

Systematic evaluation of the features influencing the accuracy of third order measurements

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SUMMARY The aims of this study were to evaluate the relationship of third order measurements on dental casts with those on lateral radiographs, and to identify those incisor features on radiographs which can best explain third order measurements on dental casts.

Lateral cephalograms and corresponding dental casts were obtained from 39 untreated Caucasians (12 males, 27 females; mean age 19.5 years; standard deviation 3.7 years) with occlusal relationships considered to be 'normal'. The upper (U1) and lower (L1) incisors were assessed with reference to the occlusal plane perpendicular which was established on the lateral radiographs, including third order angles (U1TR, L1TR) which were also derived from direct dental cast measurements (U1TA, L1TA). Both single regression and multiple linear regression analysis with stepwise variable selection were performed using third order measurements on casts as the dependent variable and crown axis (U1C, L1C), root axis (U1R, L1R), tip–apex connecting line (U1E, L1E), and radiographic third order measurements as independent variables.

Single regression analysis indicated an overall difference of 0.02 degrees between radiographic third order inclination and cast assessment in the maxilla (mandible: –2.83 degrees). A change of 1 degree in radiographic third order inclination would produce a change of 0.65 degrees for U1TA and 0.86 degrees for L1TA assessments. Third order measurements on dental casts can best be explained by a linear combination of U1TR and U1E (maxilla) and of L1TR and L1C (mandible) measurements.

This study demonstrates the functional enmeshment between two different third order assessments and the most common incisor features on lateral radiographs. Both methods of third order evaluation show sufficient reliability and are appropriate for routine orthodontic practice.

Introduction

Adequate third order incisor inclination is an essential part of upper and lower dental arch adjustment and has both functional and aesthetic objectives (Andrews, 1972; Hussels and Nanda, 1987; Perkins and Staley, 1993; O'Higgins *et al.*, 1999; Sarver, 2001; Sangcharearn and Ho, 2007). Axial incisor inclination has two aspects: root inclination and crown inclination. Crown inclination is commonly expressed in terms of third order angles (Figure 1) and also includes the expression of the morphology of the labial enamel surface (LES). Several studies of incisor features have pointed out the influence of LES and crown–root angles (CRA) on axial incisor inclination (Bryant *et al.*, 1984; Miethke and Melsen, 1999; McIntyre and Millett, 2003; van Loenen *et al.*, 2005). In the majority of radiographic inclination analyses, however, crown and root axes have been approximated to a straight line (Steiner, 1959; Proffit and Ackerman, 2000), a method which may be sufficiently accurate in subjects with a CRA of approximately 180 degrees, but which may also, for example, mimic a more proclined upper incisor crown inclination in subjects with diminished CRA (Delivanis and Kufte, 1980). Nevertheless, these cephalometric assessments not only

evaluate crown inclination but also allow judgement to be made of median complete crown–root inclination in comparison with established standards.

It is a well-established practice to refer to third order angles when describing the properties of straightwire brackets or the torque potential of incorporated archwires (Andrews, 1972). Richmond *et al.* (1998) introduced a third order gauge suitable for crown inclination measurements. Although recent studies have highlighted advantages of measuring third order angles on casts or *in vivo* (Ghahferokhi *et al.*, 2002; Devreese *et al.*, 2007; Knösel *et al.*, 2007), such as radio-hygienic incisor inclination control or transferability to straightwire bracket prescriptions, they can also be derived from lateral radiographs (Creekmore and Kunik, 1993). Finally, third order measurements can be referenced from Andrews' (1972) initial crown inclination measurements, which have also been performed on casts and have provided the basis for the later development of the straightwire technique.

This study had two objectives: (1) to compare the cephalometric and the dental cast method for assessing incisor third order angles, particularly with reference to inter-observer concordance and to evaluate the influence of

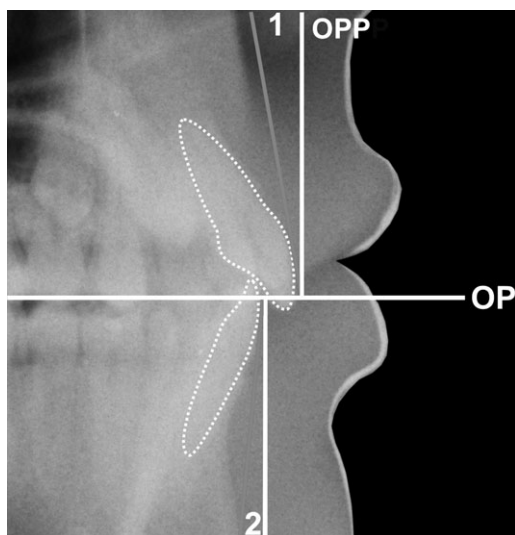


Figure 1 Diagram of upper (1, U1TA, U1TR) and lower (2, L1TA, L1TR) third order angles, ranging from facial axis-point tangent (thin line) to occlusal plane perpendicular (OPP).

inter-observer variation in occlusal plane (OP) determination, as a possible source of error, and (2) to investigate the functional relationship between the different cephalometric incisor features relevant for orthodontic treatment in relation to these third order angles.

Several single factors are likely to have an influence on third order assessments; e.g. crown inclination, root inclination, or axial inclination of the complete incisor. This study utilized single as well as multiple regression analysis (including stepwise selection of variables) to establish which of these variables could best explain the third order measurements on the casts. The purpose of the multiple regression with stepwise selection was to find an equation that best predicts the *Y* variable (dental cast assessment) as a linear combination of the other (*X*) variables and, in addition, to clarify the functional relationships between the dependent (dental cast data) and independent (radiographic data) variables. Based on these results, the causes of variation in the dependent variable could be evaluated.

In addition to evaluating the relationship of measurements made on casts with those on radiographs using regression analyses, the following null hypotheses were tested.

1. There is no correlation of third order measurements on casts with any of the other variables (crown inclination, root inclination, and axial inclination of the complete incisor); i.e. the respective correlation coefficients are equal to 0.
2. Inter-observer assessment of the OP on radiographs is reliable; i.e. the mean difference of the measurements of the two observers is equal to 0.

The rejection of the null hypothesis (1) would indicate the possibility of individually and radio-hygienically assessing the influence of the *X* variables on third order

angles by means of regression analysis. The rejection of null hypothesis (2) would mean that measurements of two different observers result in significantly different values.

Subjects and methods

Thirty-nine Caucasians [12 males, 27 females; mean age 19.5 years; standard deviation (SD) 3.7 years] were selected according to the following exclusion criteria: previous orthodontic therapy, primary teeth, missing teeth, incisor restorations, and morphological tooth anomalies. Normal occlusion cases were chosen in order to draw comparisons with established cephalometric and third order standards in the literature (Andrews, 1972; Currim and Wadkar, 2004). Therefore, inclusion criteria were a neutral (Angle Class I) molar and canine relationship and an incisor relationship which was considered as normal sagittally and vertically (i. e. well supported by the antagonistic teeth and without any need for either deep or open bite correction). The assessment for eligibility was made by three orthodontists the Department of Orthodontics, University of Göttingen. The study received the approval of the local Ethics Committee.

Cephalometric measurements

Upper (U1) and lower (L1) incisor inclination, third order angles, and crown and root axis were analyzed on lateral radiographs, utilizing nine cephalometric lines (Table 1; Figures 1 and 2).

All measurements were assessed with reference to the occlusal plane perpendicular (OPP; Figure 2). The OP was established on the lateral radiographs by drawing a line through the mesial cusps of the permanent upper and lower first molars and bisecting the distance between the edges of the upper and lower central incisors. Each cephalographic tracing was performed, by hand, by two assessors (MK and LG-R). For third order radiographic measurements [upper central incisor (U1TR) and lower central incisor (L1TR) third order radiographic measurement], the tangent at the centre of the central incisor crown [facial axis (FA) point of the incisor clinical crown] was constructed. The FA point was determined by measuring the point of bisection at the LES, disregarding the first millimetre at the labial cemento-enamel junction (CEJ), which is normally covered by gingiva. Upper central (U1C) and lower central (L1C) incisor crown and root axes (U1R, L1R) were constructed using the point of bisection of the CEJ and incisor tip and root apex, respectively (Figure 2). Finally, the entire incisor axis (U1E, L1E) was estimated using a line connecting the tip and apex.

To assess the observer variation with regard to the OP, the differences between the cephalometric tracings of assessors 1 and 2 were evaluated.

Table 1 Cephalometric lines used for angular measurements. The occlusal plane (OP) was established on the lateral radiographs by drawing a line through the mesial cusps of the permanent upper and lower first molars and bisecting the distance between the edges of the upper and lower central incisors. Further landmark descriptions are given in text.

Method	Variable	Reference lines
U1TA	Y (dependent)	Upper facial axis (FA)-point tangent (Cast) OP perpendicular
L1TA	Y (dependent)	Lower FA-point tangent (Cast) OP perpendicular
U1TR	X1 (independent)	Upper FA-point tangent (Ceph) OP perpendicular
L1TR	X1 (independent)	Lower FA-point tangent (Ceph) OP perpendicular
U1E	X2 (independent)	Upper tip-apex connecting line OP perpendicular
L1E	X2 (independent)	Lower tip-apex connecting line OP perpendicular
U1C	X3 (independent)	Upper crown axis OP perpendicular
L1C	X3 (independent)	Lower crown axis OP perpendicular
U1R	X4 (independent)	Upper root axis OP perpendicular
L1R	X4 (independent)	Lower root axis OP perpendicular

Third order measurements

Third order angles were derived from dental cast pairs, which were created at the same time as the corresponding lateral radiograph. The most proclined upper and lower central incisors were chosen, since these are easy to observe on lateral radiographs, and prepared for third order assessment by marking the FA point. The measurements were carried out using a custom-made incisor inclination gauge whose reliability has been proven in several studies (Richmond *et al.*, 1998; Ghahferokhi *et al.*, 2002; Knösel *et al.*, 2007). The device consisted of a measuring table (dimension: 270 × 130 × 130 mm) with a central slot and a 180 degree protractor mounted beneath. The slot was fitted with a brass tube which could be rotated, incorporating a retractable needle (diameter: 0.5 mm) serving as an indicator of inclination. For the assessments, the dental casts were mounted on a sliding platform (dimension: 100 × 100 × 15 mm) which was guided on a track on the measuring table (Figure 3). The OP was maintained by positioning the maxillary dental casts on the measuring platform contacting molars and premolars. The dental casts were then adjusted horizontally, with the edge of the incisor perpendicular to the table’s protractor, and then guided forward against the rotational needle until it contacted the FA point. The excursion of the needle on the protractor then indicated the dental cast third order angle of the upper or lower central incisor (U1TA, L1TA;

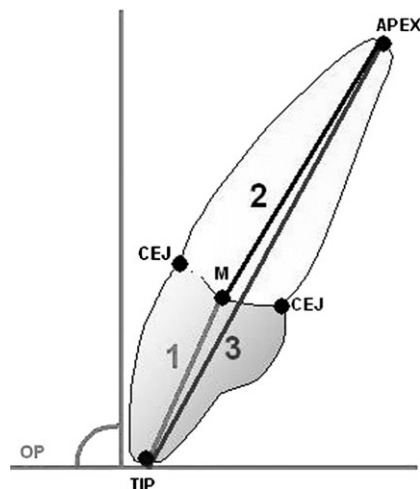


Figure 2 Schematic diagram of radiographic landmarks and measurements: incisor crown tip (TIP), incisor root apex (APEX), palatal and labial cemento-enamel junction (CEJ), midpoint between the palatal and labial CEJ (M); incisor crown axis (1, U1C), root axis (2, U1R), and complete axial inclination (3, U1E) measurements in relation to the occlusal plane perpendicular.

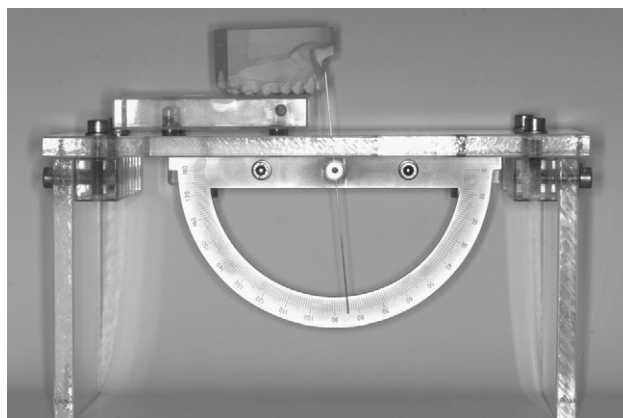


Figure 3 The third order angle recording device.

Figure. 1). Third order values were defined as positive if the FA-point tangent was posteriorly inclined.

Statistical and error analysis

Statistics were performed using SAS 9.1 software (SAS Institute, Cary, North Carolina, USA).

Comparison of methods

The relationship between cephalometric and dental cast assessments was evaluated with Pearson’s correlation coefficient, *r*, and respective 95 per cent confidence intervals. The correlation of two methods is significantly different from 0 (with an α level of 0.05) if the confidence interval (CI) does not include 0. The distributions of

measurements using different methods were compared using Wilcoxon's ranked sum test for paired samples (α level: 0.05).

Single and multiple regression

Single and multiple regression analyses were performed using the third order measurements on casts as the dependent variable (Y), whereas radiographic third order measurements ($X1$), complete incisor axis ($X2$), crown axis ($X3$), and root axis with reference to the OPP ($X4$) were specified as being the independent variables (Table 1). In addition, stepwise selection (Hocking, 1976) was used to find a linear combination of independent variables that best describes the measurements on the casts. The goodness of regression fits were assessed by the coefficient of determination, R^2 , which describes the degree of variance explained by the estimated regression model.

Error analysis and comparison of both assessors

The measurements of both assessors were compared using Pearson's correlation coefficient and Wilcoxon's ranked sum test for paired samples. In the same way, third order measurements (U1TA, L1TA) repeated at an interval of 7 days by both assessors were compared. The inter-observer deviation of the OP was evaluated using the t -test and by calculating a normal 95 per cent CI for the mean difference.

Results

Descriptive sample analysis

The distributions of the angles measured by all methods are depicted in Figure 4a,b. The mean values of both assessors for radiographic third order angulation were for the maxilla 8.24 degrees [(SD 5.3); mandible: 1.59 degrees (SD 6.3)]

and 5.54 degrees for the maxilla [(SD 4.88); mandible: -1.13 degrees (SD 6.81)] with the cast estimation. The means and SDs for both assessors and all variables are presented in Table 2.

Comparison of methods

Wilcoxon's ranked-sum test revealed that all distributions of the variables ($Y, X1, X2, X3, X4$) were significantly shifted pairwise (all P values were less than 0.001). However, the results of both methods of third order assessment (U1/L1TA, U1/L1TR) were highly correlated and there were also high correlations between the various incisor measurements on the radiographs and the third order cast assessments (Table 3, Figure 5a,b). None of the 95 per cent CIs included 0. Hence, all correlations were significantly different from 0 ($\alpha = 0.05$).

Single regression analysis

Single regression analysis was carried out prior to performing stepwise multiple regression analysis, in order to understand the functional relationships between the different variables. As can be seen from the results illustrated in Table 4, there was an overall difference between radiographic third order inclination and cast measurements of 0.02 degrees in the maxilla and -2.83 degrees in the mandible. A change of 1 degree in radiographic third order inclination (U1TR, L1TR) would produce a change of 0.65 degrees for the maxilla cast assessment (mandible: 0.86 degrees). Furthermore, the estimated overall difference between complete incisor inclination (U1E, L1E) and cast measurements was found to be -18.04 degrees in the maxilla and -20.70 degrees in the mandible. A change of 1 degree in incisor inclination would produce a change of 0.83 degrees for the maxilla cast assessment (mandible: 0.88 degrees).

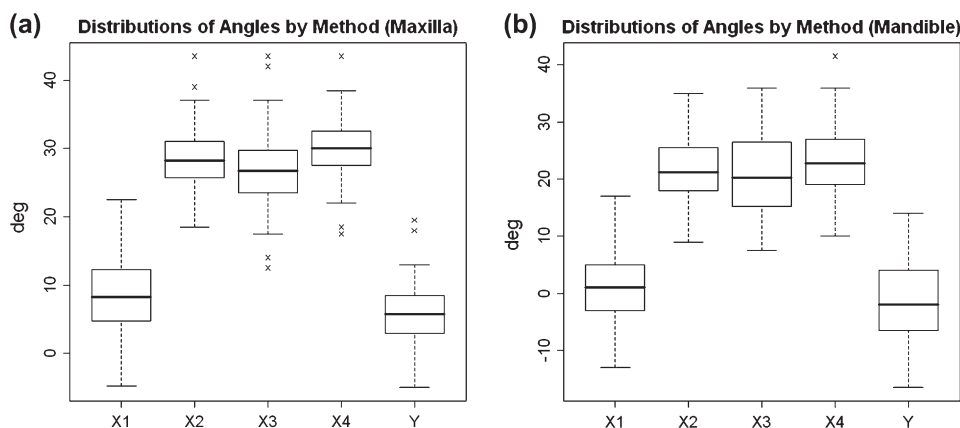


Figure 4 Distributions of angular measurements in (a) maxilla and (b) mandible, where variables $X1$ are radiographic third order measurements (U1TR, L1TR); $X2$ are complete axial inclination measurements (U1E, L1E); $X3$ are crown axis measurements (U1C, L1C); $X4$ are crown axis measurements (U1R, L1R); and Y are third order cast measurements (U1TA, L1TA).

Table 2 Means and standard deviations for all variables measured, separately for both assessors.

Variables	Assessor 1	Assessor 2
UITA	5.1 (4.9)	5.8 (5.1)
LITA	-1.9 (7.1)	-1.0 (7.2)
U1TR	7.6 (5.5)	8.9 (5.5)
L1TR	1.2 (5.9)	1.9 (6.3)
U1E	28.9 (4.6)	27.5 (4.1)
L1E	21.5 (5.9)	22.2 (6.1)
U1C	27.7 (5.3)	25.5 (5.3)
L1C	20.9 (6.3)	20.2 (6.8)
U1R	29.8 (4.5)	29.2 (4.5)
L1R	21.8 (6.0)	24.1 (6.4)

Table 3 Correlation (Pearson's coefficient *r* and 95 per cent confidence intervals) of third order measurements on casts and lateral radiographs.

Variables	Assessor		
	1	2	Both
UITA/U1TR	0.79 (0.63, 0.89)	0.67 (0.44, 0.81)	0.72 (0.59, 0.81)
L1TA/L1TR	0.60 (0.35, 0.77)	0.82 (0.67, 0.90)	0.74 (0.61, 0.82)
U1E/U1TA	0.78 (0.62, 0.88)	0.73 (0.55, 0.86)	0.74 (0.61, 0.82)
L1E/L1TA	0.80 (0.64, 0.89)	0.66 (0.44, 0.81)	0.73 (0.61, 0.82)
U1C/U1TA	0.74 (0.55, 0.86)	0.73 (0.53, 0.85)	0.70 (0.56, 0.80)
L1C/L1TA	0.83 (0.70, 0.91)	0.81 (0.66, 0.90)	0.81 (0.72, 0.88)
U1R/U1TA	0.63 (0.39, 0.79)	0.56 (0.29, 0.74)	0.59 (0.42, 0.72)
L1R/L1TA	0.74 (0.56, 0.86)	0.54 (0.27, 0.73)	0.64 (0.48, 0.76)
U1E/U1TR	0.78 (0.61, 0.88)	0.72 (0.52, 0.85)	0.73 (0.61, 0.82)
L1E/L1TR	0.55 (0.27, 0.74)	0.84 (0.72, 0.92)	0.69 (0.55, 0.79)
U1C/U1TR	0.84 (0.72, 0.92)	0.90 (0.82, 0.95)	0.85 (0.78, 0.90)
L1C/L1TR	0.50 (0.22, 0.71)	0.93 (0.87, 0.97)	0.71 (0.58, 0.81)
U1R/U1TR	0.59 (0.34, 0.77)	0.35 (0.03, 0.60)	0.46 (0.26, 0.62)
L1R/L1TR	0.51 (0.23, 0.71)	0.69 (0.50, 0.82)	0.59 (0.42, 0.72)

Multiple regression analysis with stepwise selection

Although single stepwise regression gives an indication of the functional relationships of different tested variables, it is manifest from the relatively small *R*² values (Table 4) that single variables do not sufficiently explain third order measurement outcomes.

Multiple linear regression with stepwise variable selection revealed that maxillary third order measurements (*Y* variable) on dental casts can be best explained by a linear combination of cephalometric third order angles (*X*1 variable) and complete incisor inclination (*X*2), whereas mandibular cast assessments can best be explained by a linear combination of cephalometric third order angles (*X*1) and lower crown axis measurements (*X*3). The estimated regression equations are

$$Y = -11.86 + 0.35X_1 + 0.51X_2$$

for maxillary measurements and

$$Y = -15.27 + 0.37X_1 + 0.64X_3$$

for mandibular measurements.

*R*² values were higher than in the single regression analysis. The detailed results are presented in Table 5.

Concordance of results between the two assessors

The data for the different methods revealed a high correlation between the judgements made by assessors 1 and 2. However, with Wilcoxon's test ($\alpha = 0.05$), there were significant shifts between the measurements of the two assessors with the exception of L1TR, L1C, and U1R (Table 6). The highest correlations were obtained for third order cast measurements, similar to the maxillary third order radiograph assessment (U1TR), but less than that for mandibular measurements (L1TR). Figure 6a-d illustrate

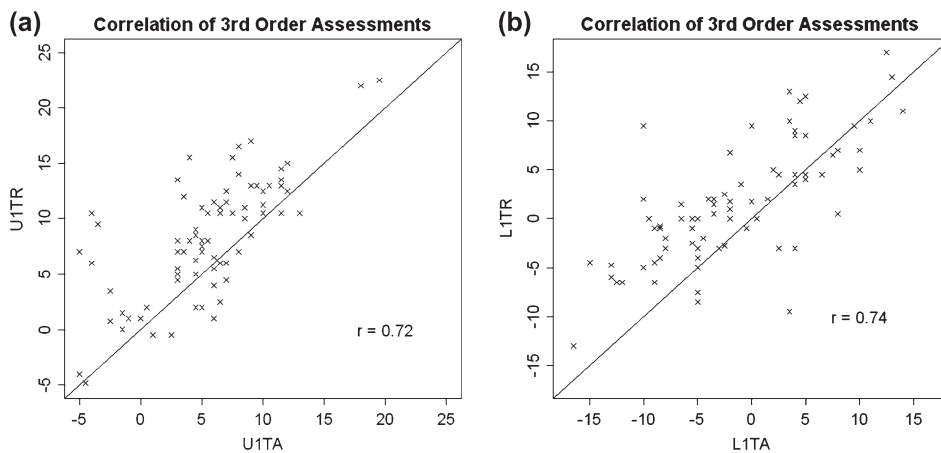


Figure 5 Correlations between (a) upper central incisor third order cast assessments on radiographs (U1TR) and dental casts (U1TA) and (b) lower central incisor third order cast assessments on radiographs (L1TR) and dental casts (L1TA).

Table 4 Single regression analysis with 95 per cent confidence interval (95% CI) and R^2 values (dental cast measurements designated as independent variable, Y).

	Regressor	Intercept		Slope		R^2
		Estimate	95% CI	Estimate	95% CI	
Maxilla	X1	0.02	(-1.42, 1.46)	0.65	(0.51, 0.80)	0.52
	X2	-18.04	(-23.10, -12.98)	0.83	(0.65, 1.01)	0.54
	X3	-11.85	(-16.01, -7.70)	0.65	(0.50, 0.80)	0.49
	X4	-13.78	(-19.95, -7.61)	0.65	(0.44, 0.86)	0.35
Mandible	X1	-2.83	(-3.98, -1.68)	0.86	(0.68, 1.05)	0.54
	X2	-20.70	(-25.00, -16.41)	0.88	(0.69, 1.07)	0.54
	X3	-19.74	(-22.92, -16.57)	0.89	(0.74, 1.04)	0.66
	X4	-18.09	(-22.90, -13.28)	0.73	(0.52, 0.93)	0.41

Table 5 Parameter estimates with 95 per cent confidence intervals (CI) and R^2 values from the multiple regression analyses.

	Intercept		Slope for X1		Slope for X2 or X3		R^2
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	
Maxilla	-11.86	(-17.6, -6.2)	0.35	(0.2, 0.5)	0.51	(0.3, 0.7)	0.61
Mandible	-15.27	(-19.1, -11.4)	0.37	(0.2, 0.6)	0.64	(0.5, 0.8)	0.71

the correlation between third order measurements on the casts and lateral radiographs.

The mean difference in OP assessment between assessor 1 and 2 was -0.39 degrees with a normal 95 per cent CI of (-0.80, 0.01). The t -test did not result in a rejection of the hypothesis that the mean difference was equal to 0 ($P = 0.06$).

Error analysis

Measurement replications in the maxilla, after 7 days, showed a significant positive correlation, whereas their shift did not significantly deviate from 0 (Table 7). Replications in the mandible were also positively correlated. However, the replications of one assessor were significantly shifted from the first measurements. The range of errors for third order measurements was calculated and is given in Table 8.

Discussion

Despite the disadvantages in evaluating incisor inclination radiographically, such as radiation exposure and inaccuracy, cephalometrics still constitute the diagnostic standard in incisor inclination analysis. Moreover, cephalometric analyses mostly coincide with reducing incisor features to a straight apex-edge connecting line. Thus, several authors have pointed out the influence of CRA and inter-individual variation in the LES on third order inclination and treatment results (Bryant *et al.*, 1984; Germane *et al.*, 1989; Miethke and Melsen, 1999; McIntyre and Millett, 2003; van Loenen *et al.*, 2005). However, it is

Table 6 Comparison of measurements of both assessors: Pearson's correlation coefficient r and results from Wilcoxon's test.

Method	r	Wilcoxon's test P value	95% Confidence interval for difference
U1TA	0.97	0.0011	(-1.25, -0.50)
L1TA	0.97	0.0065	(-1.25, -0.25)
U1TR	0.85	0.0179	(-2.25, -0.24)
L1TR	0.59	0.3259	(-2.25, 0.75)
U1C	0.92	<0.0001	(1.50, 3.25)
L1C	0.93	0.1813	(-0.25, 1.50)
U1R	0.60	0.8956	(-1.00, 1.50)
L1R	0.86	0.0003	(-3.50, -1.25)
U1E	0.87	0.0007	(0.75, 2.50)
L1E	0.91	0.0211	(-2.00, -0.25)

also customary to use third order angles to describe incisor crown inclination alone, although they do not provide information about either root features or their local relationship to hard tissue borders. Nevertheless, third order angles have been established as a standard for describing straightwire brackets and archwire properties as well as their interaction with teeth.

The null hypothesis (1) of no correlation between third order measurements on casts and other measurements was rejected. This allows an approach for calculating incisor features such as root inclination, crown inclination, and complete incisor inclination by regression analysis based on individual and radio-hygienically measured, third order values on dental casts. This means that the results of the multiple regression analysis in the present study assist in

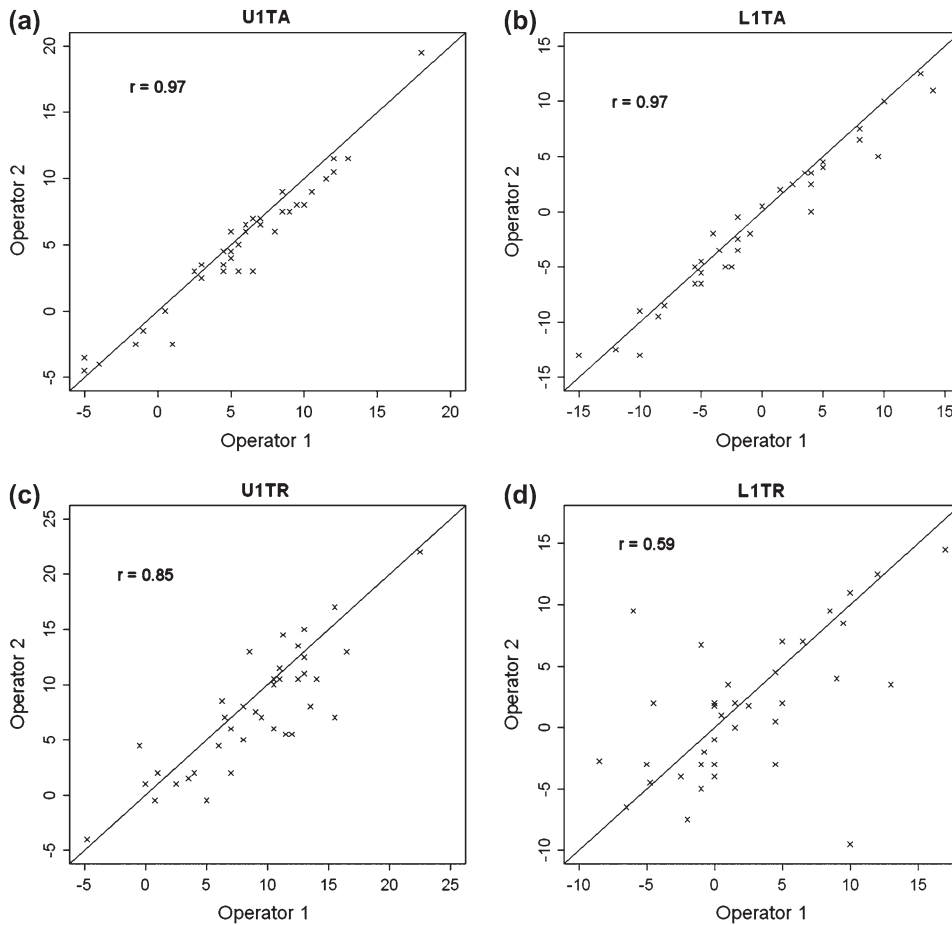


Figure 6 Inter-observer concordance of dental cast (UITA, a; L1TA, b) and radiographic (U1TR, c; L1TR, d) third order measurements.

Table 7 Comparison of replicate measurements taken initially and 7 days later.

Replications	Assessor	<i>r</i>	<i>P</i> -value correlation	<i>P</i> -value Wilcoxon test
UITA	1	0.96	<0.0001	0.5858
UITA	2	0.97	<0.0001	0.8515
L1TA	1	0.97	<0.0001	0.0056
L1TA	2	0.97	<0.0001	0.1078

clarifying the enmeshment of different approaches for describing incisor inclination.

The influence of different variables on third order values

Single regression analysis revealed the functional enmeshment of the different measurements. There was a very small overall difference between radiographic third order inclination and cast measurements of 0.02 degrees in the maxilla and a moderate difference of -2.83 degrees in the mandible. A change of 1 degree in radiographic third order inclination (U1TR, L1TR) would produce a change of 0.65 degrees for

Table 8 Range of errors for third order measurements.

Replication	Assessor	Errors between -3 and +3 degrees
UITA	1	95%
UITA	2	95%
L1TA	1	82%
L1TA	2	100%

the maxillary cast assessment and 0.86 degrees for the mandibular third order assessment. Adopting a realistic view regarding the accuracy of third order corrections using straightwire appliances and incorporating sources of error, such as a loss of torque control, it can be concluded that both methods of acquiring third order data are appropriate for orthodontic purposes.

The estimated overall difference between complete incisor inclination and upper third order cast measurements of -18.04 (mandible: -20.70) degrees is plausible with regard to the natural variation of approximately 17 degrees for the range between the FA point tangent and upper incisor axis (Bryant *et al.* 1984).

In the case of stepwise multiple regression analysis, UITA results can best be explained by a linear combination of U1TR and U1E and L1TA assessments by a linear combination of L1TR and L1C measurements. Whereas the strongest correlations between the two comparable types of third order measurements are quite plausible, it is on first sight somewhat surprising that the lower crown inclination influence dominates. Possible explanations are given by the fact that CRA, in neutral occlusion subjects, are approximately 177.5–178.5 degrees for the upper incisors (Delivanis and Kuftinec, 1980; Bryant *et al.*, 1984) and that the expression of the maxillary LES is subject to pronounced variation (Bryant *et al.*, 1984). However, little consideration has been given in the literature to the issue of mandibular incisor LES and CRA. The question of discrepancies between crown and root axes found in this study can best be addressed by pointing out that maxillary and mandibular CRA seem to be almost equally pronounced (Table 2). Group comparison results, however, indicate that lower incisor third order angles are slightly better correlated with crown inclination than complete axial inclination (Table 3), implying less pronounced variation in mandibular LES.

The accuracy of both third order methods

Descriptive sample analysis indicates that third order assessments on casts underscored radiographic estimates at a mean of 2.7 degrees (Table 2). However, both methods are in agreement with established crown inclination values for normal occlusion subjects (Andrews, 1972; Currim and Wadkar, 2004).

Small inter-observer discrepancies in third order assessment methods may result from differences in determining the OP. The *t*-test, however, did not reject hypothesis (2) that the mean difference of the two observers is equal to 0.

In not rejecting this hypothesis, it is unfortunately not possible to conclude that it is true, i.e. inter-observer assessments of the radiographic plane of occlusion on radiographs are reliable. However, as the 95 per cent CI includes 0, it was assumed that the differences were not that large. Error analysis for cast assessments also did not show significant differences in relation to intra-observer reliability (repeated measurements). It is therefore difficult to ascribe higher validity to either of the two methods as no gold standard exists for third order measurements.

Although third order estimates for both methods were strongly correlated between the two assessors, there was a significant shift in measurements, with the exception of L1TR (Table 6). However, for the dental cast method, higher correlations and smaller CIs for inter-observer shift were observed, indicating greater accuracy than with the cephalometric method. According to Baumrind and Frantz

(1971), 93 per cent of the errors in radiographic axial incisor inclination measurements can be expected within -3 and $+3$ degrees. Compared with that, the direct dental cast data in the present study are even more precise (Table 8). Several investigators (Richmond *et al.*, 1998; Ghahferokhi *et al.*, 2002; Knösel *et al.*, 2007) reported third order assessment accuracy and repeatability to exceed that of cephalometric estimation. Accordingly, inter-observer correlation analysis of radiographic and dental cast third order measurements, in this study, revealed a smaller variation for the cast method (Figure 6a–d).

Clinical implications

Inter-observer comparisons indicate that assessing third order angles using dental casts is a method that is sufficiently reliable. The transferability of measured data to commonly used archwire and bracket prescriptions is another. The regression equations derived from the variable correlations in this study show the functional enmeshments between different third order measurements and all incisor characteristics relevant for orthodontic treatment, such as crown, root, or entire tooth inclination. That is, they are suitable for calculating the different incisor features on the basis of individual cast measurements, accurately and without the need for additional radiation exposure. The predictability of the different incisor features may be beneficial for orthodontists in determining treatment plans.

Limitations of the study

This study was performed on a normal occlusion sample, with a CRA of approximately 178 degrees. However, investigations on Class II division 2 subjects have indicated a considerable variation in CRA (Delivanis and Kuftinec, 1980; Bryant *et al.*, 1984; McIntyre and Millett, 2003). Therefore, it is conjectural whether the results of this study would also apply to subjects with distinctly reduced CRA.

The proposed method, incorporating dental casts for assessing third order angles, has a limitation in estimating an incisor's local relationship with 'critical' hard tissue borders, such as upper incisor roots to the palatal cortical plate (Horiuchi *et al.*, 1998). There is still a need for careful clinical and radiographic evaluation of hard and soft tissue borders and anterior teeth.

Third order assessments on dental casts are therefore not intended to substitute for lateral radiographs, but they may be suitable for avoiding or reducing the number of consecutive radiographs and, moreover, may contribute to the completeness of clinical monitoring.

Conclusion

Assessing third order angles on dental casts is a sufficiently reliable method and one that is appropriate for routine orthodontic practice. The transferability of the data obtained

to commonly used archwire and bracket prescriptions is a further advantage. Third order angles can also be derived with sufficient accuracy from lateral radiographs.

This study demonstrates the functional enmeshment between two different third order assessments and the most common features of incisors seen on lateral radiographs. The regression equations presented are appropriate for easily calculating the relevant features of incisors, on the basis of individual cast measurements, with sufficient accuracy. Additional exposure to radiation can be avoided, thereby reducing the number of consecutive lateral radiographs during orthodontic treatment.

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