

On the Interaction between Incisor Crown-Root Morphology and Third-Order Angulation

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ABSTRACT

Objective: To evaluate the significance of crown-root angles (CRAs) by testing the null hypothesis that there are no significant differences in deviations of third-order angles to axial inclination values between Angle Class II division 2 incisors and a neutral occlusion control sample.

Materials and Methods: The study group comprised $n_{\text{total}} = 130$ whites with either Angle Class II division 2 ($n_1 = 62$; group A) or neutral ($n_2 = 68$; control group B) occlusal relationships. Upper central incisor inclination (U1) was assessed with reference to the cephalometric lines NA and palatal plane (U1NA/deg, U1PP/deg). Craniofacial sagittal and vertical relations were classified using angles SNA, SNB, ANB, and NSL-PP. Third-order angles were derived from corresponding dental cast pairs using an incisor inclination gauge. Welch's two-sample *t*-tests (α -level: .05) were used to test the null hypothesis. Single linear regression was applied to determine third-order angle values as a function of axial inclination values (U1NA, U1PP) or sagittal craniofacial structures (ANB angle), separately for group A and B.

Results: The discrepancy between axial inclination (U1NA, U1PP) and third-order angles is significantly different ($P < .001$) between groups A and B. Regression analysis revealed a simply moderate correlation between third-order measurements and axial inclinations or sagittal craniofacial structures.

Conclusion: The hypothesis is rejected. The results of this study warn against the use of identical third-order angles irrespective of diminished CRAs typical for Angle Class II division 2 subjects. Routine CRA assessment may be considered in orthodontic treatment planning of Angle Class II division 2 cases. (*Angle Orthod.* 2009;79:454–461.)

KEY WORDS: Class II division 2; Third-order angle; Upper incisor inclination; Crown-root morphology

INTRODUCTION

Adequate third-order incisor inclination is an essential part of dental arch adjustment, and the different

approaches to defining targets in incisor inclination correction highlight the issue of the front teeth representing an interface between function and esthetics. Besides the issue of esthetics as a major concern for patients seeking orthodontic treatment,¹ incisor inclination correction has to take into consideration the following points.

Correlation and Adjustment of Upper and Lower Dental Arch Length

In this context, Andrews² drew attention to the relevance of proper incisor inclination for matching upper and lower dental arch length. Hussels and Nanda³ provided mathematical formulae for calculating the effect of axial inclination on dental arch length, whereas O'Higgins et al⁴ used typodonts to quantify the effects of incisor inclination increase on arch length. Later, Sangcharearn and Ho^{5,6} demonstrated in further typodont studies the influence of incisor axial inclination on overbite, overjet, and intercuspation of posterior arch segments. Incisor crown shape also contributes

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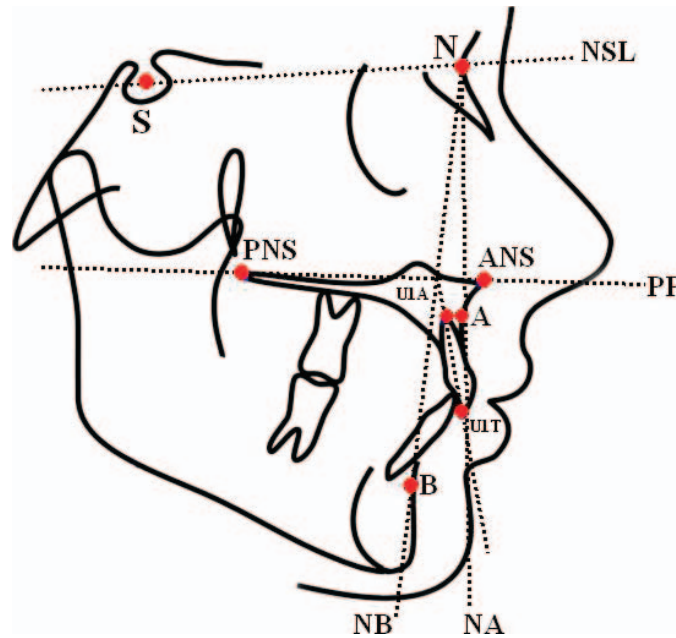


Figure 1. Schematic representation of landmarks and reference lines used for cephalometric analysis. See Table 1 for detailed description.

to this issue, as the change in inclination in incisors with parallel proximal sides results in greater increases in arch length than in those with triangle-shaped teeth.⁴

Varying Craniofacial and Dental Standards

Incisor inclination standards for untreated norm-occlusion subjects vary in different populations and in dependence on the respective craniofacial features,^{2,7,8} indicating that benchmarks used for orthodontic treatment should be based on cephalometric standards derived from the respective populations.

Soft Tissue Borders

With regard to treatment result stability, diagnosis of soft tissue borders requires special care. For example, the final position of upper incisors in relation to the lip line is considered crucial for the stability of treatment results in cover bite situations.^{9–11} In addition, inclination and position of incisors and their effect on soft tissue profile has to be considered.¹²

Hard Tissue Borders

There has been controversy regarding whether excessive proclination, especially of mandibular incisors, may be significantly correlated with gingival recession¹³ or not.^{14–16} However, there is consensus that contact of the upper incisor's roots with the cortical plate will result in root resorption.¹⁷

With regard to this point, the crown-root morphology of a certain percentage of incisors, mostly observed in

Angle Class II division 2 subjects,^{18,19} requires special consideration. In these cases, lingual translation or tipping of incisors represents a particular challenge, as root resorption may impend, even before third-order crown correction considered to be adequate for incisors with straight crown-root angles (CRAs), has been accomplished.^{19,20}

These different demands on incisor inclination correction are commonly implemented with straight-wire appliances after cephalometric incisor inclination evaluation in relation to different craniofacial reference lines, for example, the palatal plane (PP) or the NA line (Figure 1, Table 1). Third-order prescriptions of straight-wire brackets refer to the occlusal plane perpendicular (OPP), which does not coincide with these common cephalometric reference lines. The deviation between third-order angles and cephalometric incisor inclination has been described previously.^{21,22} Although the findings of these studies may be of value in cases where there is almost a straight crown-root relation, it is conjectural whether they would also apply to subjects with distinctly reduced CRA, as investigations on Angle Class II division 2 subjects have indicated a considerable variation in CRA^{17,18,23} (Figure 2).

The aims of this study were, therefore, to evaluate whether third-order recommendations for incisor inclination can be provided irrespective of the normal range of incisor crown-root morphology and to extend the applicability of established knowledge concerning diminished CRA in Angle Class II division 2 patients.^{18,19} This will be done by testing the null hypothesis that the discrepancy between third-order values

Table 1. Landmarks and reference lines used for angular measurements^a

Method	Landmarks	Reference Lines
U1TA	LACC; longitudinal axis midpoint of central incisor's clinical crown	Upper LACC tangent
U1NA	N, Nasion; most antero-inferior point on frontal bone at the nasofrontal suture A, A-Point; deepest point on curvature between ANS and alveolar crest	OP perpendicular (Cast measurement) NA line
U1PP	Incisor tip and apex ANS, anterior nasal spine PNS, posterior nasal spine Incisor tip and apex	Palatal plane Incisor axis
SNA	S, sella; midpoint Sella turcica N, Nasion	SN line NA line
ANB	A, A-Point N, Nasion B, B-Point; deepest point on curvature between pogonion and the alveolar crest	NA line NB line
NSL-PP	S, Sella N, Nasion ANS, anterior nasal spine PNS, posterior nasal spine	SN line Palatal plane
SNB	S, Sella N, Nasion B, B-Point	SN line NB line

^a See Figure 1 and text for further description of landmarks.

and complete axial incisor inclination is not significantly different in Angle Class II division 2 incisors and a neutral occlusion control sample. Rejection of the null hypothesis would warn against the identical use of third-order angles irrespective of diminished CRA typical for Angle Class II division 2 subjects. CRA as-

essment should then be included routinely in orthodontic treatment planning for Angle Class II division 2 patients.

MATERIALS

This study used standardized lateral headfilms and corresponding dental casts of 130 whites (58 males and 72 females; mean age = 18.2 years; SD = 4.1). Subjects were selected based on the following exclusion criteria: previous orthodontic therapy, primary teeth, missing teeth, incisor restorations, morphologic tooth anomalies, open bite, Angle Class III or II division 1, and missing or unclear corresponding radiographs. Subjects were divided into two groups with either neutral (Angle Class 1) or Angle Class II division 2 occlusal relationships. Group A consisted of $n_1 = 62$ subjects who met the inclusion criteria of an Angle Class II molar and canine occlusion of at least a half cusp on both sides, in combination with reclined upper incisors contacting the lower incisors. Control group B consisted of $n_2 = 68$ subjects. Inclusion criteria for these norm-occlusion cases were a neutral (Angle Class I) molar and canine relationship and an incisor relationship that was sagittally and vertically considered normal (ie, well supported by the antagonistic teeth, without the need for either deep bite or open bite correction, and not exceeding minor rotations or crowding).

Radiographs and dental casts used in the study were part of the pretreatment records and were obtained from the Dentistry Center, Department of Orthodontics at the University of Göttingen. This study was carried out in accordance with the Helsinki Criteria and approved by the local Ethics Committee.

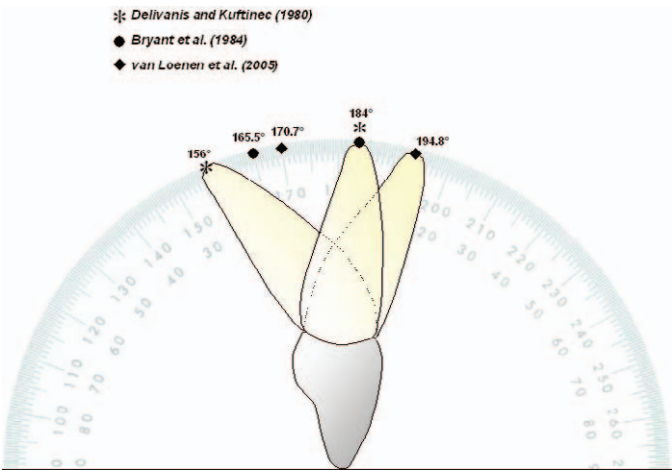


Figure 2. Variation of crown-root angles as reported in the contemporary literature.

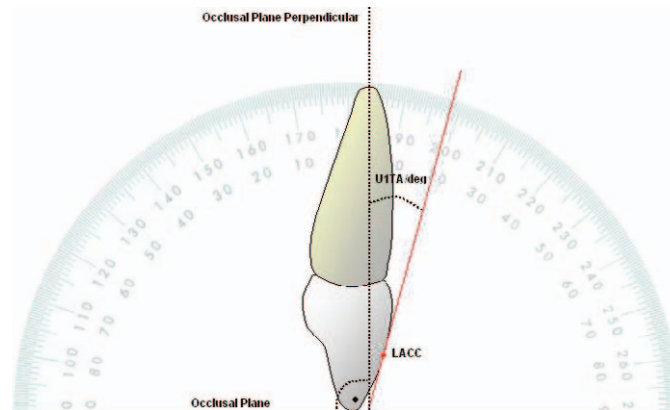


Figure 3. Schematic drawing of third-order angles.

METHODS

Cephalometric Measurements

Upper incisor inclination (U1) was assessed with reference to the cephalometric lines NA and PP. Each cephalographic tracing was performed manually by the same examiner. Angular measurements (U1NA/deg, U1PP/deg, SNA, SNB, ANB, NSL-PP) were performed on the lateral cephalograms after digitizing eight landmarks. The description of landmarks and reference lines is given in Table 1 and Figure 1.

Third-Order Measurements

Third-order angles (Figure 3) were derived from dental cast pairs that were made at the same time as the corresponding lateral radiograph. The method used incorporates a type of incisor inclination gauge that has been proven reliable in several studies already.^{21,22} The upper right central incisor was chosen and prepared for assessment by marking the longitudinal axis point of the clinical crown, LACC. For the assessments, the dental casts were mounted on a

sliding platform that was guided on a track on a measuring table (Figure 4). The occlusal plane was maintained by positioning the dental casts on the measuring platform contacting molars and premolars. The casts were then adjusted horizontally, with the edge of the incisor perpendicular to the table's protractor, and then guided straight forward against a rotatable needle until it contacted the LACC. The excursion of the needle on the protractor then indicated the incisor third-order angles (U1TA, Figure 3), which were defined as positive if the LACC tangent was inclined posterior with reference to the OPP.

Statistical Analysis

Statistical analysis was performed using the statistics software R 2.6 (R Foundation for Statistical Computing, www.r-project.org). Welch's two-sample *t*-tests (α -level: .05) were used to compare the discrepancies between third-order and axial inclination values in group A and control group B. Single linear regression analysis was applied for modeling third-order angles as a function of either axial inclination data (U1NA,

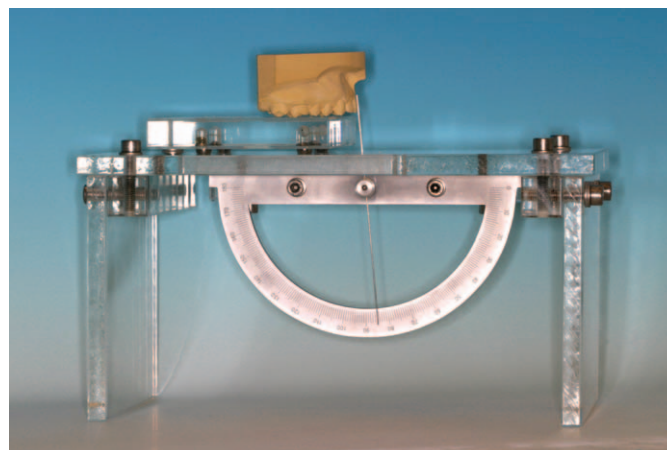


Figure 4. Third-order measuring device.

Table 2. Means and 95% confidence intervals (CIs) for measurements of the distinct angles in both groups

Angle Type	Group A (Class II/2)		Group B (Control)	
	Mean	95% CI	Mean	95% CI
U1TA	-11.08	[-12.78, -9.37]	4.90	[3.48, 6.31]
U1NA	8.14	[6.45, 9.82]	20.04	[18.29, 21.79]
U1PP	97.11	[95.54, 98.68]	109.56	[108.00, 111.11]
SNA	81.47	[80.55, 82.40]	81.28	[80.48, 82.07]
SNB	76.40	[75.36, 77.43]	78.81	[78.05, 79.57]
ANB	5.16	[4.38, 5.93]	2.46	[1.95, 2.98]
NSL-NL	7.18	[6.37, 7.99]	7.43	[6.74, 8.12]

U1PP) or sagittal craniofacial structures (ANB angle), separately for Class I and Class II division 2 subjects. Regression equations had the form $y = \text{intercept} + \text{slope} \cdot x$.

Error Analysis

For error analysis, repeated third-order measurements were performed on the control group sample by two examiners, on two occasions, at a 3-week interval and compared with Student's *t*-test for paired samples adopting an α -level of .05. The mean values of both examiners' data were considered in the calculation. The technical error of measurement was assessed using the formula²⁴

$$\text{TEM} = \left(\sum d_i^2 / 2n \right)^{1/2}$$

where d_i is the difference between the first and the second measurement on the i th subject and n is the sample size. There were no significant differences between repeated assessments according to the *t*-test ($P = .36$). The technical error of measurement was 0.66 degrees.

RESULTS

Group Comparison

Means and 95% confidence intervals of the distinct angle types in groups A and B are presented in Table 2. Distributions of the discrepancies between third-order angles and axial inclinations in both groups are given in Table 3. By applying the *t*-test, these distributions were significantly different in the two groups.

Table 3. Results of the *t*-test for comparing differences in third-order angles and axial inclinations in Class I and II/2 samples, and 95% CIs for the difference of the two groups

Sample	A (Class II/2)		B (Control)		<i>t</i> -test <i>P</i> -value	95% CI
	Mean	(SD)	Mean	(SD)		
U1NA-U1TA	19.21	(6.26)	15.14	(6.02)	.0003	[-6.20, -1.93]
U1PP-U1TA	108.18	(5.98)	104.66	(5.88)	.0010	[-5.58, -1.46]

Single Regression Analysis

Due to significant differences in comparing discrepancies of third-order and axial inclination measurements of both groups, single regression analysis was performed using third-order measurements as the dependent variable (*Y*), whereas either incisor complete axis measured with reference to lines NA (*X*1), PP (*X*2) or ANB angle (*X*3) were designated to be independent variables (Table 4). According to the estimated regression coefficients, third-order angles can be represented using U1NA angles by the equation

$$\text{U1TA}_{\text{Group A}} = -15.68 + 0.57 \cdot \text{U1NA}$$

in Angle Class II division 2 subjects, and by the equation

$$\text{U1TA}_{\text{Group B}} = -4.74 + 0.48 \cdot \text{U1NA}$$

in the neutral occlusion sample. For example, for the control group B, the equation determined that there is an overall difference between U1TA and U1NA values of -4.74 degrees and, third-order values increase by 0.48 degree when U1NA values increase by 1 degree. Analogous changes for U1PP are given in Table 4.

Figure 5a through d represents the third-order measurements vs the different independent variables, including the regression lines based on the respective estimated regression equation. The coefficient of determination R^2 , which describes the goodness of the regression fit, was relatively small in all regressions, indicating that there was also a simply moderate correlation between third-order values and the distinct independent variables. Intercepts are clearly smaller for Class II division 2 regressions than for the Class I sample, whereas slopes are rather similar in both groups.

Correlations between third-order values and axial inclinations (U1PP, U1NA) or sagittal craniofacial structures were assessed using Pearson's correlation coefficient and respective confidence intervals (Table 5). Confidence intervals that include zero reveal that the correlation is not significantly different from zero. This is the case for the correlation with ANB in Class I and with NSL-PP in both classes.

Table 4. Regression coefficients and coefficient of determination R^2 for different regressors of third-order measurements

	Regressor	Intercept		Slope		R^2
		Estimate	95% CI	Estimate	95% CI	
Class II/2 (Group A)	NA	-15.68	[-17.94, -13.42]	0.57	[0.35, 0.78]	0.31
	U1PP	-71.43	[-93.84, -49.03]	0.62	[0.39, 0.85]	0.33
	ANB	-7.71	[-13.32, -2.18]	-1.06	[-2.07, -0.06]	0.16
Class I (Group B)	NA	-4.74	[-8.15, -1.34]	0.48	[0.32, 0.64]	0.35
	U1PP	-49.6	[-70.19, -29.00]	0.5	[0.31, 0.69]	0.3
	ANB	6.51	[4.38, 8.65]	-0.66	[-1.32, 0.00]	0.05

DISCUSSION

Although a considerable variation in CRA of 24 to 28 degrees has been reported in the literature^{18,19,23,25} (Figure 2), it has not yet been shown to have any systematic impact on recommendations for third-order incisor inclination. However, it may be assumed that CRA variation has an influence on the efficiency of orthodontic mechanics, similar to the different effects of labial or lingual application of incisor intrusion mechanics.²⁶ Geron²⁶ demonstrated the influence of the variation in the distance between force insertion and the center of resistance C_{Res} (and thus the location of the center of rotation, C_{Rot}) on tooth movement: As a variation in CRA also implies a variation in the incisor's root-centroid and C_{Rot} , an effect on tooth movement may also be assumed.

Moreover, third-order angles are not only influenced by CRAs, but also by the expression of the labial enamel surface (LES) morphology,^{19,27} which shows a normal variation of 5 to 6 degrees in relation to the crown axis.^{28,29} Owing to the natural variation in LES and CRA expression, in both groups there was a rather weak correlation between third-order angles and craniofacial structures compared to correlations with incisor long axis inclination (Table 5). Bryant et al¹⁹ emphasized the variation in CRA and LES morphology, but they did not explicitly draw conclusions regarding angles with reference to torque requirements. After all, it cannot be considered evidence based to provide third-order recommendations irrespective of incisor crown-root morphology.

Distributions of the discrepancies between third-order angles and axial inclinations in both groups were significantly different (Table 3). These deviations sub-

sume CRA and LES morphology. However, because there is no evidence of a significant correlation between the LES expression and different malocclusion classes,¹⁹ we studied the influence of the CRA on the discrepancy between third-order angles and conventional incisor inclination. The results indicate that typical differences in CRA of Class I and Class II division 2 subjects show equally significant differences in deviations between third-order angles and entire axial inclination. Therefore, deviating CRA in Class II division 2 subjects may require third-order treatment recommendations different from those in Class I cases.

Single regression analysis revealed an overall difference between third-order inclination and U1NA (U1PP) measurements of -15.68 (-71.43) degrees in the Class II group, compared to -4.74 (-49.60) degrees in the control group. In addition, a change of 1 degree in third-order inclination would produce similar changes, in both groups, between 0.48 and 0.62 degrees for U1NA or U1PP assessments (Table 4). Based on these facts, consideration may be given to performing angle measurements between upper incisor roots and palatal cortical structures when planning the treatment of Class II division 2 subjects to define the space or range that can be safely used for upper incisor correction.

Clinical Implications

The distance between upper incisor roots and palatal cortical structures requires special consideration in Class II division 2 subjects and should be routinely checked in planning orthodontic treatment for these patients. Based on the results from this study, third-order recommendations for incisor inclination cannot

Table 5. Correlations and respective confidence intervals between third-order values and axial inclinations or sagittal craniofacial structures

Variable	Group A (Class II/2)			Group B (Control)		
	r	95% CI	P	r	95% CI	P
U1NA	0.56	[0.36, 0.71]	<.01	.59	[0.41, 0.73]	<.01
U1PP	0.57	[0.38, 0.72]	<.01	.55	[0.35, 0.69]	<.01
ANB	-0.40	[-0.68, -0.02]	.04	-.24	[-0.45, 0.00]	.05
NSL-PP	-0.15	[-0.42, 0.14]	.30	-.12	[-0.35, 0.12]	.33

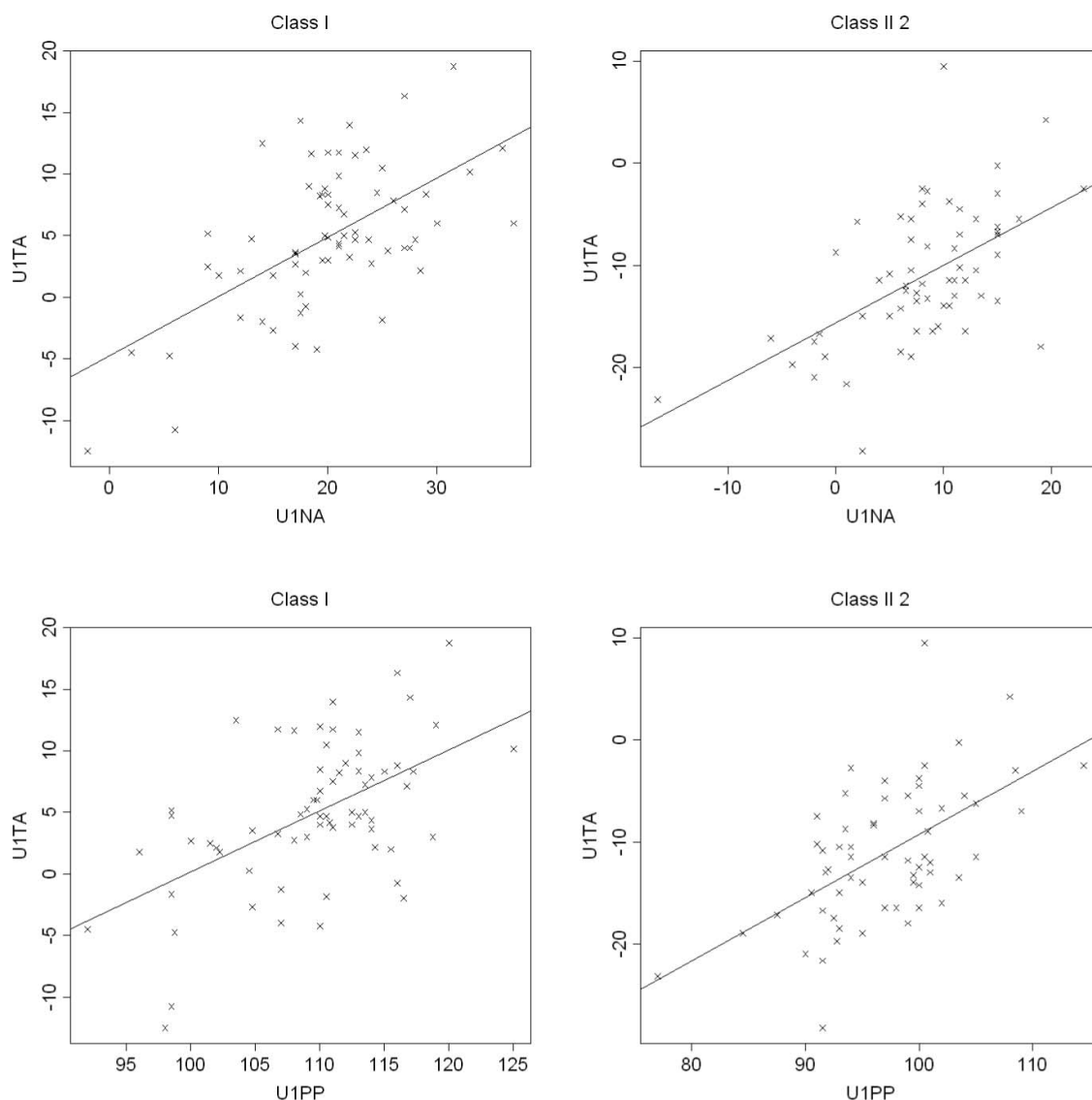


Figure 5a-d. Third-order measurements vs different radiographic angles (solid lines indicate regression lines).

be provided irrespective of the normal range of incisor crown-root morphology. The application of the proposed regression equations enables the clinician to correct incisors in Class II division 2 subjects according to cephalometric standards that, up until now, were only applicable in neutral occlusion subjects with a CRA of approximately 178 degrees. Also, the results suggest that a significantly smaller CRA may indicate a variation in the incisor's root-centroid and C_{Rot} and may therefore have an effect on tooth movement and the efficiency of incisor intrusion or uprighting mechanics.

Limitations of the study

The problem of individual risk estimation with regard to upper incisor roots' local relation to critical hard tis-

sue borders, such as the palatal cortical plate,¹⁷ has not been addressed by this study. There is still a need, of course, for careful clinical and radiographic evaluation of hard and soft tissue borders and anterior teeth, especially in Class II division 2 patients.

In an extension of our research, we therefore intend to use lateral headfilms and clinical setups to establish standards for individual optimization of functional aspects, such as arch length adjustment, in combination with minimizing the risk of upper incisor root resorption.

CONCLUSIONS

- Third-order recommendations for incisor inclination should not be made irrespective of the normal range of incisor crown-root morphology.

- The results of this study warn against the use of identical third-order angles irrespective of diminished CRA typical for Angle Class II division 2 subjects.
- The applicability of established knowledge concerning diminished CRA in Angle Class II division 2 patients is enhanced by providing regression equations for third-order data calculations according to cephalometric standards.
- Routine CRA assessment may be considered in orthodontic treatment planning for Angle Class II division 2 patients.

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