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DOI: https://doi.org/10.2319/072308-385.1

Originally published at:
Knösel, M; Jung, K; Gripp-Rudolph, L; Attin, T; Attin, R; Sadat-Khonsari, R; Kubein-Meesenburg, D; Bauss, O (2009). Changes in incisor third-order inclination resulting from vertical variation in lingual bracket placement. Angle Orthodontist, 79(4):747-754.
DOI: https://doi.org/10.2319/072308-385.1

Changes in Incisor 3rd-Order Inclination Resulting from Vertical Variation in Lingual Bracket Placement

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Submitted: July 2008

Color Figures – No

ABSTRACT

Objective: To test the null hypothesis that 3rd-order measurements are not correlated to lingual incisor features seen on radiographs.

Material and Method: The lateral headfilms of thirty-eight untreated, norm-occlusion subjects without incisor abrasions or restorations were used for 3rd-order measurements of upper and lower central incisors and assessment of the inclination of four sites suitable for lingual bracket placement with reference to the occlusal plane perpendicular. Lingual sections were determined by the tangents at the incisal fossa (S1), at the transition plateau between incisal fossa and the cingulum (S2), by a constructed line reaching from the incisal tip to the cingulum (S3), and by a tangent at the cingulum convexity (S4). Third-order angles were also assessed on corresponding dental casts using an incisor inclination gauge. Regression analysis was performed using the 3rd-order measurements of both methods as the dependent variables, and the inclination of the lingual enamel sections (S1;S2;S3;S4) as the independent variables.

Results: The null-hypothesis was rejected. For the most common bracket application sites located on the lingual shovel (S1 and S2), 3rd-order inclination changes of 0.4-0.7 degrees are expected for each degree of change in the inclination of the lingual surface. The impact of bracket placement errors on 3rd-order angulation is similar between sections S1 and S2 and the cingulum convexity (S4). Section S3 proved to be least affected by inter-individual variation.

Conclusion: 3rd-order measurements are correlated to lingual incisor features. Accordingly, 3rd-order changes resulting from variation in lingual bracket placement can be individually predicted from radiographic assessments.

Key words: Lingual Orthodontics; 3rd-Order Inclination; Lingual Incisor Morphology; Lingual Bracket Placement

INTRODUCTION

As the demand for esthetic dentistry has increased in recent decades, so also has the relevance of lingual orthodontic appliances. Esthetic incisor inclination constitutes both a significant issue in orthodontics, as well as a major concern especially for those patients requiring lingual orthodontics.

Incisor inclination assessment is usually performed by estimating the inclination of the complete incisor axis on lateral headfilms (LH) in relation to different cephalometric reference lines[1], or by estimating crown inclination using the facial surface tangent (FST) at the center of the clinical crown[2] (Facial-axis-point, or FA-point). The former has the advantage of providing information about both crown and root inclination, whereas the latter is referred to 3rd-order values of straight-wire appliances (SWA) and allows prediction of the inclination of the esthetically important facial enamel surface.

Labial straight-wire appliances (SWA) are usually placed on the FA-point[2]. Their 3rd-order prescriptions indicate the bracket slot inclination to the bracket base perpendicular (BBP), and, consequently, the inclination of the FST with reference to the occlusal plane perpendicular (OPP), respectively, (Figure 1) after incorporation of full-size arches.

Lingual 3rd-order bracket prescriptions, however, do not refer to the OPP or the inclination of the facial enamel surface, as represented by the FST. They are solely representative of the angle between the slot and the BBP, and they do not explicitly refer to the site at which these brackets are supposed to be placed. There are two reasons why the lingual bracket is its own single reference plane: lingual bracket application is more complicated than labial bracketing, as it needs to compensate for specific lingual features, such as (1) differing tooth diameters[3], and (2) discontinuously and distinctively curved lingual incisor morphology compared to the facial enamel surface[4]. Accordingly, the inclination of the lingual surface of the incisors changes relative to the occlusal plane at different bonding heights. These difficulties have created the need for customized bracket placement using set-ups[5] or bracket placement devices[4], which both mostly coincide with varying vertical bracket positions: Applying these cast-orientated approaches, it is mainly the incisor angulation depending on the diagnostic set-up which conditions the vertical position of the bracket on the lingual surface and thus its 3rd-order property[4], in contrast to labial bracket application using the FA-point[2].

The distinctive features of the lingual incisor shape imply that relatively small variations in lingual bracket positioning may result in apparent deviations from the desired 1st- and 3rd-order expression[6] which has led to the recommendation of bonding lingual appliances indirectly[7].

However, even when using the indirect bonding method, there is still a certain percentage of errors during bonding[7]. Also, when brackets have to be re-attached, they are often placed directly, a method which is more prone to error[7]. Therefore, a decision may be considered initially in favour of lingual sections that are less sensitive to bracket placement errors.

Whereas labial incisor features, bracket height variation, and their effect on torque have been the topic of a range of studies[8-10], little consideration has been given in the literature to the relationship between the inclination of the different lingual morphology features and labial enamel surface characteristics[8].

Differentiation of lingual sections

The most common sites of the lingual enamel surface considered as appropriate for bracket placement[4] may be broadly divided between the lingual fossa section (S1) and the transition plateau between the incisal fossa and the cingulum convexity (S2). For compensation of different tooth diameters, it is also customary to level differences between bracket base and lingual enamel surface with a composite material[3], thereby placing brackets on an imaginary line between the incisal edge and the cingulum (S3).

Whereas labial straight-wire appliances are considered to be standard treatment, lingual straight-wire appliances have still not come of age, as the problem still remains that they have to cope with the inherent problem of varying tooth diameters as a function of tooth type and bracket-bonding height, resulting in visible 1st-order errors[6] if not compensated by excessively large anterior brackets. However, Takemoto et al[11] drew attention to the fact that diameters of different tooth types show minor variation near the gingival margin, and they proposed a lingual straight-wire approach placing brackets close to the gingival margin at the cingulum. Therefore, the most prominent part at the cingulum convexity (S4) was also considered in this study to be a possible site for lingual bracketing.

The aims of the present study were (1) to evaluate the relationship between the FST and different lingual sites

(S1;S2;S3;S4) appropriate for bracket placement, and (2) to assess the changes in FST or 3rd-order inclination resulting from variation in bracket placement at these sites.

The null hypothesis was that 3rd-order measurements on casts or on radiographs do not show a significant correlation with lingual incisor features (S1;S2;S3;S4) seen in lateral headfilms (LH); i.e., the respective correlation coefficients are equal to 0. A rejection of the null hypothesis would not only allow calculation of the magnitude of changes in FST inclination resulting from varying lingual bracket placement, but also provide the basis for transferring established labial incisor 3rd-order inclination standards to lingual bracket placement adjustment.

MATERIALS AND METHODS

Incisor assessments were performed on the lateral headfilms (LH) and corresponding dental casts of 38 subjects (12 males, 26 females; mean age 19.5 years; SD 3.7) selected according to the following exclusion criteria: previous orthodontic therapy, primary teeth, missing teeth, incisor restorations or abrasions, and anomalous tooth morphology. Inclusion criteria were a neutral (Angle Class I) molar and canine relationship, and a normal incisor relationship in the sagittal plane and vertically. The sample was taken from the Dentistry Center, Department of Orthodontics at the University of Göttingen. The study received the approval of the local Ethics Committee.

Cephalometric measurements

Each LH tracing was performed manually by two assessors. For 3rd-order radiographic measurements (U1TR, L1TR), the facial surface tangent (FST; Figure 1) was constructed at the FA-point, which was determined by measuring the mid-point of the labial enamel surface on the LH. In order to record the sagittal lingual characteristics incisor features with reference to their correlation with the FST, the lingual enamel surface was differentiated into three sections and one constructed line considered as suitable sites for lingual bracket application (Table 1). These were analyzed with LHs, as illustrated in Figure 2, using 11 cephalometric lines (Table 1). All measurements were assessed with reference to the occlusal plane perpendicular (OPP; Figure 1).

Cast measurements

In addition to estimating 3^{rd}-order angles from radiographs, they were also derived from corresponding dental cast pairs, as the radio-hygienic approach of assessing incisor inclination using casts and a type of incisor inclination gauge has recently proven to have sufficient accuracy and reliability[12,13].

The most proclined upper and lower central incisors were chosen, since these are easy to observe in lateral radiographs. They were prepared for assessment by marking the mid-point of the labial enamel surface (FA-point). For these assessments, the dental casts were orientated on the gauge table according to the occlusal plane, and 3^{rd}-order angles were indicated by a wire-pointer which could be rotated and which was adjusted according to the FST (Figure 3). The excursion of the wire-pointer on a protractor then indicated the incisor 3^{rd}-order angles (U1TA, L1TA, Figure 2), which were defined as positive if the FST was inclined in the posterior direction.

Statistical and Error Analysis

The significance of differences between 3^{rd}-order angles determined from both methods and the distinct lingual reference angles (S1;S2;S3;S4) were tested using paired t-tests and 95% confidence intervals. Correlations between 3^{rd}-order angles and lingual reference angles were defined by Pearson's correlation coefficient ρ. Additionally, an evaluation was made of whether these correlations were significantly different from zero. Differences and correlations between the measurements of the two assessors were evaluated in the same way.

In order to describe the relationship between the FST and lingual surface angles in more detail, single regression analysis (SRA) was used. Also, multiple regression (MRA) was used for describing 3^{rd}-order angles by a suitable linear combination of the lingual incisor features. Stepwise variable selection was applied to remove those radiographic angles from the linear combination which did not make a sufficient contribution to the description of 3^{rd}-order angles.

The significance level for all tests was $\alpha = 5\%$. Correlation analyses, SRA and t-tests were made with R 2.6 software (www.r-project.org). MRA was performed using SAS 9.1 (SAS Institute, Cary, NC, USA).

For error analysis, systematic differences between repeated measurements of the lingual reference angles were performed by examiner 1 for twenty arbitrarily chosen individuals on two occasions. The technical error of measurement was assessed by the formula TEM = $(\Sigma d_i^2/2n)^{1/2}$, where d_i is the difference between the first and the second measurement on the i^{th} subject and n is the sample size.

RESULTS

3rd-order angles on casts (U1TA, L1TA) differ significantly from all lingual reference angles in radiographs, but are positively correlated with each of these (Table 2a). Differences between radiographic 3rd-order angles (U1TR, L1TR) and all lingual angles were slightly smaller, but significant, whereas the correlation between these was slightly higher overall (Table 2b). Figure 4 depicts the distributions for all angle measurements. Differences between 3rd-order assessments on casts and LH were significantly different from zero, but significantly correlated with each other (all $p<0.01$). 95% confidence intervals and Pearson's correlation coefficient are presented in Table 3.

The technical error of measurement was lowest for maxillary section S2 (TEM=1.4) and greatest for the mandibular section S2 (TEM=2.5) (Table 4). The proportion of observations for which the error was greater than 2, 3 or 4 degrees is given in Table 5.

Table 6 gives the inter-observer correlations and differences between the various measurements. U1TA, U1TR and L1TA measurements differed significantly, but were also significantly positively correlated.

Single Regression Analysis

Due to small 95% confidence intervals between the measurements of both assessors, the measurements were averaged prior to performing regression analysis.

The estimated regression parameters for the equation 'a = intercept + slope * b' are given for the 3rd-order angles on casts in Table 7a and for the radiographic 3rd-order data in Table 7b. For maxillary 3rd-order cast angles (U1TA), the estimated regression equation means, for example, that there is an overall difference to section S2 of -21.3 degree and for each further increase of S2 by 1 degree, angle U1TA increases by 0.4 degrees.

Multiple Regression Analysis

In the maxilla, the selection procedure left only S1 and S3 angles for describing 3rd-order cast measurements by the regression equation ($R^2 = 0.52$):

U1TA = -16.6 + 0.3 · S3 + 0.2 · S1.

This means that there is an overall difference between U1TA angles and the given linear combination of -16.6 degrees. Additionally, U1TA angles increase by 0.3 and 0.2 when S3 and S1 angles increase by 1 degree, respectively. For the mandible, regression analysis yielded an equation including only S3 angles to describe L1TA angles ($R^2 = 0.50$):

L1TA = -36.0 + 0.8 · S3.

Maxillary 3rd-order angles read from the radiographs were modeled by

U1TR = -23.5 + 0.7 · S3; ($R^2 = 0.70$)

and, for the lower incisors, by

L1TR = -23.7 + 0.5 · S4 + 0.3 · S1; ($R^2 = 0.55$).

DISCUSSION

The null hypothesis of 3rd-order measurements not showing a significant correlation with lingual incisor features seen in lateral headfilms was rejected, allowing a comparison of the inclination of lingual enamel sections to the FST. The value of this finding is that changes in 3rd-order or FST inclination resulting from vertical variation in lingual bracket position can be individually predicted with LH assessments and the use of the regression equations presented in this study.

Relationship between FST and lingual sections appropriate for bracket placement

The correlation with 3rd-order angles of both methods (U1TR-L1TA) and the distinctive lingual reference lines declined in most correlations investigated in the order S3>S1>S4>S2 (Table 2a, b). Section S2 showed the lowest correlation with 3rd-order angles in both the maxilla and mandible, with ρ values between 0.49 (L1TA) and 0.61 (L1TR).

A possible explanation may be the fact that the construction of a line between two points (section S3) may be less error prone than that of a tangent. Moreover, it is likely that the order of decreasing correlations may reflect inter-individual variation in lingual enamel section inclinations. Accordingly, the inclination of the section S2 may be subject to a more pronounced variation, as may be the case with other lingual enamel sections or the FST, whereas S3 assessments seem the most reliable maxillary lingual parameter with only 10% of errors exceeding 2 deg (Table 5).

Changes in FST inclination resulting from lingual bracket placement variation

According to SRA, the results for modeling either radiographic or dental cast 3rd-order angles from lingual surface measurements were similar (Table 7a, b). The change in 3rd-order inclination caused by a variation in the bracket site of 1 degree was smallest for section S2 (0.4 degrees U1TA or U1TR; 0.5 L1TA or L1TR) and highest for S3 in the maxilla (0.7 degrees U1TR) and S4 in the mandible (0.9 degrees L1TA); i.e., per degree of individual variation at the most common bracket sites S1 and S2, which are located on the lingual shovel, maxillary 3rd-order inclination changes of 0.4-0.5 degrees have to be expected (mandible: 0.5-0.7 degrees). This finding may be of interest in relation to directly placed lingual brackets, which are often adapted to these sites and recently have gained more relevance in less complicated orthodontic cases[14]. Regarding 3rd-order error proneness, our results (Table 7a, b) also indicate that site S2 in both maxilla and mandible may be considered as the most appropriate for a direct lingual bracket placement approach. If section S3 is considered as a constructed reference line, 3rd-order changes of up to 0.7-0.8 degrees have to be expected per degree of variation in S3.

The cingulum convexity (site S4), which may be of value for the lingual SWA approach, showed a correlation of 0.68 (mandible: 0.74) to radiographic 3rd-order angles, and maxillary variations of 0.5 degrees (mandible: 0.7) if the FST inclination changes 1 degree (Table 7b). The 3rd-order error proneness for direct bracket placement or re-bonding on site S4 may therefore be regarded as being similar to that of the commonly used site for lingual bracket placement S1 (Table 7a, b).

The MRA unravels the functional enmeshment between the FST and the inclination of the differentiated lingual enamel sections. Being most strongly correlated with FST, maxillary S1 and S3 angles contributed the most to the description of 3rd-order angles on casts (mandible: S3 only). Also, S3 inclinations can best explain radiographic 3rd-order (U1TR) measurements; whereas L1TR angles are better described by the lines S1 and S4. These outcomes may reflect the shape of the lingual enamel surface, the curvatures of which are obviously less pronounced in lower than in upper central incisors.

There is no point or line which can be valid defined as a general reference for lingual bracket application. However, as the lingual site with the highest correlation with FST and one which is subject to less inter-individual variation than other lingual sections, the reference line S3 may be considered to be representative for lingual enamel surface inclination, similar to the FST in labial 3rd-order assessments and, in further research, may be substantiated for all types of teeth using, for example, 3d-CAD/CAM methods and larger samples.

Clinical Implications

Relating labial and lingual morphological features to one reference line, the OPP, creates a basis for comparing both lingual and labial 3rd-order bracket prescriptions and allows the transfer of established targets in 3rd-order corrections, as formulated in terms of labial 3rd-order values, to the lingual side.

The cingulum convexity (S4) can be considered for the lingual straight-wire approach, as single regression indicates that the impact of bracket placement errors on 3rd-order angulation, especially when using direct bonding techniques, is similar to commonly frequented lingual sections (S1;S2).

Directly bonded lingual appliances especially may benefit from a bracket base design that adapts to lingual surface inclinations of sections S1 and S2 as much as possible with regard to minimizing bonding failures[7].

The value of the regression equations presented here (Table 7a, b) is that they enable the practitioner to estimate 3rd-order changes resulting from vertical variation in lingual bracket placement and individual lingual incisor morphology, as well, on the basis of common treatment planning documents, within the limitation set by the accuracy of radiographic estimates.

CONCLUSIONS

- Using the regression equations presented in this study, 3rd-order changes resulting from variation in lingual bracket placement can be individually predicted following radiographic assessments.
- 3rd-order inclination changes of 0.5 (mandible: 0.7) degrees may occur per degree of change in the most common bracket application sites located on the lingual shovel (sections S1 and S2).
- Reference line S3 seems least affected by inter-individual variation and may be considered to be representative of lingual enamel surface inclination.
- The cingulum convexity (S4) seems acceptable for a lingual straight-wire approach from the perspective of impact of bracket placement errors on 3rd-order angulation.

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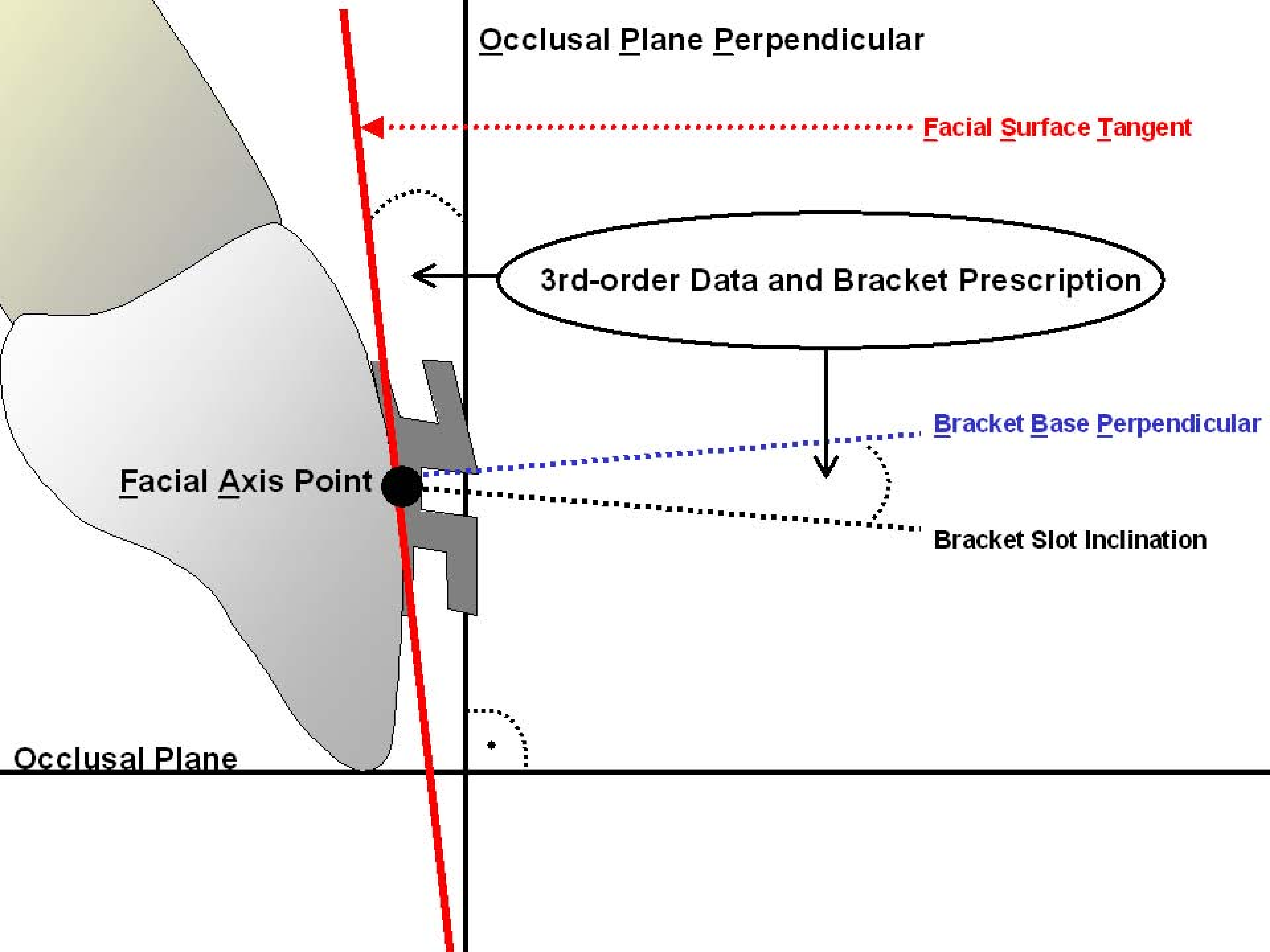
FIGURE LEGENDS

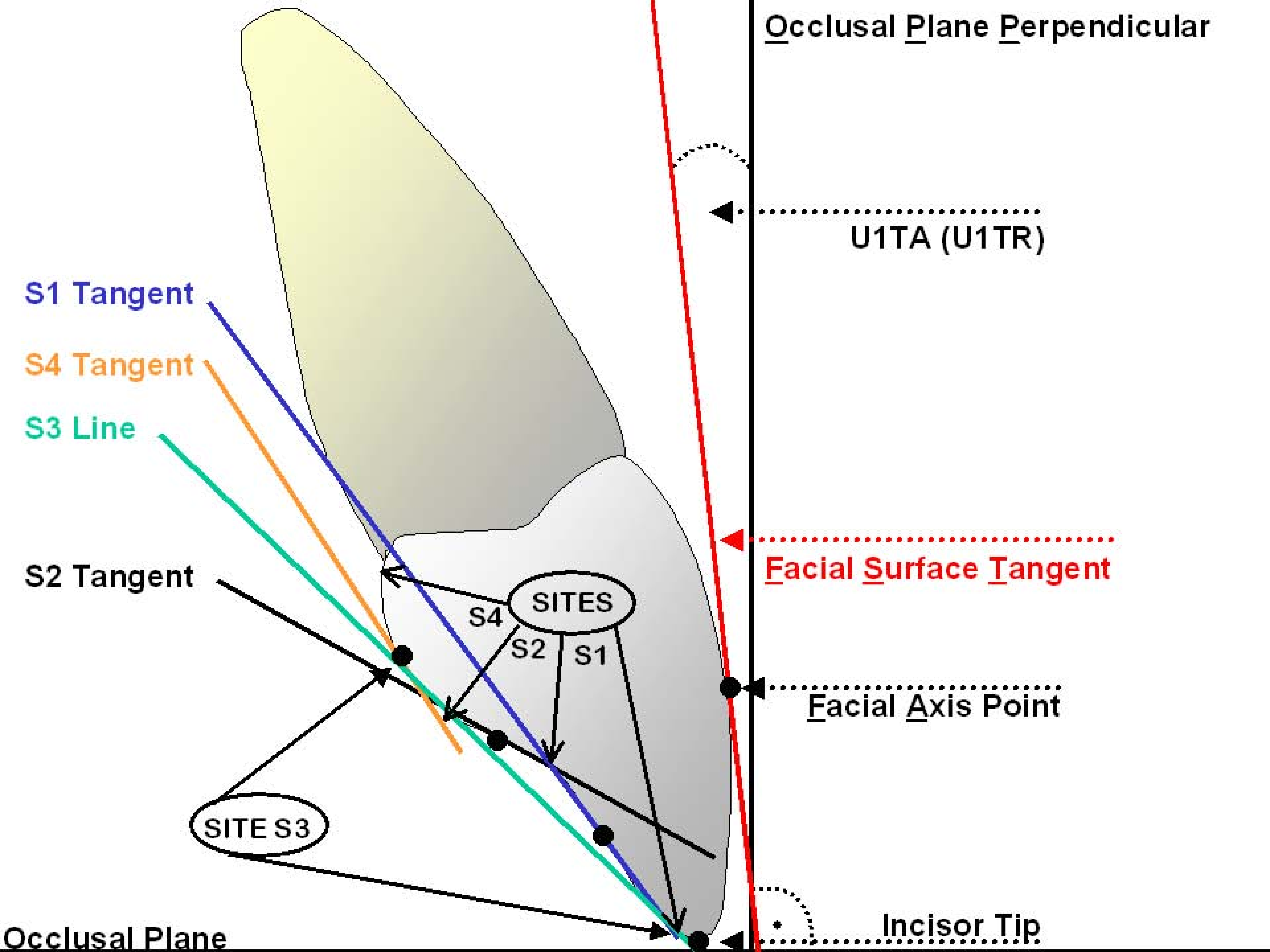
Figure 1. Both bracket-slot inclination, in relation to the bracket-base perpendicular (BBP), and facial surface tangent (FST) at the FA-point, in reference to the occlusal plane perpendicular (OPP), integrate 3rd-order data (U1TA/U1TR; L1TA/L1TR).

Figure 2. Radiographic assessments of lingual sections according to Table 1 were determined from the tangents at the midpoint of the incisal fossa (S1), at the transition plateau between incisal fossa and the cingulum (S2), using a constructed line reaching from the incisal tip to the tuberculum (S3), and by a tangent at the most prominent part of the cingulum convexity (S4).

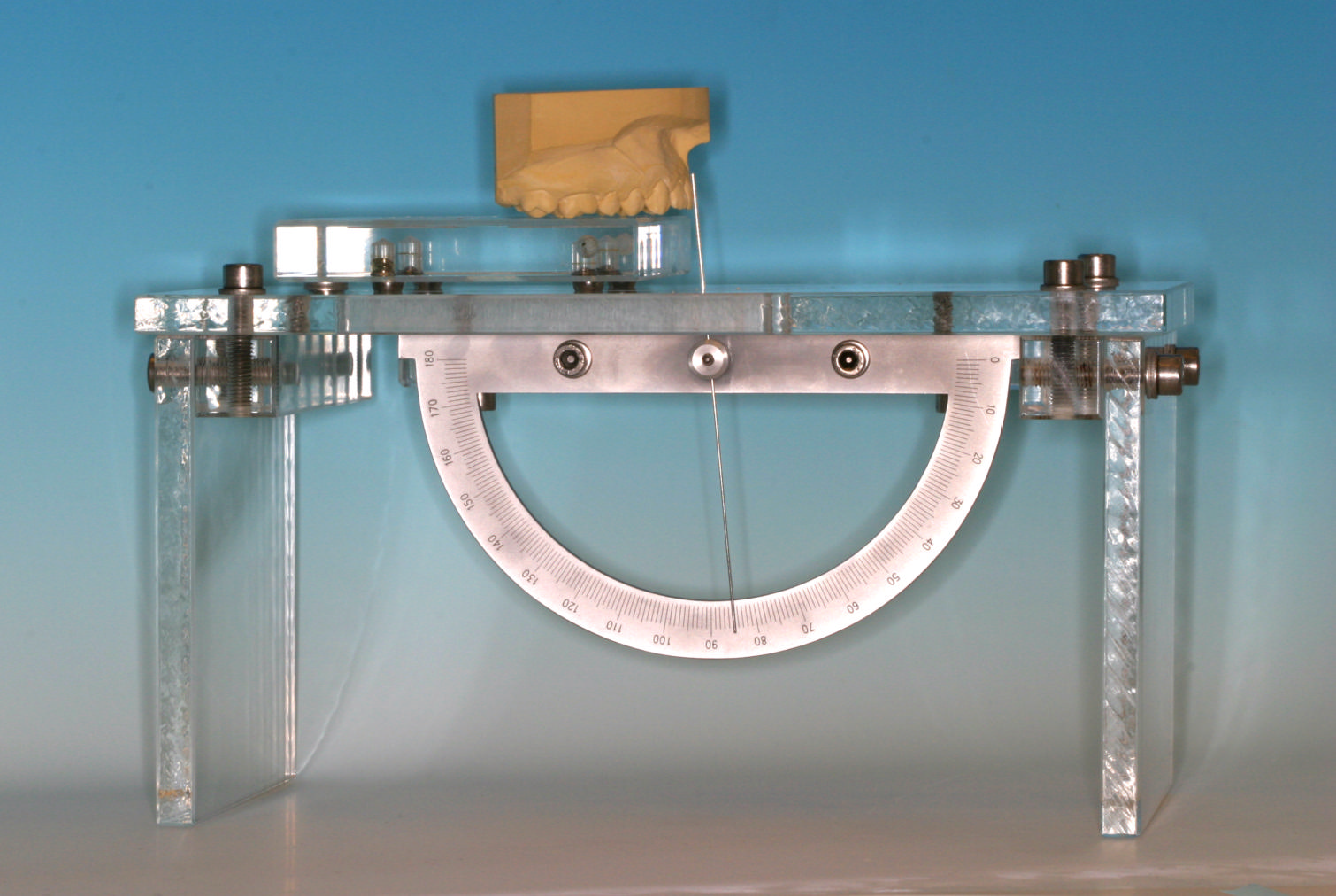
Figure 3. The gauge for recording 3rd-order angles on casts.

Figure 4. Distribution of 3rd-order measurements on casts (U1TA;L1TA) and on radiographs (U1TR;L1TR) compared to lingual reference angles on radiographs (S1;S2;S3;S4). Values of both operators were averaged.


Occlusal Plane Perpendicular
Facial Surface Tangent
3rd-order Data and Bracket Prescription
Bracket Base Perpendicular
Facial Axis Point
Bracket Slot Inclination
Occlusal Plane



Occlusal Plane Perpendicular
U1TA (U1TR)
S1 Tangent
S4 Tangent
S3 Line
S2 Tangent
SITES
S4
S2
S1
Facial Surface Tangent
Facial Axis Point
SITE S3
Incisor Tip
Occlusal Plane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TABLES

Table 1: Cephalometric and cast reference lines used for determining 3rd-order angles and differentiating the sites suitable for lingual bracket application. The occlusal plane (OP) was represented on the lateral headfilms by a line through the mesial cusps of the permanent first upper and lower molars and bisecting the distance between the edges of the upper and lower central incisors. A detailed landmark description is given in text.

Method	Reference lines
U1TA, L1TA	upper/lower incisor facial surface tangent (cast); OP perpendicular
U1TR, L1TR	upper/lower incisor facial surface tangent (cephalogram); OP perpendicular
upper / lower S1	tangent at the midpoint of the incisal fossa of upper/lower incisor; OP perpendicular
upper / lower S2	tangent at the transition plateau between incisal fossa and cingulum; OP perpendicular
upper / lower S3	constructed line reaching from the incisal tip to the cingulum; OP perpendicular
upper / lower S4	tangent at the midpoint of the cingulum convexity of upper/lower incisor; OP perpendicular

Jaw	Lingual section	Difference		Correlation	
		p (t-test)	95% CI	p	ρ (Pearson)
Maxilla	S1	< 0.01	[22.1, 25.5]	< 0.01	0.68
	S2	< 0.01	[58.7, 62.6]	< 0.01	0.57
	S3	< 0.01	[39.0, 42.1]	< 0.01	0.70
	S4	< 0.01	[35.8, 39.0]	< 0.01	0.65
Mandible	S1	< 0.01	[29.6, 33.1]	< 0.01	0.71
	S2	< 0.01	[53.4, 58.0]	< 0.01	0.49
	S3	< 0.01	[40.9, 44.3]	< 0.01	0.71
	S4	< 0.01	[37.5, 41.0]	< 0.01	0.66

Table 2a. Correlation (ρ) and difference (95% confidence interval) between 3rd-order cast assessments (U1TA; L1TA) and the distinct lingual sections. (Measurements of both assessors were averaged).

Jaw	Lingual section	Difference		Correlation	
		p (t-test)	95% CI	p	ρ (Pearson)
Maxilla	S1	< 0.01	[19.3, 22.6]	< 0.01	0.69
	S2	< 0.01	[55.9, 59.7]	< 0.01	0.59
	S3	< 0.01	[36.6, 38.9]	< 0.01	0.83
	S4	< 0.01	[33.0, 36.1]	< 0.01	0.68
Mandible	S1	< 0.01	[26.8, 29.9]	< 0.01	0.72
	S2	< 0.01	[50.9, 54.4]	< 0.01	0.61
	S3	< 0.01	[38.0, 41.0]	< 0.01	0.68
	S4	< 0.01	[34.9, 37.5]	< 0.01	0.74

Table 2b. Correlation (ρ) and difference (95% confidence interval) between radiographic 3rd order angles (U1TR; L1TR) and the distinct lingual sections. (Measurements of both assessors were averaged).

Table 3. Differences between 3rd-order cast estimates (U1TA, L1TA) and 3rd-order lateral headfilm assessments (U1TR, L1TR):

Jaw	Assessor 1		Assessor 2	
	95% CI	ρ (Pearson)	95% CI	ρ (Pearson)
Maxilla	[1.7, 4.5]	0.66	[1.4, 3.7]	0.79
Mandible	[1.6, 4.4]	0.81	[1.2, 5.1]	0.6

Lingual Section	TEM Maxilla	TEM Mandible
S1	1.7	1.8
S2	1.4	2.5
S3	1.7	1.7
S4	2.1	2.1

Table 4: The technical error of radiographic lingual measurements (TEM; degrees).

Lingual Section	Error (Degrees)	Maxilla	Mandible
S1	> 2	35%	55%
	> 3	15%	15%
	> 4	10%	0%
S2	> 2	30%	75%
	> 3	10%	40%
	> 4	0%	25%
S3	> 2	15%	45%
	> 3	10%	15%
	> 4	10%	5%
S4	> 2	60%	60%
	> 3	35%	20%
	> 4	10%	15%

Table 5: Range of errors for radiographic lingual surface measurements.

Jaw	Angle	Difference		Correlation	
		p (t-test)	95% CI	p	ρ (Pearson)
Maxilla	U1TA	< 0.01	[-1.1, -0.3]	< 0.01	0.97
	U1TR	0.01	[-2.2, -0.3]	< 0.01	0.85
	S1	0.02	[-4.0, -0.4]	< 0.01	0.73
	S2	0.80	[-1.1, 1.4]	< 0.01	0.86
	S3	0.61	[-1.6, 0.9]	< 0.01	0.84
	S4	0.13	[-0.4, 2.7]	< 0.01	0.77
Mandible	L1TA	< 0.01	[-1.5, -0.3]	< 0.01	0.97
	L1TR	0.43	[-2.6, 1.1]	< 0.01	0.59
	S1	0.17	[-3.3, 0.6]	< 0.01	0.68
	S2	0.20	[-3.7, 0.8]	< 0.01	0.56
	S3	0.87	[-1.8, 1.5]	< 0.01	0.71
	S4	0.57	[-1.3, 2.3]	< 0.01	0.60

Table 6: Correlation (ρ) and difference (95% confidence interval) between the measurements of the two assessors.

	Lingual Section	Intercept	Slope	R^2
Maxilla	S1	-8,7	0.5	0.46
	S2	-21.3	0.4	0.33
	S3	-19.5	0.5	0.49
	S4	-16.2	0.5	0.42
Mandible	S1	-23.4	0.7	0.50
	S2	-30.7	0.5	0.24
	S3	-36.0	0.8	0.50
	S4	-34.2	0.9	0.44

Table 7a: Estimated regression parameters for the single regression of lingual angles S1, S2, S3, S4 on 3rd-order cast angles (U1TA; L1TA). Measurements of both assessors were averaged prior to performing regression analysis.

	Lingual Section	Intercept	Slope	R^2
Maxilla	S1	-6.8	0.5	0.47
	S2	-21.1	0.4	0.35
	S3	-23.5	0.7	0.70
	S4	-15.8	0.5	0.46
Mandible	S1	-15.6	0.6	0.52
	S2	-25.8	0.5	0.37
	S3	-23.8	0.6	0.46
	S4	-26.6	0.7	0.55

Table 7b: Estimated regression parameters for the simple regression of lingual angles S1, S2, S3, S4 on radiographic 3rd-order angles (U1TR; L1TR). Measurements of both assessors were averaged prior to performing regression analysis.