; \sigma_{est} = 5.534),$$
$$U1NL = 112{,}486 - (1.189 \times ANB), (R = 0.392; \sigma_{est} = 5.913),$$
$$L1ML = 90.75 + (1.334 \times ANB), \text{ and } (R = 0.383; \sigma_{est} = 6.83)$$

and for the third-order angles

$$U1TA = -4.744 + (0.481 \times U1NA^{\circ}), (R = 0.594; \sigma_{est} = 4.711),$$
$$L1TA = -20.642 + (0.711 \times L1NB^{\circ}), (R = 0.649; \sigma_{est} = 5.254),$$
$$U1TA = -49.598 + (0.497 \times U1NL), (R = 0.546; \sigma_{est} = 4.908),$$
$$L1TA = -62.466 + (0.632 \times L1ML), \text{ and } (R = 0.676; \sigma_{est} = 5.089),$$

where R is the coefficient of correlation and σ_{est} is the standard error of estimate.

Descriptive statistics

Table 6 contains descriptive statistical data of axial inclination and skeletal configuration. Cephalometric assessments of upper incisor inclination showed a natural range of 39 degrees for U1NA/deg and 24 degrees for the U1NL (mean 109.47 degrees, SD 6.43 degrees) variables. Lower incisor inclination showed a variation of 28.5 (L1NB/deg) and 36.75 degrees (L1ML; mean: 94.2 degrees, SD 7.2 degrees), respectively. Third-order angles varied between 31.25 degrees U1TA and 30.3 degrees L1TA for the lower incisor measurements. In the upper arch, U1TA assessments underscored U1NA/deg values with a mean of 15.14 degrees (SD 6.0) and U1NL data at a mean of 105.0 degrees (SD 6.02). Lower incisor third-order measurements were a mean of 28.02 degrees (SD 5.52) smaller than L1NB data and deviated at a mean of 97.27 degrees (SD 4.84) from L1ML data (Table 6).

Discussion

The mean axial inclination findings (U1NA/deg, L1NB/deg, U1TA, and L1TA), as well as the wide range of 39 degrees for the 1NA/deg variable and 28.5 degrees for 1NB/deg in this sample are in agreement with previous studies on naturally occuring incisor inclination variation in untreated subjects with normal occlusion (Hasund and Ulstein, 1970; Andrews, 1972; Ellis and McNamara, 1986). Moreover, the sagittal-skeletal range measured (Table 6) is nearly identical to that described by Casko and Shepherd (1984), who considered a wide range of ANB, −3 to 8 degrees, as normal. Thus, the findings of the cephalometric parameters in the present study were close to well-accepted norms in the literature and can be judged as representative.

From the results in Table 2, it is obvious that even in untreated ideal occlusion subjects the correlation of U1NA/

Table 5 Upper and lower incisor radiographic and direct dental cast findings: coefficients of correlation.

	U1NA (deg)	U1NA (mm)	U1NL (deg)	L1NB (deg)	L1NB (mm)	L1ML (deg)
U1TA (deg)	0.59 ($P < 0.001$)	0.54 ($P < 0.001$)	0.56 ($P < 0.001$)			
U1NA (deg)	x	0.822 ($P < 0.001$)	0.735 ($P < 0.001$)			
U1NA (mm)	0.822 ($P < 0.001$)	x	0.6055 ($P < 0.001$)			
L1TA (deg)				0.65 ($P < 0.001$)	0.64 ($P < 0.001$)	0.66 ($P < 0.001$)
L1NB (deg)				x	0.79 ($P < 0.001$)	0.815 ($P < 0.001$)
L1NB (mm)				0.79 ($P < 0.001$)	x	0.61 ($P < 0.001$)

Table 6 Descriptive statistics of third-order cephalometric incisor inclination findings and skeletal data.

Variable	Minimum	Maximum	Mean	Standard deviation
U1TA (deg)	−12.5	18.75	4.9	5.85
U1NL (deg)	96	120	109.47	6.43
U1NA/deg	−2	37	20.04	7.2
U1NA/mm	−4	10	3.35	2.6
L1TA (deg)	−20.3	10	−3.0	6.9
L1ML (deg)	77.75	114.5	94.2	7.2
L1NB/deg	11.5	40	24.8	6.31
L1NB/mm	0	9.5	4.3	2.13
SNA (deg)	73.75	90	81.27	3.29
SNB (deg)	72.25	84.5	78.81	3.14
ANB (deg)	−3.5	7.5	2.46	2.12
NSL-NL (deg)	0.5	14.5	7.43	2.85
NSL-ML (deg)	20.25	45	31.9	5.28
ML-NL (deg)	14.5	38.25	24.5	4.86

deg to the sagittal position of the maxilla (SNA) is significantly stronger than that to the sagittal position of the mandible (SNB), whereas in the same manner lower incisor inclination (L1NB/deg) to SNB is significantly stronger than to SNA. Thus, axial incisor inclination depends more on the sagittal position of the respective jaw and less on the antagonistic jaw. Bearing that in mind, it is not surprising that the mean U1TA in ideal occlusion subjects is with a mean of 4.9 degrees (SD 5.85) not much different compared with that in mixed malocclusion samples (Knösel *et al.*, 2007). However, owing to dentoalveolar compensation, the range of the 1TA variable (31.25 degrees U1TA/deg and 30.3 degrees L1TA/deg) is smaller than in the malocclusion sample, where U1TA/deg was a mean of 42.7.

Contrary to untreated malocclusion samples (Knösel *et al.*, 2007), this untreated ideal occlusion group illustrates a strong correlation between cephalometric axial inclination data (U1NA/deg, L1NB/deg, U1NA/mm, L1NB/mm, U1NL, and L1ML; Table 3) and sagittal-skeletal data, thus being in agreement with classical studies (Steiner, 1960; Hasund and Ulstein, 1970; Solow, 1980; Segner, 1989). As the correlation of sagittal-skeletal patterns (ANB) to upper incisor inclination data proved to be more distinct than to lower incisor findings (Table 2), it can be stated that the natural dental compensation of sagittal-skeletal discrepancies in the ideal occlusion sample is less expressed via the lower than via the upper incisors. This conforms with the findings of Creekmore (1997) who proposed that the determination of the amount and direction of axial incisor inclination correction should be based on the position of the upper incisors and not on the lower incisors as commonly recommended (Tweed, 1954; Steiner, 1960; Ricketts *et al.*, 1972).

The constituted correlation coefficients between antero-posterior skeletal pattern and axial incisor inclination (Table 2) demonstrate the dental compensation mechanism of a natural skeletal variation. The present study links the realms of antero-posterior skeletal pattern and third-order assessments in a natural ideal occlusion group for the first time, thus representing a guideline to treat patients according to cephalometric data with enhanced accuracy. As a consequence, from the correlation between antero-posterior skeletal data and cephalometrically assessed inclination (U1NA/deg and L1NB/deg), it is recommended to start incisor inclination adjustment by predefining upper and lower incisor position according to the regression equation U1NA = 25.099 − (2.053 × ANB) and L1NB = 21.268 + (1.433 × ANB), respectively. For facilitation, the regression equations might be integrated in diagnostic and treatment planning programme. The gained values could then be used to constitute the required third-order angle using the regression equation U1TA = −4.744 + (0.481 × U1NA degrees) and L1TA = −20.642 + (0.711 × L1NB degrees). The amount of third-order correction needed in an individual case is the discrepancy between the calculated third-order angle and the present 1TA, which is easily derived from dental cast measurements. The use of the presented regression equations helps to translate the cephalometric data into third-order data, which constitute the reference framework of straightwire appliances: whenever a straightwire appliance is chosen or some additional torque is created, it is identified as third-order angles and not cephalometric data. Thus, the presented method is instrumental in adapting third-order movements required by orthodontists to cephalometric diagnosis with enhanced precision.

Although the radiographically assessed axial inclination data and the third-order values were also strongly correlated (Table 5), there was no significant correlation between the third-order angle (U1TA and L1TA) and either the skeletal-vertical (NSL-NL, NSL-ML, and ML-NL; Table 3) or the skeletal-sagittal findings (SNA, SNB, and ANB; Table 2). This leads to the assumption that it is crown morphology that is responsible for the lack of correlation between the third-order and skeletal-sagittal data as it seems to differ interindividually (Taylor, 1969; Dellinger, 1978; Meyer and Nelson, 1978; Germane *et al*., 1989). According to morphological studies, the labial surface angle, as formed by the facial tangent and the long axis of the tooth, varies up to 24 degrees (Carlsson and Rönnermann, 1973; Fredericks, 1974; Bryant *et al.*, 1984; Vardimon and Lambertz, 1986). Whereas existing relationships between 1TA values and axial inclination data might be explained by the fact that both the incisor tip–apex connecting line and the LACC tangent are related to different areas of the same tooth, it is the crown shape that shows an interindividual difference which seems to be sufficiently strong to result in a reduction of the relationship between the inclination of the LACC tangent and the skeletal findings.

To minimize unexpected outcomes in pure straightwire treatment incorporating, at most, minor third-order bends, it would be necessary to adapt third-order adjustments of brackets to crown morphology, either by indirect bonding by adding or subtracting the amount of inclination in the third-order direction or with the use of custom made brackets.

However, axial incisor inclination is only one part of treatment planning, which also consists of providing good facial and soft tissue aesthetics in consideration of the antero-posterior position of the anterior teeth, alignment, stability, good occlusion, and correct functionality. To all these orthodontic challenges, straightwire appliances cannot be the universal answer. However, the findings of the present study can be a guideline to adjust incisor inclination in harmony with skeletal structures and in coincidence with individual requirements.

Conclusion

According to this ideal occlusion sample, incisor inclination is strongly correlated with skeletal-sagittal data, but little with skeletal-vertical findings. The natural dental compensation of sagittal-skeletal discrepancies is less executed in the lower than the upper incisors.

This study allies the realm of cephalometric assessment of incisor inclination and antero-posterior skeletal patterns with the field of contemporary orthodontic incisor inclination correction, thus providing an enhancement of the applicability of accepted cephalometric standards for axial incisor inclination. As a consequence, third-order movements can be adapted to cephalometric diagnosis with higher precision. The use of third-order measurements in combination with the presented regression equations for defining targets in incisor inclination correction according to naturally found standards is recommended. Further research will concern routine testing of the presented linear regression formulas on a new sample.

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