Reproducibility of Probing Depth Measurement by an Experimental Periodontal Probe Incorporating Optical Fiber Sensor

Kazuki Ishihata,* Noriyuki Wakabayashi,* Juro Wadachi,* Tatsuya Akizuki,† Yuichi Izumi,† Kazuo Takakuda,‡ and Yoshimasa Igarashi*

Background: An experimental periodontal sensor probe (SP) equipped with an optical fiber for recording function was developed. The aim was to test the intraexaminer reproducibility of probing using the SP and to assess the consistency with the manual probe (MP).

Methods: The SP was assembled with an external sheath covering the probe tip of an MP. The sheath was slid backward by the free gingival margin while probing and the sliding distance was detected by the sensor. The probing was conducted with the walking stroke at six sites for four first molar teeth in six maintenance patients with the SP and the MP at a 1-hour interval. The deepest reading in the vicinity of each site was recorded. The measurements were rerecorded 1 week later.

Results: The mean depth was 3.03 and 3.08 mm recorded by the MP and SP, respectively. Although no significant difference was found between the probes (P >0.05) in all measurement sites, the mean depth at the lingual site of the upper left first molar was noticeably lower with the SP. For sites ≥7 mm, significantly lower depth was recorded by the SP (P <0.05). Zero discrepancy in duplicate measurements was found in 76% of all sites with MP and 92% with SP.

Conclusions: The reproducibility of the SP was comparable to that of the MP. The results indicate that for sites of maintenance patients with probing depth <7 mm there was excellent agreement obtained by a single examiner using the SP compared to the MP. *J Periodontol 2012;83:222-227.*

KEY WORDS

Optical fibers; periodontal pocket; reproducibility of results.

* Removable Partial Prosthodontics, Division of Oral Health Sciences, Graduate School, Tokyo Medical and Dental University, Tokyo, Japan.
† Section of Periodontology, Department of Hard Tissue Engineering, Graduate School, Tokyo Medical and Dental University.
‡ Division of Biosystems, Department of Biodesign, Institute of Biomaterials and Bioengineering, Tokyo Medical and Dental University.

Periodontal probes are used to determine the presence and severity of periodontal disease and to assess the effect of periodontal treatment.[1,2] The probes are used not only to measure probing depth (PD), but also to determine attachment level, presence of plaque and calculus, presence of inflammation, bleeding on probing (BOP) and suppuration, and anatomic features, such as irregularities of the root.[3] Pressure-sensitive automated periodontal probes have been developed to reduce the factor of variability of probing force.[4,5] Improved reproducibility of the PD recorded by automated probes with controlled probing force has been reported,[6-8] whereas others found no improvement of the reproducibility.[9-11] The advantages of the automated probes also include an electronic readout function and the capacity for electronic data collection, by which PD at each probing site is recorded and stored by the software installed in the probing device or in a personal computer. The electronic recording of the measurements offers tremendous advantages for clinicians who work alone, because it automatically collects data without writing transcription and it prevents transcription errors in clinical records and research data.

Despite extensive research on the development of automated probes, they are

doi: 10.1902/jop.2011.110047

not primarily used for periodontal examination. The conventional manual periodontal probe is still the major instrument used for diagnosis and evaluation of treatment. The diameter and shape of the probe tip are important factors that affect measurement of PD. One of the reasons for dentists to continue using conventional manual probes (MPs) may be that examination of the periodontal sulcus is a sensitive procedure that can be affected by the shape of the periodontal probe tip. In this context, an alternative concept was to modify the conventional probe by attaching a sensor to record the PD. This sensor probe (SP) could register the PD at each measurement site without writing transcription. At the same time, it could serve as a conventional diagnostic tool to assess the various anatomic features within the periodontal sulcus by the same probe tip configuration as the conventional probes.

Optical fibers can be used as sensors to measure strain and other quantities by modifying a fiber so that the quantity to be measured modulates the intensity, phase, polarization, wavelength, or transit time of light in the fiber.[12] Sensors that vary the intensity of light are the simplest, because only a simple source and detector are required. A particularly useful feature of intrinsic fiberoptic sensors is that they can, if required, provide distributed sensing over very large distances. The fibers are particularly useful when applied as remote sensing material for periodontal probes that aim to acquire information in the mouth because of its small size, and the fact that no electrical power is needed. They can be safely used for recording measurements within human tissues without heat and electrical shock.[13]

This study aims to develop a periodontal probing system constructed by equipping the conventional probe with an optical fiber sensor to record the PD, and to assess the reproducibility of the measurements. The intraexaminer reproducibility of PD measurements using an SP was compared to a conventional MP on periodontal maintenance patients.

MATERIALS AND METHODS

SP

An experimental SP was constructed based on a conventional MP[§] with Williams markings, which was equipped with an optical fiber sensor[‖] (Figs. 1A and 1B). The probe part had a tapered prong with a diameter of 0.5 mm at the tip. The original probe tip was covered with an external sheath (ES), which was designed to slide along the long axis of the probe tip as the cylinder edge was slid backward by the free gingival margin when the probe was inserted into the periodontal sulcus. The ES was placed with a coil spring pushing the cylinder back to the probe tip position with slight pressure (≈15 g based on a preliminary load test), and covered by a 1-mm diameter stainless steel cylinder laser-welded to the probe shank. The pressure of the cylinder was sufficiently small to permit assessment of anatomic features of the root by this probe the same as is done with a conventional MP. The total length of the tine increased from 20 mm of the original probe to 28 mm with the stainless steel cylinder. The resulting gap distance between the probe tip and the sheath edge was detected, and transferred by means of a 0.15-mm stainless steel wire to the optical reflector (OR) held by a stainless steel housing (3-mm diameter) welded to the probe handle. The movement of the OR was then transmitted to the optical fiber sensor that was held in the same stainless steel housing. The sensor signals were transformed into electric voltage, and fed into a personal computer outside the mouth through a soft cord. The PD was registered 10 times per second, and displayed in the computer monitor in front of the clinician (TA) in real time. Measurement of the depth at a probing site was completed when an operator confirmed the right placement of the probe was confirmed and touched the foot pedal connecting the computer. Data were stored in software or output as text file for export.

Calibrations

The sensor component was initially calibrated on a three-dimensional stage. The OR was manually displaced with every 1-mm increment through a range of 1 to 12 mm, while the output electric voltage was recorded. The measurement was repeated 10 times for each displacement. The linear regression analysis indicated that the displacement and the output voltage correlated well ($r^2 = 0.999$). The approximated relation was used in the software to convert the electric data into the length. The accuracy of the SP was then tested by means of artificial steps made of thin acrylic plates (5-mm thickness). Five acrylic plates were piled to create steps of lengths 2, 4, 6, and 8 mm that were measured using a digital caliper. Measurement by the probe was repeated 10 times. The PDs were rounded to the nearest millimeter. The mean and the standard error for each length was 2.02 ± 0.010, 3.98 ± 0.015, 6.05 ± 0.011, and 7.97 ± 0.010 mm, respectively.

Patients

From May 2010 to August 2010, six individuals (3 males and 3 females, aged 43 to 73 years; mean age: 56.7 years) undergoing periodontal maintenance therapy at the Faculty Practice of the Department of Periodontics, Tokyo Medical and Dental University Dental Hospital, Tokyo, Japan, were recruited for this study. They were initially diagnosed with moderate-to-advanced periodontitis, and had generalized radiographic evidence of bone loss of 30% to 60%. All

§ PCP UNC-15, Hu-Friedy, Chicago, IL.
‖ FX11-A, SUNX, Aichi, Japan.

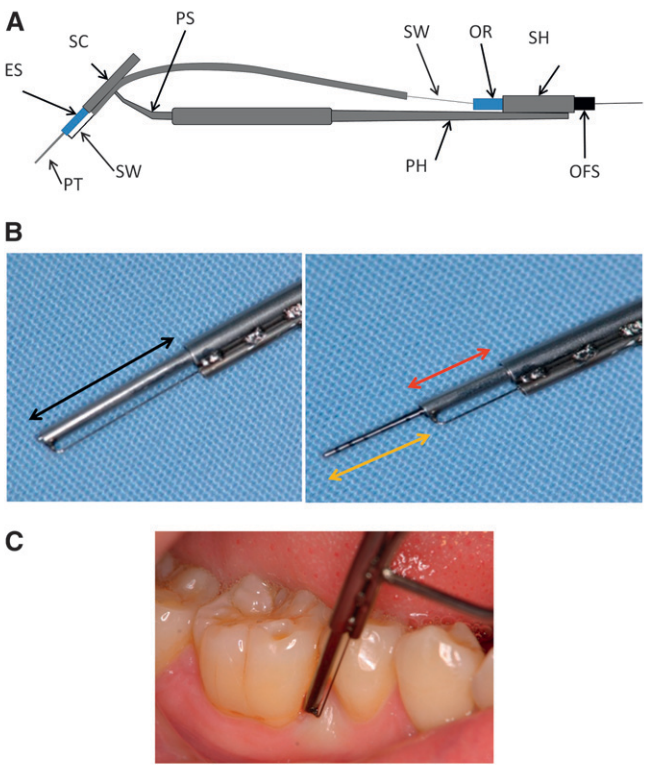

Figure 1.
The structure of the SP. ***A)*** *Schematic illustration of the SP made based on the conventional probe assembled with an optical fiber sensor. PT = probe tip; ES = external sheath; SC = stainless steel cylinder; PS = probe shank; SW = stainless steel wire; OR = optical reflector; SH = stainless housing; PH = probe handle; OFS = optical fiber sensor.* ***B)*** *The ES completely covers the PT before probing (black arrow). Because the cylinder edge is slid backward by the gingival margin on probing (red arrow), the length of the PT that appears corresponds to the PD (yellow arrow).* ***C)*** *The SP during test measurement. The probe tip is inserted in the periodontal pocket at the mesio-buccal site of the mandibular right first molar tooth.*

patients had received initial periodontal therapy consisting of oral hygiene instructions, supragingival and subgingival debridement, and periodontal surgery. The inclusion criteria for the patients was the presence of a periodontal pocket of ≥5 mm at ≥1 site for the first molar teeth, and the presence of all four second premolar teeth, first molar teeth, and second molar teeth.[14] The patients had no complaints of pain or acute symptoms. Those who required antibiotic coverage or sedation for examination were excluded. All experimental procedures were approved by the institutional research ethics committee (Tokyo Medical and Dental University, Yushima, Bunkyo-ku, Tokyo), and written informed consent was obtained from each patient before participation in the study.

Probing Depth Measurements

The measurements on the first day (day 0) were made by means of the manual and the SPs at a 1-hour interval. The probes were assigned to a random order according to coin toss before test for each patient. Before measurement, the examiner (TA), a periodontist accredited by the Japanese Society of Periodontology with 9 years of clinical experience, was given an opportunity to use the SP for practice on a patient who was not enrolled in this study, and was asked to insert the probe parallel to the root surface (Fig. 1C). The first molar teeth of the upper right, upper left, lower left, and lower right quadrants were examined in that order. PD measurements were recorded for six sites on each tooth: the disto-buccal (DB), mid-buccal (B), mesio-buccal (MB), disto-lingual (DL), lingual (L) and mesio-lingual (ML). They were recorded in that order, 24 sites per patient (total, 144 sites). PD measurements were made with the walking stroke and one deepest reading in the vicinity of each site was recorded.[15] With the MP, the PDs were rounded to the nearest millimeter. The gingival inflammation was assessed through the presence or absence of BOP for each measurement. Duplicate measurement was performed 1 week later (day 7). The order for the probes was changed, whereas the same order was used for the teeth and sites.

Data Analyses

The measurement sites were classified into three levels: 1) shallow (<4 mm); 2) moderate (≥4 and <7 mm); and 3) deep sites (≥7 mm). The frequency distribution of differences between the probes and between the duplicate measurements was calculated. Mann-Whitney *U* test was used to test the significant difference in PD by the effects of the probes and duplicate measurements.¶ The intraexaminer reliability was also tested by κ analysis for duplicate measurement of each probing method. *P* values of <0.05 were accepted as statistically significant.

RESULTS

The difference in the mean overall PD between the sensor and MPs was not significant for any of the measurement sites (P <0.05) (Fig. 2). The mean PD at 144 sites was 3.03 mm with the MP and 3.08 mm with the SP. The frequency distribution of differences in the measurements between two probing methods indicated a good consistency with a difference within ±1 mm shown in 98% of all sites on day 0 and in 95% of all sites on day 7 (Fig. 3). In 105 and 93 sites, no difference was observed between the probes on days 0 and 7, respectively.

The mean PD of the subdivided shallow, moderate, and deep groups are shown in Figure 4. For the deep sites, the SP recorded a significantly lower mean value of 6.6 mm compared to the MP value of 7.4 mm (P <0.05). Table 1 shows the proportional distribution of the three groups for all individual sites that were

¶ SPSS v.11.5, IBM, Chicago, IL.

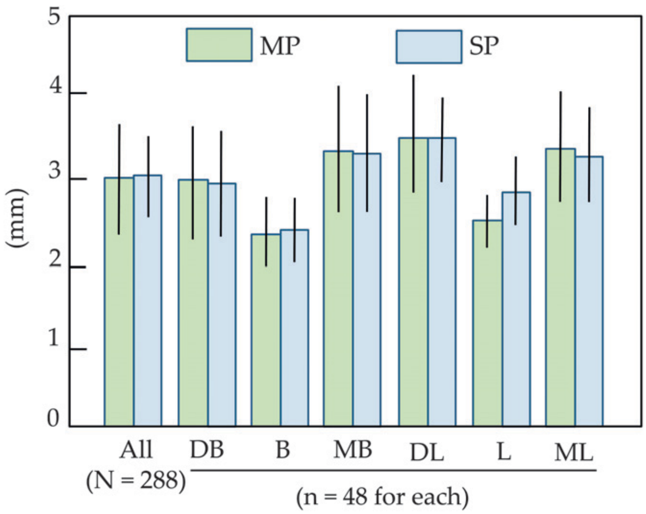

Figure 2.
The mean ± SD of the PDs for all measurement sites (All) and the six individual sites: the disto-buccal (DB), mid-buccal (B), mesio-buccal (MB), disto-lingual (DL), lingual (L), and mesio-lingual (ML). Six subjects, four molar teeth, and two duplicate measurements were included in the data. The difference in the mean overall PD between the sensor and MPs was not significant for each and all of the measurement sites (P <0.05).

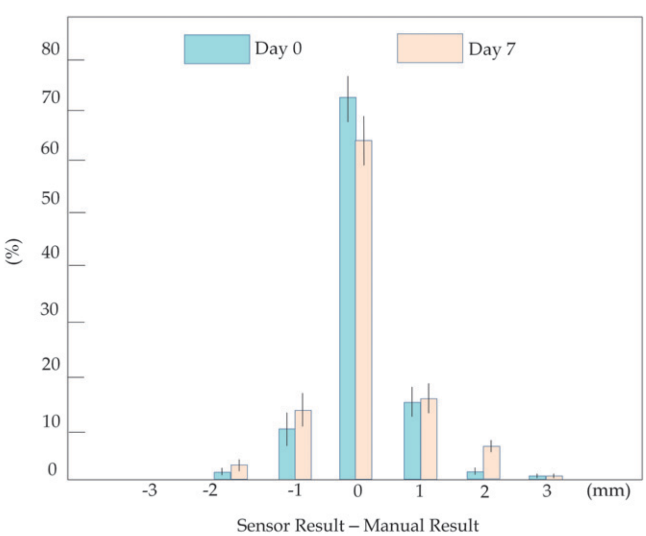

Figure 3.
Frequency distribution of differences between measurements by the manual and SPs at days 0 and 7. The mean ± SD was calculated by subtracting the MP result from the SP result for each measurement site of the six subjects and four molar teeth.

measured by the two probing methods. The buccal and lingual sites offered larger percentages of the shallow pockets compared with the approximal sites. The proportion of combined moderate and deep pockets was least at the buccal site with 4.2% by both probes, whereas it was highest at the mesio-buccal site with 41.7% by the sensor and 33.3% by the MP. Both prob-

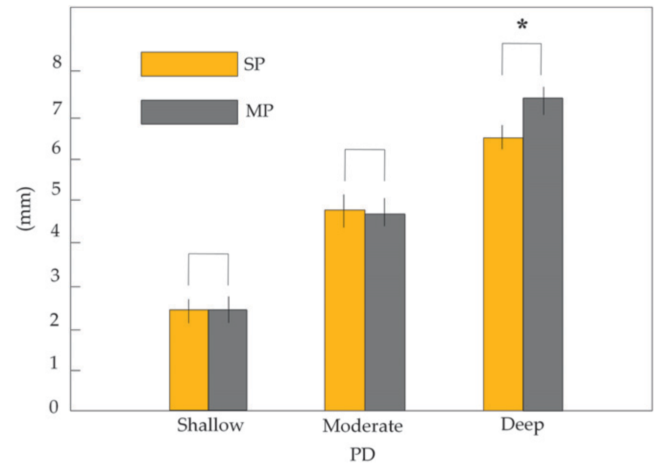

Figure 4.
*The mean ± SD of the PDs in the shallow, moderate, and deep measurement sites for the sensor and MPs. Six subjects, four molar teeth, six measurement sites, and two duplicate measurements were included in the data. *Statistically significant difference between the two probes (P <0.05).*

ing methods indicated that the level of BOP at the proximal sites was substantially higher than the buccal and lingual sites. Significant differences in the BOP were not found between the probing methods.

Figure 5 shows the frequency distribution of the differences between the duplicate measurements. The differences between the duplicate measurements over all sites with the MP ranged between −1 and 1 mm. Zero discrepancy or no measurement error was found in 76% of the cases with the MP, whereas the SP showed zero discrepancy in 92% of the sites. The reproducibility indicated by the average κ value of all subjects between the duplicate measurements was 0.88 for the SP and 0.65 for the MP.

The largest discrepancy of the mean depth between the probes was found at the lingual site of the upper left molar tooth. At this site, the mean depth with the SP was 0.83 mm greater than that with the MP on day 0, and it was 0.67 mm greater on day 7. In contrast, at the buccal site, the depths by the different probes matched in three of four teeth on day 0, and two of four teeth on day 7, in all six subjects.

DISCUSSION

The results indicate that the mean PD recorded for each probing site of the molar teeth by the SP was in agreement with that by the conventional MP. However, in periodontal pockets with PD ≥7 mm, significantly less PD was recorded by the SP than by the MP. It can be speculated that the applied pressure from the sheath edge displaced the gingival margin that lies loose around the neck of the tooth with a deep periodontal pocket, resulting in reduction of probing measures. Potential influence of the pressure made by the internal

Table 1.

Percentage Distribution of Shallow, Moderate, and Deep Sites in all Sites and BOP by SP and MP

Probing Methods and Three Levels of PD	Measurement Sites						Mean
	DB	B	MB	DL	L	ML	
MP							
Shallow (<4 mm)	83.4	95.8	66.7	75	95.8	70.8	81.3
Moderate (≥4 and <7 mm)	8.3	4.2	25	16.7	4.2	25	13.9
Deep (≥7 mm)	8.3	0	8.3	8.3	0	4.2	4.8
BOP (%)	50	20.8	45.8	41.6	16.7	41.6	37.5
SP							
Shallow (<4 mm)	83.4	95.8	58.3	70.8	79.2	62.5	75
Moderate (≥4 and <7 mm)	12.5	4.2	37.5	25	20.8	37.5	22.9
Deep (≥7 mm)	4.2	0	4.2	4.2	0	0	2.1
BOP (%)	45.8	16.7	41.6	41.6	20.8	41.6	34.8

DB = disto-buccal; B = mid-buccal; MB = mesio-buccal; DL = disto-lingual; L = lingual; ML = mesio-lingual.

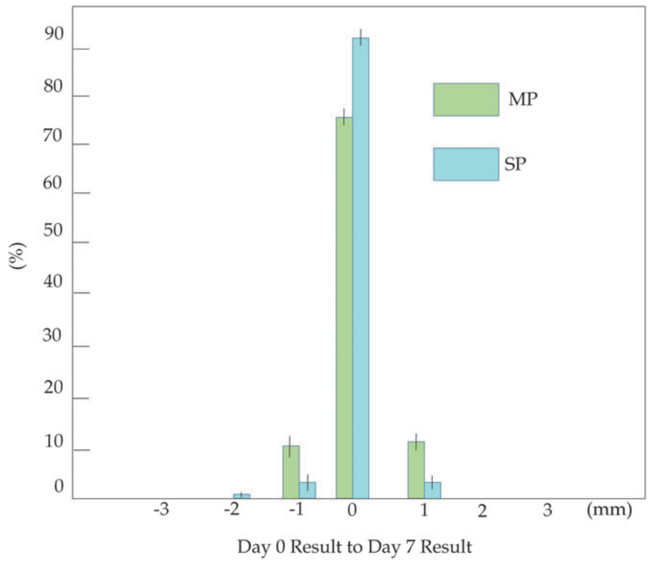

Figure 5.
Frequency distribution of differences between measurements at days 0 and 7 for the two probing methods. The mean ± SD was calculated by subtracting the day 7 result from the day 0 result for each measurement site of the six subjects and four molar teeth.

coil spring to push the cylinder back to the probe tip position should not be underestimated. The probing site distribution of the moderate and deep PDs in patients of this study was comparable to that reported by previous studies on automated probes.[8,16] The BOP (%) was higher than those shown in a similar study.[14] However, the study patients did not have active untreated periodontal disease and the sites evaluated were not acutely inflamed because they had been treated previously and were being maintained. It was therefore indicated that the study population consisting of periodontal maintenance patients used in this study was appropriate to test the reproducibility of the sensor system in patients with moderate to advanced periodontitis. Because the deep sites amounted to only 4.8% and 2.1% of all the probing sites of this study based on the manual and sensor measurements, respectively (Table 1), further studies are required to assess the influence of the sheath pressure on the measurements and the potential need for improvement of this device, and the reproducibility of the measurement in acutely inflamed sites.

Although the difference in the mean PD between the sensor and the MPs was not significant for each of the 24 measurement sites, the mean depth at the lingual of the upper left molar was noticeably greater by the SP than that by the MP. The result was not expected because the measurement inconsistency was more likely to occur in the proximal sites than in the buccal and lingual sites because of potential variation in probe angulation and placement, and resistance from lateral forces exerted by the pocket wall.[7,10,11,17] The relatively lower matching rate between the sensor and MPs at the lingual site might be attributed to the total length of the tine of the SP, including the ES in which it runs, which might make it difficult to get adequate access to posterior probing, especially in the maxillary dentition.[8]

The results of the duplicate measurements indicate good reproducibility of both probing methods. Matched results were found in 18 sites for the SP, which was considerably more than the four sites for the MP (Fig. 5). The better performance of the SP may partially be caused by the higher resolution of 0.1 mm. The measured depth was rounded to the nearest millimeter, without potential visual errors that could be associated with the MP. In agreement with well-controlled studies of attachment level measurements,[7,8,17-19] the result of this study with a single examiner indicated duplication of the measurements within 1 mm on average. The high correlation between duplicate examinations shown for each of the sensor and MPs is consistent with previous reports of cumulated variance of 8.5% for pocket and attachment level measurement with a conventional probe.[20]

While probing in periodontal maintenance patients, clinicians may encounter remaining calculus, plaque, and overcontouring of restorations. Unlike most of the automated probes with different probe tip shape and dimension, the SP with the conventional probe tip may pose advantages because the shape of the probe tip can affect the sensitivity of the examination inside the periodontal sulcus. The experimental SP of this study could serve as an automated data collector without the writing transcription, while it is potentially used as a diagnostic tool to assess various anatomic features inside the periodontal sulcus.

CONCLUSIONS

A modified conventional periodontal probe equipped with an optical fiber sensor to record the PD was developed and the PD reproducibility of the system evaluated. The results indicate that for sites of periodontal maintenance patients with PD <7 mm there was excellent agreement obtained by a single examiner using an SP compared to a conventional probe. The experimental SP incorporating the conventional probe tip may be useful as a routine diagnostic tool for periodontal disease, while serving as an automated data collector.

ACKNOWLEDGMENTS

This study was supported by a Grant-in-Aid (No. 20592307 to NW) for research from the Japan Society for Promotion of Science/The Ministry of Education, Culture, Sports, Science and Technology, Japan. The authors report no conflicts of interest related to this study.

REFERENCES

1. Listgarten MA. Periodontal probing: What does it mean? *J Clin Periodontol* 1980;7:165-176.
2. Garnick JJ, Silverstein L. Periodontal probing: Probe tip diameter. *J Periodontol* 2000;71:96-103.
3. Van der Velden U, Abbas F, Armand S, et al. Java project on periodontal diseases. The natural development of periodontitis: Risk factors, risk predictors and risk determinants. *J Clin Periodontol* 2006;33:540-548.
4. Chamberlain AD, Renvert S, Garrett S, Nilvéus R, Egelberg J. Significance of probing force for evaluation of healing following periodontal therapy. *J Clin Periodontol* 1985;12:306-311.
5. Garnick JJ, Keagle JG, Searle JR, King GE, Thompson WO. Gingival resistance to probing forces. II. The effect of inflammation and pressure on probe displacement in beagle dog gingivitis. *J Periodontol* 1989;60: 498-505.
6. Abbas F, Hart AA, Oosting J, van der Velden U. Effect of training and probing force on the reproducibility of pocket depth measurements. *J Periodontal Res* 1982; 17:226-234.
7. Osborn J, Stoltenberg J, Huso B, Aeppli D, Pihlstrom B. Comparison of measurement variability using a standard and constant force periodontal probe. *J Periodontol* 1990;61:497-503.
8. Wang SF, Leknes KN, Zimmerman GJ, Sigurdsson TJ, Wikesjö UM, Selvig KA. Reproducibility of periodontal probing using a conventional manual and an automated force-controlled electronic probe. *J Periodontol* 1995;66:38-46.
9. Van der Velden U, de Vries JH. The influence of probing force on the reproducibility of pocket depth measurements. *J Clin Periodontol* 1980;7:414-420.
10. Kalkwarf KL, Kaldahl WB, Patil KD. Comparison of manual and pressure-controlled periodontal probing. *J Periodontol* 1986;57:467-471.
11. Quirynen M, Callens A, van Steenberghe D, Nys M. Clinical evaluation of a constant force electronic probe. *J Periodontol* 1993;64:35-39.
12. Zhao Y, Ansari F. Quasi-distributed fiber-optic strain sensor: Principle and experiment. *Appl Opt* 2001;40: 3176-3181.
13. Bozkurt A, Onaral B. Safety assessment of near infrared light emitting diodes for diffuse optical measurements. *Biomed Eng Online* 2004;3:9.
14. Barendregt DS, Van der Velden U, Timmerman MF, van der Weijden GA. Comparison of two automated periodontal probes and two probes with a conventional readout in periodontal maintenance patients. *J Clin Periodontol* 2006;33:276-282.
15. Carranza FA, Takei HH. Clinical diagnosis. In: Newman MG, Takei HH, Klokkevold PR, Carranza FA, eds. *Carranza's Clinical Periodontology*, 10th ed. St. Louis: Saunders Elsevier; 2006:552.
16. Mayfield L, Bratthall G, Attström R. Periodontal probe precision using 4 different periodontal probes. *J Clin Periodontol* 1996;23:76-82.
17. Badersten A, Nilvéus R, Egelberg J. Reproducibility of probing attachment level measurements. *J Clin Periodontol* 1984;11:475-485.
18. Kingman A, Löe H, Anerud A, Boysen H. Errors in measuring parameters associated with periodontal health and disease. *J Periodontol* 1991;62:477-486.
19. Mullally BH, Linden GJ. Comparative reproducibility of proximal probing depth using electronic pressure-controlled and hand probing. *J Clin Periodontol* 1994; 21:284-288.
20. Grossi SG, Dunford RG, Ho A, Koch G, Machtei EE, Genco RJ. Sources of error for periodontal probing measurements. *J Periodontal Res* 1996;31:330-336.

Correspondence: Dr. Noriyuki Wakabayashi, Removable Partial Prosthodontics, Division of Oral Health Sciences, Graduate School, Tokyo Medical and Dental University, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8549, Japan. E-mail: wakabayashi.rpro@tmd.ac.jp.

Submitted January 25, 2011; accepted for publication May 10, 2011.