

Quantitative Tooth Mobility Evaluation Based on Intra-Oral Scanner Measurements

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Disclaimer

Luiz Meirelles, Rafael Siqueira and Hom-Lay Wang have filed a provisional patent based on the technique presented.

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Running title

Accuracy of tooth mobility based on Intra-Oral Scanner Measurements

Summary sentence

An accurate and precise technique was successfully applied for monitoring tooth mobility in a typodont model based on intra-oral scanner measurements.

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Abstract

Background Tooth mobility assessment is subjective and current techniques require the translation of a continuous variable to a categorical variable based on the perception of the examiner. The aim of this study was to evaluate the reliability of a novel technique to assess tooth mobility.

Methods Three experienced periodontists were asked to push tooth #16 into a buccal position to in a typodont model with different mobility (M1-M2). Tooth position was obtained using an intra-oral scanner and files were compared in metrology software. Mobility was calculated at three reference points at the cervical (C), middle (M) and occlusal (O) regions of the buccal surface of the tooth to determine the linear deviation in the 3 axes (x, y, z). Reliability was determined by intraclass-correlation coefficient, differences between M1 and M2 determined by t-test, and the analysis of variance (ANOVA) was used to compare the data at the C-M-O regions.

Results Excellent reliability was assessed by Cronbach's alpha above 0.9 on the X-Y-Z axes for both mobility tested, except for M1-C X (0.85), M1-M Y (0.89), and M2-M Z (0.89). The correlation between the examiners demonstrated excellent ($>.90$) or good ($.75 > X < .90$) consistency, except for M1-C Y (.73; examiner 1-2) and M1-M X (.69; examiners 1-3). Significant changes were detected in all axes at the three reference points comparing M1 and M2, and a similar proportional change was observed between O-M-C reference points for M1 and M2.

Conclusions A novel technique to assess tooth mobility based on intra-oral scanner measurements provided reliable data in an in vitro experiment.

Key words (MeSH): periodontal disease; precision medicine, tooth mobility, quantitative evaluation, reliability of results

Introduction

Tooth mobility is a routine evaluation performed to support the diagnosis and prognosis of periodontal disease. Miller in 1938 proposed a classification based on the displacement of the crown and categorized tooth mobility according to horizontal and vertical thresholds¹. Ramfjord in 1967 proposed a classification based on clinical aspects of tooth mobility, related to functional parameters, in attempt to overcome errors related to the lack of precision and accuracy of existing alternatives and to focus clinically relevant aspects². The major problem of current tooth mobility techniques is not related to the classification but is the inherent subjective nature of the assessment that requires the translation of a continuous variable to a categorical variable, grouping together a broad range of values in subgroups based on the perception of the examiner.

Clinical data investigating tooth prognosis demonstrated the potential of tooth mobility measurements to define the treatment outcome. Fleszar et al (1980) demonstrated that sites with moderate (4-6 mm) and deep (7-12 mm) probing depths experienced attachment loss (AL) associated to higher mobility compared to firm teeth after the first year following the periodontal therapy³. The relevance of initial mobility on periodontal disease progression was highlighted in a 28 years retrospective study.⁴ The patients with $AL \geq 2$ mm had tooth mobility at baseline and during the follow up, indicating that tooth mobility is a significant risk factor for future AL⁴. Wang et al (1994) examined patients with furcation involvement after 8 years following periodontal therapy⁵. Molar teeth with mobility at baseline or 1 year had higher AL compared to molars without mobility, independent of furcation involvement. In contrast, sites treated with surgical and non-surgical periodontal therapy combined to occlusal adjustment demonstrated gain in clinical attachment level after 1 year independent of the initial mobility⁶.

Complex electronic and mechanical devices were developed to generate accurate measurements of physiological and pathological displacements of tooth. Parfitt in 1960 developed an electronic device to measure the axial tooth displacement⁷. The author suggested that axial

displacement would better relate to potential damage to all periodontal fibers, whereas bucco-lingual displacement was primarily related to the fibers in the cervical region. Muhlemann in 1951 developed a mechanical device to measure bucco-lingual displacement in response to different loads providing quantitative outcomes⁸. Clinical data using the Muhlemann device successfully demonstrated a decrease in tooth mobility after non-surgical and surgical periodontal therapy^{9, 10}. However, the clinical application of such experimental devices was limited due to the time required to set-up and the overall patient experience. The efforts to obtain reliable quantitative data on tooth mobility highlights the clinical relevance of such parameters. The development of a user-friendly concept based on objective measurements will provide the opportunity to establish reliable oral health outcomes to define the need to treat and evaluate patient's prognosis.

In the present study, we present a technique to determine tooth mobility based on intra-oral scanner (IOS) measurements. The aim was to develop an accurate and precise technique to provide reliable three-dimensional (3D) quantitative oral health outcomes for physiological and non-physiological movements of the tooth.

Material and Methods

Images Acquisition

The current method is based on the 3D comparison of digital models obtained with intra-oral scanner (IOS)⁸. A first digital impression of the typodont¹ on its original configuration was obtained and defined as the baseline. A series of digital impressions of the typodont was taken with the operators pushing the typodont's tooth to be analyzed into a buccal direction. The force was applied with the tip of the handle of a dental mirror placed in the lingual surface. The goal was to promote a movement in the tooth that simulates dental mobility commonly associated to periodontitis similar to the daily practice (Figure 1).

A series of tests have been performed to develop the proposed method. In the current experiment, a typodont model was used to simulate the clinical environment and 2 different degrees of tooth mobility were created by changing the tightness of the screw holding tooth #16. Each operator was asked to push the tooth into a buccal position to promote the movement, with the use of the cable of a dental mirror (Figure 1A). The operator was asked also to hold the instrument at the final position of tooth movement while a second operator performed the scanning. Three experienced periodontists evaluated two different mobility and repeated the measurements 10 times. The operators were asked to simulate the same force and direction used in a clinical setting. No instructions were provided to the operators regarding direction and magnitude of the force during the experiment.

Mobility Evaluation

Digital impressions of the models were obtained and the stl files were exported from the IOS software¹ and compared using a comprehensive metrology platform[#]. For the different evaluations, one baseline digital impression was obtained as reference and the different tested scenarios compared to generate the deviations at different pre-determined points in the crown (#16). The two models for each evaluation were then aligned using surfaces in the image not affected by the force applied to #16 (Figure 1B). The aligned models were processed and the buccal surface of the tooth was oriented in the screen at 90° with the ground plane using regions not affected by the displacement of #16 (Figure 1C). For the displacement analysis, three reference points at the buccal surface of the tooth were chosen to determine by linear deviation in the 3 axes (x, y, z). The 3 areas chosen were in the cervical, middle and occlusal third of the tooth crown (Figure 2A). The linear measurements of the movement in the 3 different axes were collected for statistical analysis. The x, y and z axes represent the bucco-lingual, apical-coronal, and mesio-distal directions of the tooth anatomy. It was determined that a positive value during the analysis represented a change to the buccal, apical, and mesial for the present evaluation, and a negative value would relate to the lingual, coronal and distal, respectively (Figure 2B).

Statistical Analysis

The statistical analysis was performed to evaluate (1) reliability; (2) differences from mobility 1 and mobility 2, and (3) the variation in the different regions (cervical, middle, and occlusal). The reliability was analyzed by intraclass correlation coefficient (ICC). ICC estimates and their 95% confident intervals were calculated using an statistical software**. Based on the 95% confident interval of the ICC estimate, values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 are indicative of poor, moderate, good, and excellent reliability, respectively¹¹. In addition, the inter-item correlation was evaluated offering a paired analysis of the different examiners. Data from mobility 1 and 2 was analyzed by t-test for each examiner (data not shown) or pooled to support a comprehensive interpretation. Data analysis among the cervical, middle and occlusal points was performed by one-way analysis of variance (ANOVA). Significance level was set at 95%. Tooth displacement was calculated in microns (μm).

Results

Reliability

Table 1a and 1b shows the mean \pm standard deviation (SD), inter-item correlation, Cronbach's alpha, Cronbach's alpha confidence interval (CI - 95%), and the F test for the ICC analysis. The reliability of the technique is supported by the high Cronbach's alpha on the x, y and z axes for both mobility tested that scored above 0.9 in all groups, except for mobility 1 cervical x (0.850), mobility 1 middle y (0.891), and mobility 2 middle z (0.892). The analysis of the correlation between the examiners demonstrated excellent (above .90) or good (between .75 and .90) consistency of the measurements, except for mobility 1 cervical on the y axis between examiners 1-2 (.728), and mobility 1 middle in the x axis between examiners 1-3 (.692). A graphic representation of the data demonstrates the consistency of the measurements obtained in the different axes (Figure 3).

Mobility 1 x Mobility 2

Significant changes were detected in all axes at the cervical, middle and occlusal points comparing mobility 1 and 2 (Table 2). For the x axis, higher displacement towards the buccal direction ($P < 0.001$) was observed to mobility 2 compared to mobility 1 in the cervical, middle and

occlusal points. The y axis showed a significant displacement to the apical direction at the cervical ($P < 0.001$) and middle ($p=0.002$), whereas the displacement ($P < 0.001$) at the occlusal was to the coronal direction, indicating a shift in resulting direction from mobility 1 to mobility 2 in the occlusal compared to the cervical and middle points. For the z axis, a displacement ($P < 0.001$) at all points was observed to the distal direction.

Cervical (C) x Middle (M) X Occlusal (O)

The data reporting the values calculated in the different points along the x,y,z axes is summarized in Figure 4. The x axis demonstrated a gradual increase for both mobility in the middle compared to cervical ($p < 0.001$), and for occlusal compared to middle for mobility 1 ($p = 0.02$) and mobility 2 ($p=0.04$). For the y axis, increase displacement to the coronal was observed to M compared to C ($P < 0.001$) and O compared to M ($P < 0.001$) for mobility 1 and 2. The z axis demonstrated higher displacement to the mesial for M compared to C ($P < 0.001$) and O compared to M ($P < 0.001$) for both mobility 1 and 2. Despite a significant difference in the values observed in mobility 1 compared to mobility 2, a similar change in percentages was observed between the cervical-middle and cervical-occlusal points, indicating a consistent movement in all points in all axes (Figure 4).

Discussion

A novel concept to evaluate tooth mobility is presented based on intra-oral scanner measurements using a typodont. An excellent reliability was obtained testing different mobility as demonstrated by a high Cronbach's alpha above 0.9, and an inter-examiner correlation between $0.75 > x < 0.9$ (good) or above 0.9 (excellent). Previous evaluation of mobility data was obtained based on a categorical data using 5¹² or 2¹³ scores. The data was reported lower Cohen's k varying from poor (0.4) to moderate (0.6) between 2 examiners with 19 patients¹³. Higher values between 2 examiners based on the Pearson's correlation coefficient of 0.86 was obtained with the first set of 26 patients and

0.98 with 24 patients after recalibration¹². The agreement of the data reported by the analysis of correlation should be done with caution, since the coefficient shows the magnitude of the relationship, not the agreement. The reliability of the measurement depends on (1) the clarity of the criteria, (2) number of categories and (3) training of the examiners¹³. We here propose a process based on an objective measurement excluding the factors 1 and 2 that will generate an outcome restricted to the magnitude and the direction of the force applied by the operator.

Persson & Svensson (1980) in a clinical study associated greater tooth mobility measurements in periodontally compromised individuals, using a loading/sensing device. The apparatus utilized at the time was complex and presented several limitations like one dimensional recording possibility and no access to posterior teeth¹⁴. Schulte et al. (1992) examined the relationship between tooth mobility, assessed by means of the Periotest® (PTV value) and some clinical parameters of periodontal disease. The results showed that the percentage of bone loss was the parameter that was most highly correlated ($r=0.55$) to the PTV value. Periotest instrument was also used in other studies, but a major limitation of this device is its restriction to only measure damping characteristics with a predefined frequency^{15, 16}. Increased tooth mobility at baseline of periodontal treatment was one of the factors strongly associated with high levels of additional attachment loss during maintenance^{4, 5}. Since tooth mobility could be a factor affecting severity, progression and therapeutic outcome of periodontal disease^{3, 17}, accurate measurement is of great interest. In this experiment, a significant difference in mobility from 8 μm in the y axis in the middle up to 121 μm in the x axis in the occlusal was successfully characterized. The displacement was significantly different within each examiner (data not shown) and with the data pooled (Table 2). The present technique is an accurate alternative for the measurement that could be correlated to periodontal clinical parameters allowing a precise evaluation of periodontally compromised patients.

Different approaches to monitor tooth mobility and to understand the behavior of the periodontal ligament were reported in previous studies. The majority of the methods described were limited to *in vitro* application and *in vivo* studies are very scarce¹⁸⁻²⁰. Other studies implemented newly developed measurement systems in their investigations^{21, 22}. Konermann et al. 2017²¹

developed a new device for *in vivo* measurement of tooth mobility. The authors demonstrated precision and validity in clinical use of the device, however it requires the construction of an individual splint for the upper jaw of each patient for intraoral fixation of the device. Moreover the measurement performance demanded high precision from the investigator in terms of splint adaption and patient supervision to avoid unwanted movements potentially impacting the measurement results. The current approach is a user-friendly non-invasive technique that can be performed by the dentist and the dental hygienist.

A valid measurement approach recording tooth mobility upon displacement within the subtle range of physiological and non-physiological strains has not been developed. The introduction of digital dentistry and more recently the popularization of intra-oral scanners helped clinicians to perform more versatile and precise dental procedures leading to more predictable treatment outcomes. The application of this new technology for treatment has been developed very quickly, however the application of in the diagnosis and prognosis fields is in the early stages. The successful implementation of a device to monitor tooth mobility depends on the development of clinical data associated to physiological and disease thresholds accounting for individual values. It is a complex challenge since tooth mobility is a phenomenon related to several continuous and intermittent biological and physical variants²³. This first set of data obtained with a typodont model was able to detect a difference as low as 8 μm (Table 2), but the clinical significance of such subtle variation alone may not indicate progression or remission of disease compared to baseline values. Well established clinical parameters, such as clinical attachment level and radiographic bone loss, will remain valid to classify the patient's disease and will be used to facilitate the interpretation of the scan results in future clinical experiments.

Conclusion

Here, we introduce a novel digital approach based on intra-oral scanner measurements that can be clinically applied to monitor tooth mobility during periodontal evaluation and treatment.

Different from previous techniques, the current concept generates results as continuous variable, providing the opportunity to objectively assess the changes independent of the operator's perception.

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Figure Legends

Figure 1 – Illustration of how the intra-oral scanning device can be used for detecting tooth mobility.

1A. In vitro simulation of dental mobility in a similar way to what is done currently in a daily practice. The tip of a mirror Handle pushed #16 to the buccal direction generating a displacement.

1B. Alignment of the two digital models obtained by intra-oral scanning. Three coincident areas were chosen as reference in each model for alignment.

1C. Three-dimensional (3D) comparison of the two digital models aligned. The buccal surface of #16 shows different colors highlighting the displacement of the tooth, indicating the amount of deviation between baseline and mobility 1 or mobility 2 models.

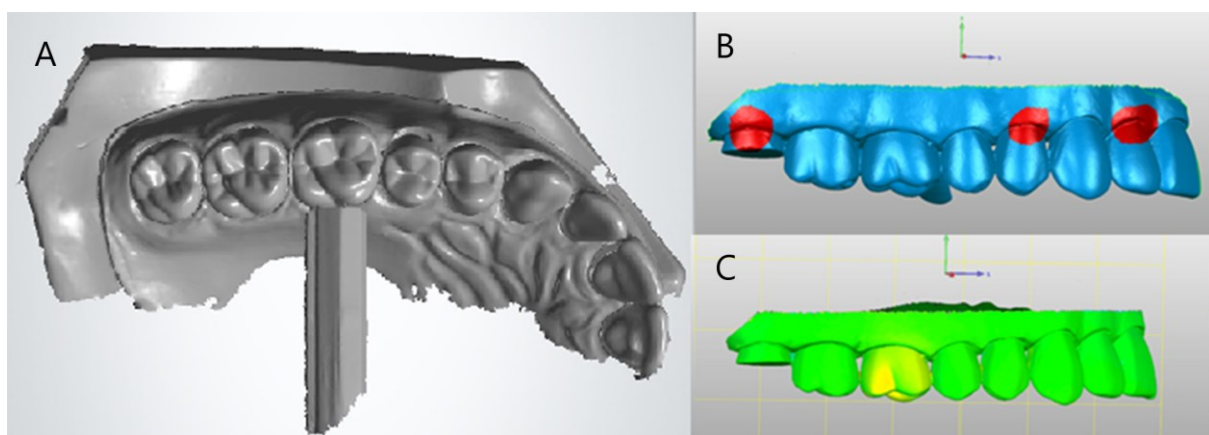


Figure 2 – Demonstration of intra-oral scanning device for recording 3 aspects of tooth mobility

2A. Three different points were chosen to measure the linear movement in the 3 different axis.

2B. X, Y, Z axes direction in relation to the buccal-lingual, coronal-apical and mesio-distal planes.

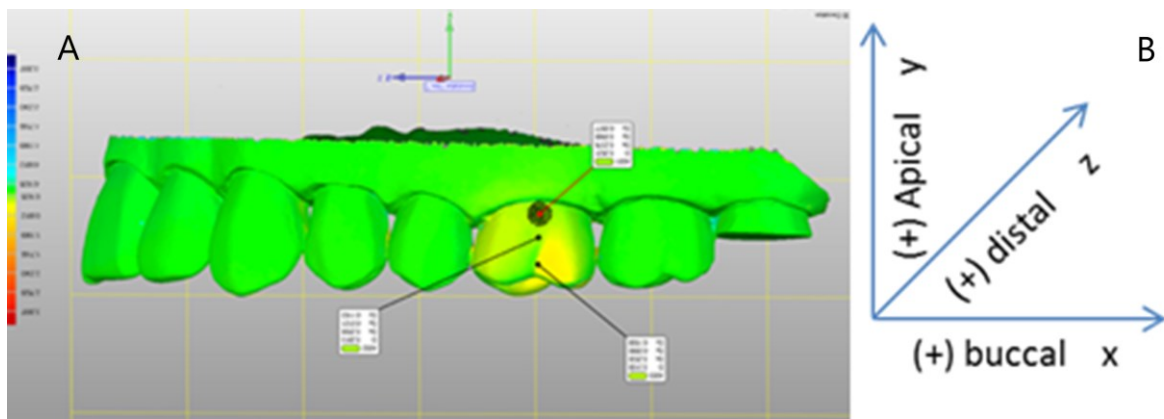


Figure 3 – Scatter plot of the data obtained at different axes showing a limited dispersion of the data in the different reference points for mobility 1 (M1) and 2 (M2). Value reported in μm , $n=30$.

3A. X axis displacement

3B. Y axis displacement

3C. Z axis displacement

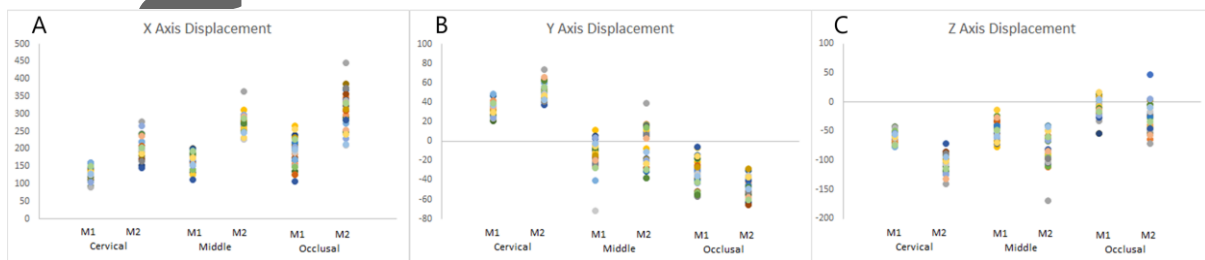
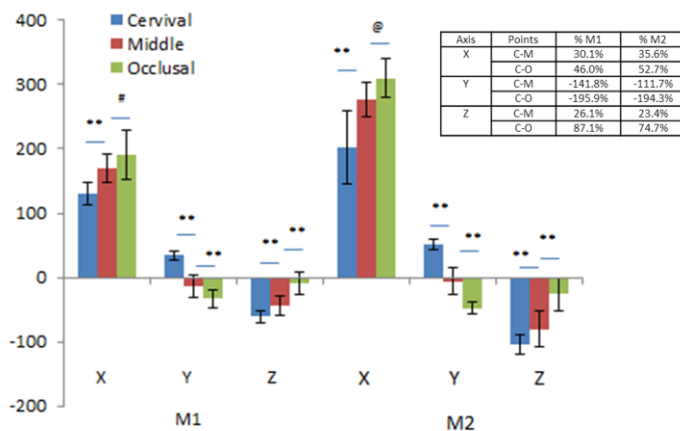


Figure 4. Different mobility observed along the cervical, middle and occlusal points as reported in absolute values. (**) = $p < 0.001$, # = 0.02, @ = 0.04. However, mobility ratio between the cervical-middle and cervical-occlusal followed a similar trend between M1 and M2.



Footnotes

§ Trios 3, 3shape (Copenhagen/ Denmark).

‡ Columbia Dentoform, (New York/NY/, USA).

¶ Trios Dental System, 3Shape (Copenhagen/Denmark).

Geomagic Control X, 3D systems (Morrisville/ North Carolina/ USA).

** SPSS, version 24, IBM (Armonk/New York/USA).

Tables

Table 1A. Reliability analysis of the data obtained for mobility 1 in the three reference points analyzed (cervical, middle and occlusal) reported by the axis (x,y,z) and by examiners (1,2 and 3).

		Mobility 1														
		Cervical					Middle					Occlusal				
Axis	Examiners	Mean + SD	Inter-Item Correlation	C' α	CI (95 %)	F Test	Mean + SD	Inter-Item Correlation	C' α	CI (95 %)	F Test	Mean + SD	Inter-Item Correlation	C' α	CI (95 %)	F Test
x	1	12.43	1-2 = .986	.850	.559	.000	17.89	1-2 = .961	.972	.918	.000	21.13	1-2 = .912	.966	.902	.000
		7.2		.959			17.3		.992			26.0		.991		
		13.24	1-3 = .933				14.95	1-3 = .929				14.52	1-3 = .960			
	2	25.7					21.2					20.1				
		13.27	2-3 = .901				17.84	2-3 = .953				22.12	2-3 = .885			
		13.3					15.0				22.1					
3	32.8	1-2 = .944	.931	.798	.001	7.1	1-2 = .963	.891	.681	.000	35.5	1-2 = .961	.825	.946	.000	
	4.7		.981			11.5		.971			11.7		.995			
	35.6	1-3 = .976				16.4	1-3 = .791				24.3	1-3 = .987				
y	2	9.4					12.7					14.4				
		33.6	2-3 = .976				19.4	2-3 = .791				38.3	2-3 = .987			
		33.6					19.4				38.3					

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		5.2	.958				2 +	.900				0 +	.934			
							23.					12.				
							8					3				
		-	1-2 =	.9	.86	.0	-	1-2 =	.9	.88	.0	-	1-2 =	.9	.82	.0
		61.	.982	54	6 -	00	46.	.859	61	5 -	00	17.	.963	42	9 -	00
	1	1 +			.98		2 +			.98		8 +			.98	
		7.9			8		17.			9		21.			4	
							8					0				
		-	1-3 =				-	1-3 =				-	1-3 =			
		59.	.931				41.	.969				1.5	.848			
	z	2					7 +					+				
		12.					12.					13.				
		9					5					9				
		-	2-3 =				-	2-3 =				-	2-3 =			
		63.	.950				47.	.913				4.3	.905			
	3	0 +					8 +					+				
		7.9					15.					13.				
							3					1				

Mean \pm SD (μm), inter-item correlation between each examiner, Cronbach's alpha ($C's \alpha$) for the three examiners, Cronbach's alpha confidence interval (CI), and the F test for the Cronbach's alpha.

Table 1B Reliability analysis of the data obtained for mobility 2 in the three reference points analyzed (cervical, middle and occlusal) reported by the axis (x,y,z) and by examiners (1,2 and 3).

		Mobility 2														
		Cervical					Middle					Occlusal				
Axis	Examiners	Mean + SD	Inter-Item Correlation	C' α	CI (95 %)	F Test	Mean + SD	Inter-Item Correlation	C' α	CI (95 %)	F Test	Mean + SD	Inter-Item Correlation	C' α	CI (95 %)	F Test
x	1	19 2.0 + 33. 7	1-2 = .848	.9 49	.85 2- .98 6	.0 00	29 1.1 + 28. 7	1-2 = .847	.9 10	.73 7 - .97 6	.0 00	36 2.8 + 36. 1	1-2 = .857	.9 37	.81 6- .98 3	.0 00
	2	20 2.1 + 26.	1-3 = .836				26 5.4 + 19.	1-3 = .692				29 9.8 + 30.	1-3 = .945			

		7				1					8						
		21	2-3 =			27	2-3 =				26	2-3 =					
		5.4	.949			0.2	.917				8.0	.916					
	3	+				+					+						
		30.				24.					54.						
		7				9					6						
		49.	1-2 =	.9	.80	.0	10.	1-2 =	.9	.79	.0	-	1-2 =	.9	.92	.0	
	1	7+	.728	33	3-	00	5+	.843	31	9-	00	54.	.953	76	8-	00	
		9.0				2	6			1		0+			99		
		52.	1-3			-	1-3				-	1-3			3		
	2	7+	=c.819			10.	=.888				45.	=.928					
		8.4				4+					1+						
		51.	2-3 =			-	2-3 =				-	2-3 =					
	3	3+	.928			18.	.856				45.	.968					
		8.6				0+					9+						
		-	1-2 =	.9	.82	.0	-	1-2 =	.8	.68	.0	-	1-2 =	.9	.72	.0	
	1	10	.807	40	5-	00	98.	.860	92	5-	00	35.	.876	06	4-	00	
		0.9				8+				1		1+			97		
		18.				33.						33.			5		
		1				0						6					
		-	1-3 =			-	1-3 =				-	1-3 =					
	2	10	.899			79.	.884				24.	.759					
		2.3				8+					9+						
		14.				16.					18.						
		1				0					7						
		-	2-3 =			-	2-3 =				-	2-3 =					
	3	10	.881			60.	.882				18.	.926					
		8.4				4+					9+						
		13.				18.					22.						
		9				4					4						

Mean \pm SD (μ m), inter-item correlation between each examiner, Cronbach's alpha (α) for the three examiners, Cronbach's alpha confidence interval (CI), and the F test for the Cronbach's alpha

Axis	Point	Δ M2-M1 (μm)	Direction	p-value
X	Cervical	73	Buccal	p<0.001
	Middle	107	Buccal	p<0.001
	Occlusal	121	Buccal	p<0.001
Y	Cervical	17	Apical	p<0.001
	Middle	8	Apical	P=0.002
	Occlusal	-16	Coronal	p<0.001
Z	Cervical	-43	Distal	p<0.001
	Middle	-34	Distal	p<0.001
	Occlusal	-18	Distal	p<0.001

Table 2. Change observed to mobility 1 and mobility 2 in the three axis and three points evaluated. The mean value and resulted magnitude Δ (M2-M1) and direction of the displacement is reported.