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Correlations between photogrammetric measurements of tooth mobility and the Periotest method

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Abstract

Objective. The purpose of the present study was to investigate whether or not the quantitative Periotest values of anterior teeth correlate with quantitative metric values of tooth mobility under vertical (VL) and horizontal load (HL) in periodontally healthy subjects. ***Materials and methods.*** Thirty-one subjects with good periodontal conditions were included and subjected to two different tooth mobility measurement techniques. Periotest values were measured at reproducible measurement points in the vertical (vPT) and horizontal (hPT) dimensions of upper central and lateral incisors and canine teeth. Using the optical measurement technique (photogrammetry), tooth mobility was measured under load in the horizontal (HL) and vertical loading directions (VL) at different load forces. Pearson's correlation coefficients were used to determine exploratory associations. ***Results.*** The comparison between hPT and HL showed no correlations between the two measurements except for 'weak' and 'moderate' correlations for teeth 21 and 23. The analysis of correlations between vPT and VL data showed statistically significant correlations for both the left and right canine teeth that ranged from 'weak' to 'high'. Comparisons between hPT values and VL and between vPT and HL showed significant correlations at a few loading forces only. ***Conclusion.*** Quantitative Periotest values cannot be used to draw conclusions about the metric assessment of tooth mobility. For this purpose, the photogrammetric technique could be an additional tool for scientific questions.

Key Words: *correlation study, diagnosis, Periotest, photogrammetry, tooth mobility*

Introduction

The measurement of tooth mobility has been investigated in a number of studies published in the dental literature over many years [1–5]. An evaluation of patients' tooth mobility is a prerequisite for diagnostic assessments and treatment strategies. Subjective methods where the tooth is deflected between two instrument handles are widely accepted in the clinical routine, but are operator-dependent and non-reproducible [4]. Objective measurement techniques often require complex experimental set-ups [6–9]; however, quantitative information about tooth mobility is feasible. These techniques are based on the principle that a defined load can be applied to the tooth and mobility can be assessed with mechanical [10,11] or optical [6–9] devices. For *in vitro* assessments of forces related to tooth mobility, laser diodes [12], magnetic sensors [13] or universal testing machines [11] can be used. The intra-oral analyses of tooth mobility were arranged with specific devices, e.g. periodontometer [14,15], the holographic interferometry [8,9] and the laser vibrometry [6].

A cost-efficient and time-saving alternative to obtain objective information about tooth mobility is the Periotest method [16–18], an accepted technique for diagnostic findings in different dental fields such as periodontology [19,20], traumatology [21–24], implantology [25,26], oral surgery [27] or orthodontics [28,29]. The damping character of the test object in the surrounding tissue is measured and described in a metrical scheme between –8 and 50, where low values indicate a short deflection time and a high stability [16,30]. Different investigations certify a high reproducibility of measurements (clinical degree of tooth mobility 0–2) [16,22,31,32], whereas the

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reproducibility is minimally reduced for teeth with a higher degree of mobility [16]. In clinical evaluations it was found that horizontal Periotest values correspond with the results of subjective tooth mobility assessments [16,33–35].

A new method for the metric analysis of tooth mobility was developed using photogrammetrical principles. In an *in vivo* examination [36], axial forces up to 81 N were induced to anterior teeth and three-dimensional tooth mobility was measured. In a further study [37], lower horizontal forces up to 18 N were induced to the anterior teeth and provided quantitative information about tooth displacement. It was proven that this measurement technique is highly reproducible [37].

Photogrammetric techniques have been used for various biomechanical analyses and were introduced in dental research for *in vitro* and *in vivo* examinations [36,38–40]. A prominent advantage of this technique is that small displacement values of the teeth can be quantitatively evaluated, independent of movements of the test person's jaw [41]. Limitations of this measurement technique are the complex experimental set-up and the high initial costs of the optical system. This makes the technique unfeasible for daily dental routine, but useful for scientific research. Another detriment of the technique is that the test specimens must be located in the field of view of the camera system. Thus, for intra-oral application, the technique is limited to the anterior region.

In contrast with the photogrammetrical measurement technique, the quantitative Periotest method that is used in the daily dental routine cannot provide information about the metric three-dimensional displacement of the test object. Thus, the aim of the present analysis was 3-fold: First, to determine if horizontal and vertical Periotest values could be correlated with the metric measurement of tooth mobility in healthy dental subjects. It was hypothesized that there would be correlations between both types of measurement and that the Periotest method could indirectly provide information about the metric tooth displacement. If this was proven correct, the second aim was to calculate a conversion factor between the two methods. An additional goal was to identify if the vertical Periotest values correlate with horizontal displacements and the horizontal Periotest values with vertical displacements, as assessed by the optical measurement technique.

Materials and methods

Volunteer selection

A group of 31 dental students were asked to participate (mean age 23.9 years, age range 21–36). For the computer-aided random selection the students' name lists of the 3rd and 4th year dental students of the university was used. All volunteers received written and oral information about the study design and signed a consent form. The study was independently reviewed and approved by the University's ethical committee (Ethical Committee Re. No. 3673) and the investigation was carried out in accordance with the Helsinki Declaration at the Dental Clinic of the University Erlangen-Nuremberg.

Prior to the investigation, several periodontal parameters were assessed to verify healthy periodontal conditions. These included pocket depth of less than 3 mm and tooth mobility grade 0, according to classification of the German Periodontal Association [42]). Only vital teeth (sensible reaction to frozen carbon dioxide) without enamel cracks and sensitivity to percussion were included in the study. The presence of carious lesions or fillings and prosthodontic crown restorations was not allowed. All volunteers, not meeting the inclusion criteria, were excluded. After maxillary impression (Panasil Binetics Putty and Panasil contact plus, Kettenbach, Eschenburg, Germany), casts (GC Fuji Rock, EP, Muenchen, Germany) were made to prepare a vacuum splint (Erkudor 1.0/120 mm; Erkodent, Pfalzgrafenweiler, Germany) with a small hole on the labial aspect (4 mm away from the incisal edge and in the middle of the crown in mesio-distal dimension) and the middle of the incisal edge of all anterior teeth to ensure reproducible measurement points. The splints were used as a template to transfer the vertical and horizontal measurement points for each tooth using a waterproof pencil.

Periotest analysis and photogrammetrical measurement of tooth mobility

Three repeated Periotest measurements were consecutively taken from all maxillary incisors and canines in the horizontal (hPT) and vertical (vPT) dimensions using a Periotest device (Periotest; Gulden, Modautal, Germany) and were taken by the same experienced operator according to the manufacturer's instructions. The hand-piece tip was placed with a distance of 1 mm to the vestibular tooth surface, perpendicular to the vertical and horizontal plane.

For the photogrammetric measurements of tooth displacement, the test subjects were seated in an upright position with their heads fixed to a headrest by an adaptable clamp to minimize extensive head movements. The teeth were cleaned with 70% alcohol and an adhesive tape (Leukotape classic weiss, BSN medical GmbH, Hamburg, Germany) with a stochastic surface pattern was fixed to the tooth's surface to obtain an area for photogrammetric measurements as described in previous investigations [36,37].

For vertical load application (VL), the test subjects were asked to bite down on a custom designed loading device containing a sub-miniature load cell (ELFM

250 N; Measurement Specialties, Inc, Aliso Viejo, CA) (Figure 1). For horizontal load application (HL), a specific loading device (ELFM B1, Measurement Specialties) was used to manually perform a slight tracking along the tooth in the horizontal direction. To avoid overload on the teeth, the actual load values were displayed on the amplifier, releasing an acoustical alert when defined thresholds (VL >81 N, HL >18 N) were exceeded. A photogrammetric system (Aramis; GOM mbH, Braunschweig, Germany) was used to analyze tooth mobility. Measurements were taken at 9 N intervals up to 81 N for VL and in 3 N intervals up to 18 N for HL by a pair of synchronized high-resolution digital cameras (Unifoc, Componon-S 2.8/50, Schneider, Kreuznach, Germany). The unloaded initial configuration was used as a baseline (Figure 2). The photographs were processed and correlated using special software (Aramis software; GOM mbH). Three-dimensional images of teeth during all load steps were calculated by the software program and an absolute displacement vector of the loaded tooth was calculated (Figure 3). Three measurements of each tooth were performed, with an intervening time period of 120 s to assure realignment [43].

Data from three-dimensional tooth mobility measurements (VL and HL) were correlated with the results of the Periotest method (hPT and vPT). Statistical analysis was performed using the SPSS software package (Version 17, SPSS Inc., Chicago, IL) and SAS (Version 9, SAS, Heidelberg, Germany). Correlation coefficients according to Pearson [44] were used to show exploratory associations between two variables. Correlation coefficients (r) of $r \geq 0.50$ were considered 'moderate' associations, $r \geq 0.70$ good associations and $r \geq 0.90$ as optimal associations. A value of $p \leq 0.05$ was considered to denote a significant difference. There was no adjustment for multiple statistical tests, thus tests for significance were interpreted in a descriptive manner.

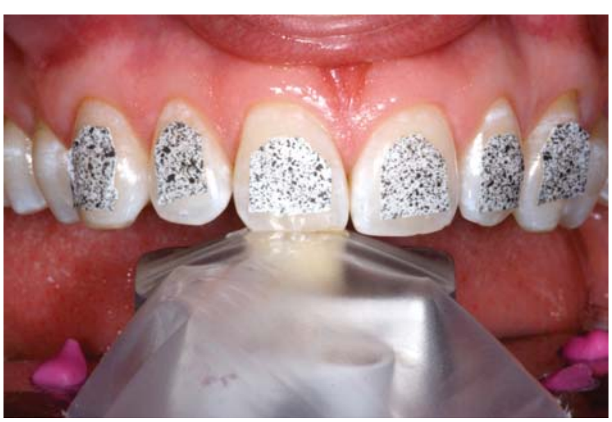

Figure 1. Extraoral anterior view of the experimental set-up of vertical load application. The magnet retained loading device maintained in position by a metal plate that is attached to the mandibular teeth by silicone material. For hygiene reasons the load device is covered with a single-use plastic cover. Adhesive tape with a stochastic surface pattern is fixed on all six anterior teeth. Surface pattern is tracked by digital image correlation system over all load stages.

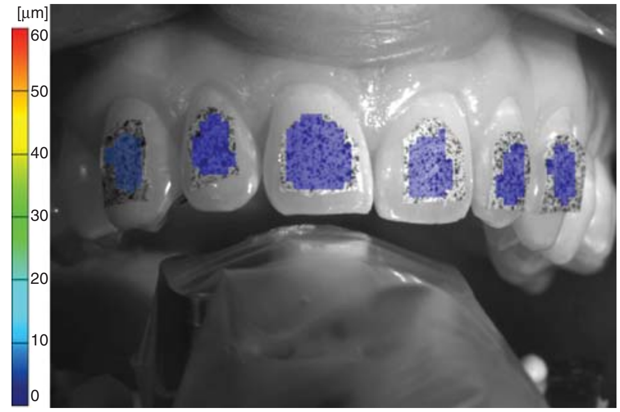

Figure 2. Anterior screen image of surfaces as calculated by the measurement system prior to load application. The color scale on the left depicts the absolute displacement values in µm (blue: 0 µm; green: 30 µm; red: 60 µm).

Results

Periotest data in the horizontal direction (hPT) were correlated to HL (Table I). There were no correlations between the two measurements, except for teeth 21 and 23, which indicated significant 'weak' and 'moderate' correlations ($p \leq 0.05$). For the left and right canine teeth the vPT and VL results showed statistically significant correlations that ranged from 'weak' to 'high' (Table II). However, no correlations between the two different measurement techniques were found for the other teeth. The comparison of

Figure 3. Anterior screen image of surfaces as calculated by the measurement system during load application. Tooth displacement was measured against reference areas on adjacent unloaded teeth (blue areas). Tooth displacement at 9 N is shown as an example (see color scale).

Table I. Pearsons correlation coefficients between hPT, vPT and HL.

		hPT and HL			vPT and HL		
Tooth	Tensile force (N)	Coefficient (*r*)	*p*-value	Evaluation	Coefficient (*r*)	*p*-value	Evaluation
13	3	−0.06	0.782	No correlation	0.4	0.065	No correlation
	6	−0.19	0.408		0.4	0.068	
	9	0.04	0.870		0.58*	0.005	Moderate correlation
	12	0.05	0.812		0.51*	0.015	
	15	0.13	0.550		0.39	0.071	No correlation
	18	0.04	0.859		0.35	0.113	
12	3	0.18	0.424	No correlation	0.19	0.386	No correlation
	6	0.23	0.307		0.02	0.936	
	9	0.01	0.953		−0.07	0.743	
	12	0.14	0.520		−0.16	0.486	
	15	0.28	0.210		−0.04	0.869	
	18	0.31	0.156		0.04	0.877	
11	3	0.06	0.802	No correlation	0.05	0.835	No correlation
	6	0.06	0.794		−0.05	0.821	
	9	0.05	0.816		−0.01	0.961	
	12	−0.09	0.693		0.00	0.991	
	15	−0.17	0.457		0.02	0.938	
	18	−0.16	0.464		0.03	0.902	
21	3	0.27	0.223	No correlation	−0.24	0.286	No correlation
	6	0.29	0.185		−0.37	0.088	
	9	0.48*	0.026	Weak correlation	−0.33	0.128	
	12	0.45*	0.035		−0.32	0.143	
	15	0.43*	0.045		−0.32	0.151	
	18	0.51*	0.016	Moderate correlation	−0.29	0.192	
22	3	−0.02	0.926	No correlation	0.05	0.809	No correlation
	6	−0.02	0.916		0.18	0.429	
	9	0.22	0.324		0.3	0.173	
	12	0.21	0.342		0.21	0.342	
	15	0.36	0.103		0.35	0.108	
	18	0.35	0.113		0.24	0.274	
23	3	0.37	0.093	No correlation	0.59*	0.004	Moderate correlation
	6	0.29	0.197		0.37	0.089	No correlation
	9	0.47*	0.026	Weak correlation	0.36	0.103	
	12	0.43*	0.044		0.24	0.284	
	15	0.36	0.102	No correlation	0.2	0.384	
	18	0.3	0.170		0.26	0.237	

hPT = horizontal Periotest value; vPT = vertical Periotest value; HL = photogrammetrical measurement of teeth mobility during horizontal loading.
*Indicates statistical significance.

vPT to HL showed no significant correlations, except for teeth 13 and 23 (Table I). These correlations were statistically significant. Comparisons between hPT and VL showed significant correlations for teeth 12, 11, 21 and 22 that ranged from 'weak' to 'high' (Table II).

Discussion

In this clinical evaluation only periodontally healthy volunteers within an age range of 20–35 years were selected from a distinct population. In a previous study by d'Hoedt et al. [16] the same age group

Table II. Pearsons correlation coefficients between vPT, hPT and VL.

		vPT and VL			hPT and VL		
Tooth	Axial loading (N)	Coefficient (*r*)	*p*-value	Evaluation	Coefficient (*r*)	*p*-value	Evaluation
13	9	0.86*	<0.001	High correlation	0.07	0.800	No correlation
	18	0.69*	<0.001	Moderate correlation	−0.01	0.953	
	27	0.74*	<0.001	High correlation	0.00	0.986	
	36	0.79*	<0.001		−0.04	0.829	
	45	0.79*	<0.001		0.02	0.917	
	54	0.75*	<0.001		0.05	0.796	
	63	0.72*	<0.001		0.02	0.908	
	72	0.8*	<0.001		−0.06	0.802	
	81	0.86*	<0.001		0.00	0.994	
12	9	0.53	0.080	No correlation	0.8*	0.002	High correlation
	18	0.32	0.087		0.47*	0.008	Weak correlation
	27	0.33	0.083		0.49*	0.007	
	36	0.34	0.084		0.52*	0.006	Moderate correlation
	45	0.35	0.090		0.53*	0.006	
	54	0.36	0.096		0.56*	0.006	
	63	0.39	0.094		0.6*	0.005	
	72	0.41	0.129		0.79*	<0.001	High correlation
	81	0.53	0.078		0.8*	0.002	
11	9	0.33	0.264	No correlation	0.65*	0.017	Moderate correlation
	18	0.16	0.391		0.49*	0.006	Weak correlation
	27	0.06	0.752		0.39*	0.038	
	36	0.02	0.918		0.39*	0.042	
	45	0.04	0.839		0.42*	0.034	
	54	−0.01	0.956		0.28	0.188	No correlation
	63	−0.13	0.583		0.23	0.320	
	72	−0.16	0.525		0.23	0.347	
	81	0.27	0.368		0.33	0.270	
21	9	0.3	0.294	No correlation	0.54*	0.047	Moderate correlation
	18	0.1	0.609		0.43*	0.018	Weak correlation
	27	0.12	0.547		0.43*	0.019	
	36	0.17	0.384		0.5*	0.005	Moderate correlation
	45	0.28	0.156		0.41*	0.033	Weak correlation
	54	0.36	0.080		0.46*	0.021	
	63	0.27	0.211		0.38	0.076	No correlation
	72	0.28	0.258		0.45	0.062	
	81	0.35	0.219		0.51	0.061	
22	9	0.15	0.616	No correlation	0.45	0.104	No correlation
	18	0.19	0.331		0.55*	0.002	Moderate correlation
	27	0.2	0.299		0.54*	0.002	
	36	0.19	0.323		0.54*	0.002	
	45	0.09	0.678		0.38	0.057	No correlation
	54	0.08	0.702		0.35	0.082	
	63	0.2	0.366		0.36	0.104	
	72	0.31	0.165		0.21	0.353	
	81	0.26	0.369		0.48	0.083	

Table II. (*Continued*).

Tooth	Axial loading (N)	vPT and VL			hPT and VL		
		Coefficient (*r*)	*p*-value	Evaluation	Coefficient (*r*)	*p*-value	Evaluation
23	9	0.47*	0.033	Weak correlation	0.12	0.614	No correlation
	18	0.47*	0.013		0.32	0.099	
	27	0.46*	0.013		0.24	0.226	
	36	0.53*	0.005	Moderate correlation	0.3	0.134	
	45	0.46*	0.016	Weak correlation	0.26	0.185	
	54	0.5*	0.007	Moderate correlation	0.28	0.161	
	63	0.5*	0.011		0.28	0.182	
	72	0.54*	0.006		0.3	0.153	
	81	0.55*	0.010		0.33	0.150	

vPT = vertical Periotest value; hPT = horizontal Periotest value; VL = photogrammetrical measurement of teeth mobility during vertical loading.
*Indicates statistical significance.

was tested, mainly focusing on factors influencing the Periotest values. Significant differences were detected within the tested subjects. However, no significant correlation between the measurements and the age or gender was found. The reason for using only periodontally healthy volunteers were references that demonstrate a higher reproducibility of the Periotest measurements for teeth with a clinical degree of mobility between 0–2, whereas measurements on highly mobile teeth (degree of mobility 3) were less reproducible [16]. The same study focused on various other influencing factors, concluding that the reliability of the Periotest method depends on the operator, the use of reproducible measuring points, the angulation of the hand-piece and the distance of the hand-piece to the test object [16]. All these points were particularly taken into consideration during the planning and experimental procedure of the present study.

In most studies Periotest measurements were typically arranged in a horizontal direction [20,21, 26,31]. Recently, the vertical application was introduced for diagnostics in trauma cases, as a method for early detection of tooth ankylosis [22,45] as well as for splint rigidity testing [22,23,46].

Evaluating the results of the present study, the hypothesis that the Periotest values correlate with metric measurements of tooth mobility, assessed by the photogrammetric technique, must be mostly rejected.

Lukas et al. [47] found a correlation between the subjectively evaluated, increased tooth mobility (degree of loosening) and the deflection, caused by the Periotest hand-piece. The metric deflection was measured by high-speed filming. Scholz and Lukas [35] reported a correlation between the degree of loosening and the metric assessment of tooth displacement. The tooth deflection was induced by a mechanical device using forces between 3–8 N. According to these references it was expected that correlations between the metric measurement of horizontal tooth movement and the Periotest values would be found in our examination. However, the comparison between hPT and HL showed only a few mostly 'weak' or 'moderate' correlations. Thus, it can be assumed that the two different measurement systems do not correspond in the horizontal dimension. One reason that no correlation was detected could be that the Periotest measurement uses a low force (8 g) induced at a high velocity (0.2 m/s) to the tooth surface [48] for measuring the damping characteristics of the surrounding tissue [16,30,33]. Applying lower forces to periodontally healthy teeth generates a micro-movement of the tooth within the periodontal ligament whereas the force application to periodontally compromised teeth results in a deflection up to the alveolar socket wall [47]. The time of contact (0.5–2.3 ms) between the Periotest device and the tooth is measured and allows, because of its correlation with clinical degrees of mobility, the tooth stability to be determined [16,30]. The high degree of correlation between the horizontal Periotest values and the clinical degree of mobility could be explained by the low forces and short deflection time applied during the process of tapping the tested tooth between two instrument handles, as reported by Lukas et al. [47].

Contrariwise, using the optical measurement technique, a minimum force of 3 N was applied in the horizontal loading direction, which is ~40-times greater than the Periotest force. The initial type of tooth mobility is most likely a tipping around an axis of rotation inside the periodontal ligament [49]. When applying greater forces, the PDL is compressed and the continuing force leads to a deformation of the alveolar bone [50,51]. Thus, information about the force-related mobility can be obtained. Because both the soft surrounding tissues and the alveolar bone have an effect on the movement pattern, this contrasts with the mobility characteristics induced by the Periotest method. However, this could be of great interest because comparable forces that occur during mastication have a similar effect on the soft and hard tissue as the forces applied during the photogrammetrical measurement. It has to be considered that the results of this study can not provide information at which force level the tooth mobility is caused by the elastic properties of the PDL or influenced by the alveolar socket deformation.

Comparing the vertical Periotest values with tooth mobility induced by axial loading with forces up to 81 N, only correlations for both the left and right canine could be found (vPT and VL, Table II). A reason for this could be the significantly lower mobility of canine teeth compared with incisors and the reduced damping character of canine teeth. However, the correlations with all other teeth do not indicate a predictable pattern.

To get widespread information, the event correlations of different loading conditions of the two measurement systems were calculated. Periotest data in the vertical direction were correlated with horizontal tooth mobility measurements (vPT vs HL) and horizontal Periotest data were compared with vertical tooth mobility measurements (hPT vs VL). No predictable correlation was found. This could be because of the different loading axis and the different level of loading forces.

Information about the mobility characteristics of teeth in their surrounding periodontal tissue are of great interest in dental research and practise. Both the metric measurements and the quality of tooth mobility are important diagnostic findings in, e.g. the clinical monitoring of treatment strategies of periodontal disease [19,20] or traumatic injuries [45,52] and for evaluating the suitability of teeth as a basis for prosthodontic treatment [53].

The study showed that both evaluated tooth mobility measuring methods provide different valuable information. The Periotest method mainly describes the damping characteristics and properties of the PDL caused by small forces. This is desirable during the follow-up of trauma cases (e.g. to detect early ankylosis [22]) or during the osseointegration process of implants [25]. In contrast the photogrammetric measurement can provide quantitative metric information about tooth mobility under physiological load, e.g. during mastication. It can be assumed that the photogrammetric measurement technique can provide important information about tooth mobility as an additional tool.

Concluding the results of the current investigation, it can be stated that a translation of Periotest values to quantitative displacement data is not feasible, within the protocol of this particular study.

However, the optical technique is not yet applicable for routine dental controls because of the complex experimental set-up and high costs of the measurement system. Future efforts are required to develop an optical system based on photogrammetric principles to allow for effective and time-saving measurements during routine dental diagnostics.

Furthermore it must be recognized that the results of the study are limited to periodontally healthy test subjects. Further investigations must be done to evaluate the tooth mobility of subjects with periodontal disease or dental implants and to test whether correlations between the two measurement systems can be detected when applying smaller loads.

Conclusions

Within the limitations of this study, the following conclusions can be drawn for periodontally healthy test subjects.

(1) Periotest values and displacement vectors of anterior teeth, assessed by the non-contact optical measurement technique, show no predictable correlation.
(2) Metric tooth mobility data cannot be calculated from Periotest values within the present set-up.
(3) Both the Periotest method and the photogrammetrical measurement can provide valuable information for different clinical indications.
(4) Photogrammetrical measurement could be an additional tool for obtaining information about the metric tooth displacement under load, but is limited to complex experimental set-ups.

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