Journal of Clinical Periodontology
Official Journal of The European Federation of Periodontology
Founded by the British, Dutch, French, German, Scandinavian, and Swiss Societies of Periodontology

J Clin Periodontol 2009; 36: 212–218 doi: 10.1111/j.1600-051X.2008.01360.x

Detection of the cemento-enamel junction with three different probes: an "in vitro" model

Dick S. Barendregt, Ubele van der Velden, Mark F. Timmerman, Hankie M. Bulthuis and Fridus van der Weijden

Department of Periodontology, Academic Centre for Dentistry Amsterdam, Amsterdam, The Netherlands

Barendregt DS, van der Velden U, Timmerman MF, Bulthuis HM, van der Weijden F. Detection of the cemento-enamel junction with three different probes: an ''in vitro'' model. J Clin Periodontol 2009; 36: 212–218. doi: 10.1111/j.1600-051X.2008.01360.x.

Abstract

Aim: The purpose of the present study was to test the accuracy and precision with which the cemento-enamel junction (CEJ) can be assessed using three commercially available periodontal probes with different tip endings in both deciduous and permanent teeth.

Material and Methods: An ''in vitro'' model was developed, consisting of 70 extracted permanent and 30 deciduous human teeth mounted in plaster with an artificial gingiva made of silicone rubber. The probes tested were the Merritt-B probe, the ball-ended CPITN probe and the Vivacare TPS beveled-ball probe. With each probe, duplicate CEJ assessments were carried out at six sites per tooth by four examiners. Upon completion, the distance between the CEJ and the artificial gingival margin was determined using a stereomicroscope.

Results: The mean difference between the microscopic assessment and the mean clinical probe measurements in permanent teeth was −0.05 mm with the Merritt-B, 0.11 mm for the CPITN and 0.19 mm with the TPS probe. In deciduous teeth, the differences were −0.02, 0.35 and 0.63 mm, respectively. In both permanent and deciduous teeth, only the Merritt-B did not differ from the microscopic assessment.

Conclusions: Results showed that the use of the Meritt-B probe offered the most accurate location of the CEJ in both permanent and deciduous teeth.

Key words: CEJ; cemento-enamel junction; periodontal probe; reproducibility

Accepted for publication 10 November 2008

Loss of connective tissue attachment is an important parameter for the assessment of periodontal destruction and disease progression. In periodontal health, the collagen fibrous attachment reaches up to the cemento-enamel junction (CEJ) (Schroeder & Listgarten 1997). The CEJ can therefore serve as a fixed reference point to establish the degree of periodontal clinical attachment loss (CAL) (Glavind & Loë 1967). Although CAL should ideally be measured from the base of the pocket to the CEJ, various factors including variation in probing force (Hassell et al. 1973, Van der Velden 1979, Mombelli et al. 1992), periodontal inflammation (Armitage et al. 1977, Van der Velden & Jansen 1980, Fowler et al. 1982, Bulthuis et al. 1998), tactile and visual assessment errors (Watts et al. 1995), root morphology (Theil & Heaney 1991) and probe design (Barendregt et al. 1996) can affect the accuracy of probing pocket depth measurements. The CEJ is often positioned subgingivally and difficulties are experienced in the accurate clinical assessment of this anatomical landmark with a periodontal probe (Badersten et al. 1984). Where most periodontal parameters are liable to visual observational error, the CEJ is obviously liable to this phenomenon but also to tactile error due to lack of a clear demarcation (Watts, 1987). In addition, on the proximal surfaces, the partial vertical course of the CEJ may increase difficulty in assessing the CEJ (Badersten et al. 1984). Therefore, when combining probing pocket depth and assessment of the CEJ for measuring CAL, the possible measurement errors are additive and the accuracy is affected (Jeffcoat et al. 1986).

The existing literature on the validity of the clinical assessment of the CEJ is sparse. A measurement is valid if it is

Conflict of interest and sources of funding statement

The authors declare that they have no conflict of interests. The study was self-funded by the authors and Academic Centre for Dentistry Amsterdam.
The study was self-funded by the authors and Academic Centre for Dentistry Amsterdam.

both accurate and precise (reproducible). In an effort to increase both the accuracy and the reproducibility of CEJ detection, different probe shapes have been used to increase tactility in finding the subtle demarcation indicative for the CEJ (Hug et al. 1983, Watts 1989, Reddy et al. 1997, Karpinia et al. 2004). However, no clear conclusion can be provided based on these studies with respect to the ''correct'' probe design that will improve the accuracy.

Because of the difficulties of identifying the CEJ in studies on disease progression or the effect of periodontal treatment on the attachment level, other landmarks were explored for a valid clinical attachment measurement. Osborn et al. (1990) introduced the Florida Disk Probe® (Florida Probe Company, Gainesville Florida, USA), where the occlusal surfaces or the incisal edge of the tooth serve as a reference for the clinical attachment level. The reproducibility of this model of the Florida Probe® was tested by Marks et al. (1991). They showed, comparing clinical attachment-level measurements from a stent with the Florida Probe® and the Florida Disk Probe®, that the latter probe was as reproducible in achieving (relative) clinical attachment-level measurements as the Florida Probe®. However, as discussed by the authors, when the occlusal surface or the incisal edge is restored in the course of the investigation, this reference for the relative attachment level is no longer valid. Pihlstrom et al. (1992) also studied the reproducibility of relative probing attachment-level measurements using a stent as a reference point. They concluded that stents increase the intra- and inter-examiner reproducibility. Stents are therefore useful in studies evaluating treatment modalities. However, for monitoring disease progression based on the attachment-level measurements in large epidemiological studies, the CEJ is the reference point of choice (Pihlstrom 1992). Furthermore, in order to evaluate clinically to what extent attachment loss is present, the CEJ must be used. Thus, a valid assessment of the CEJ is a prerequisite for proper estimation of the amount of periodontal breakdown. Therefore, the purpose of the present study was to test the accuracy and precision with which the CEJ can be assessed using three commercially available periodontal probes with different tip endings in both deciduous and permanent teeth.

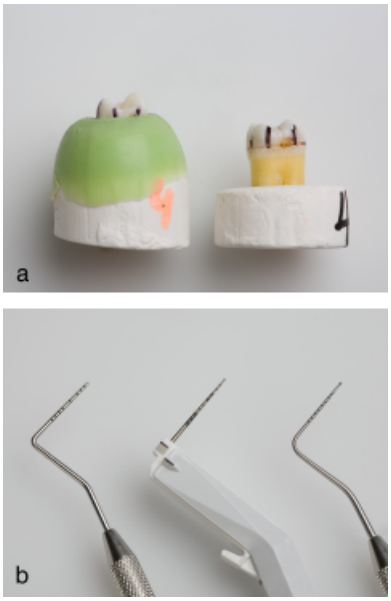

Fig. 1. (a) From left to right: 1) model with artificial gingiva for clinical assessments; 2) model without artificial gingiva for microscopic evaluation (b) From left to right: 1) Conventional manual probe Merritt-B (Hu-Friedy, Chicago, USA), 2) Vivacare TPS probe and 3) CPITN probe (WHO) Hu-Friedy, Chicago, USA).

Material and Methods

Experimental tooth models

For this study, 70 permanent (third molars excluded) and 30 deciduous extracted intact human teeth without restorations were selected. The group of permanent teeth included 10 incisors, five cuspids, 10 premolars and 10 molars of the upper and lower jaw, respectively. The group of deciduous teeth consisted of three upper incisors, four upper cuspids, 13 upper and 10 lower molars. After having been cleaned of debris and calculus, the teeth were individually mounted in plaster up to and including the apical 1/2 of the root. Next, an artificial gingiva was prepared of silicone rubber (Dublicil®, Komponente A,B/Spec., Dreve-Dentamid, Germany) covering the remaining part of the root and the cervical part of the crown up to half of the crown length, thus covering the complete CEJ (Fig. 1a).

Probes

Three commercially available probes were investigated for their ability to identify the subgingival CEJ:

(a) *Conventional manual probe Merritt-B (Hu-Friedy, Chicago, IL, USA)* (Fig. 1b): this tapered probe has a rounded tip with a diameter of 0.5 mm and Williams markings at 1 mm intervals from 1 to 3, 5 and 7 through 10 mm.
(b) *CPITN probe (WHO) (Hu-Friedy)*: the probe has a spherical ball-like tip with a diameter of 0.5 mm. The probe was modified to have markings at each millimetre from 3 to 10 mm. The small dimensions at the tip of the probe did not allow for markings at 1 and 2 mm (Fig. 1b).
(c) *Vivacare TPS probe (Vivadent)*: this probe is made of rigid metal and has a tip, which is designed as a hemisphere with a diameter of 0.5 mm. The transition to the 0.2 mm tapered shaft sharply cuts back circumferentially to create a defined equatorial rim. This design is supposed to improve the tactile sensation. Broad-banded black markings are present at a 3.0–5.0 and an 8.0–11.0 mm distance from this rim. Finer calibrations at 1 mm intervals are present to provide a more accurate reading. The probe has a standardized pressure feature to increase the accuracy of pocket depth assessments. For this study, which specifically looked at the CEJ, the force-controlled mechanism was locked (Fig. 1b).

Clinical assessment of the CEJ

Four experienced examiners (two periodontists and two dental hygienists) performed clinical measurements to detect the subgingival position of the CEJ in relation to the position of the artificial gingiva. Both the experimental permanent and the deciduous tooth models were randomly divided into three sets. In order to ensure that all examiners assessed the same site with the three different probes, the clinical measurements were performed in three sessions, with an interval of at least 1 week. Per examiner, in each session, one of the three probes was assigned to one of the sets of experimental tooth models. The order in which the four examiners used the three probes was randomized. The sets were scored in a fixed sequence throughout the three sessions.

Duplicate recordings were made in each session at a 60-min. interval at the distobuccal (DB), midbuccal (B), mesiobuccal (MB), distolingual (DL),

lingual (L) and mesiolingual (ML) sites. Positional error for the site and direction of probing was controlled by marking the location of these six sites with a distinct black vertical line made by a waterproof marker on the clinical crowns of the experimental teeth. The apical end of this vertical line stopped at the gingival margin (Fig. 1a). Each measurement was rounded off to the nearest millimetre. No attempts were made to blind the examiners to the probes because it was recognized that blinding, given the study design, would have been impossible.

Microscopic assessment of the CEJ

After all the clinical CEJ assessments had been completed, a microscopic assessment was performed as the true reference for the position of the CEJ. For the microscopic assessments, the apical end of the black vertical line as used for the clinical assessments served as the reference point for the position of the gingival margin (Fig. 1a). After the silicone rubber gingiva was removed (Fig. 1b), the distance between the CEJ and the apical end of the vertical marking, indicating the gingival margin, was determined using a stereomicroscope at $\times$ 80 magnification and a caliper with a electronic readout at all six marked sites. The measurements were rounded off to one-tenth of a millimetre.

Statistical analysis

The site was used as the unit of analysis for the CEJ measurements of the four examiners and the three different probes. The site was used in this way because measurements were performed on extracted teeth with a randomly moulded gingiva. Therefore, independence between sites at each tooth could be assumed. The repeated measures analysis was performed entering Probes, Examiners, and First/Second Measurement as within-subject factors and permanent/deciduous teeth as the between-subject factor. For the accuracy of the probes, the microscopic assessment served as the true reference. The same model of repeated measures analysis was used for analysing the difference with the microscopic measurement for each individual probing assessment.

Post hoc testing was performed for differences between the examiners. To test for systematic differences between sessions and per examiner, paired Student's *t*-tests were used. Intra-examiner paired assessments were also analysed by percentage of agreement. The Pearson correlation coefficient was used to test the inter-examiner paired readings. *p*-Values of <0.05 were considered as being statistically significant.

Results

In Table 1, the results are presented of the microscopic assessment and the duplicate clinical assessments of the distance from the CEJ to the gingival margin with the three probes at permanent and deciduous teeth. In permanent teeth, the microscopic measurements showed a mean distance of 2.58 mm. Owing to the orientation of the CEJ to the artificial gingiva, the distance between the gingival margin and the CEJ ranged between 0.9 and 4.6 mm. The latter was found at a buccal surface. Inter-proximally, the smallest distance was found between the gingival margin and the CEJ, i.e. 0.9 mm. The microscopic assessment in the deciduous teeth ranged from 1.2 to 4.9 mm, with a mean of 3.12 mm. The orientation of the CEJ to the artificial gingiva provided the smallest distance at the inter-proximal surface, i.e. 1.2 mm.

The clinical measurements performed at the permanent teeth with the three probes showed a comparable range, i.e. 0–5 mm. The mean assessment of the gingival margin to the CEJ ranged from 2.39 to 2.63 mm. With all three probes, the second assessment in the permanent teeth was significantly deeper, ranging from 0.05 to 0.09 mm, compared with the first assessment. The clinical measurements at the deciduous teeth with the Merritt-B probe ranged from 1 to 6 mm, from 1 to 5 mm for the CPITN probe and from 1 to 4 mm with the TPS probe. The differences between the first and the second measurement were small, ranging from 0.01 to 0.07 mm, more apical for the second measurement.

Intra-examiner reproducibility

For the intra-examiner reproducibility, the mean difference between the first and the second assessment of the distance from the CEJ to the gingival margin is presented by examiner for each of the three probes (Table 2). In permanent teeth, the difference varied between -0.18 and 0.04 mm with the Merritt-B probe, -0.24 and 0.08 mm for the CPITN probe and -0.13 and 0.10 mm for the TPS probe. Repeated measures analysis showed a significant effect of the examiners on the difference between the first and the second assessment. Post-testing showed that the estimation of the CEJ by examiner 3 was significantly deeper at the second assessment with all three probes, but amounted to 93% of agreement within $\pm$ 1 mm ($p<0.05$). Examiner 1 assessed the CEJ with the Merritt-B probe the second time more apically, but achieved 99% agreement with all the probes. The overall percentage of agreement for differences between the -1 and +1 mm was for the Merrit-B probe and the TPS probe 98%.

In deciduous teeth, the mean difference varied between -0.04 and 0.07 mm with the Merritt-B probe, -0.13 and 0.03 mm for the CPITN probe and -0.13 and 0.08 mm for the TPS probe (Table 2). The repeated measures analysis showed that examiners had a significant effect on the comparison of the first and the second assessment, except for the Merritt-B

Table 1. Descriptives: the mean microscopic distance (in mm) from the cemento-enamel junction (CEJ) to the gingival margin in permanent and deciduous teeth and the mean distance (in mm) of the first and the second assessment with the three probes (standard deviation in parenthesis)

	Microscope	Merritt-B	CPITN	TPS
Permanent teeth ($n = 420$ sites)				
Mean distance	2.58 (0.72)	2.63 (0.51)	2.47 (0.54)	2.39 (0.46)
1st assessment		2.58 (0.53)	2.44 (0.60)	2.36 (0.53)
2nd assessment		2.67 (0.55)	2.50 (0.55)	2.41 (0.47)
Overall significance*		$p<0.001$	$p<0.001$	$p<0.001$
Deciduous teeth ($n = 180$ sites)				
Mean distance	3.12 (0.63)	3.14 (0.45)	2.77 (0.37)	2.48 (0.37)
1st assessment		3.14 (0.49)	2.73 (0.40)	2.47 (0.42)
2nd assessment		3.13 (0.50)	2.80 (0.42)	2.50 (0.40)
Overall significance*		$p<0.001$	$p<0.001$	$p<0.001$

*Paired *T*-test for difference between the first and the second assessment with the three probes.

Table 2. Intra-examiner reproducibility: the mean difference (in mm) between the first and the second assessment of the distance from the cemento-enamel junction (CEJ) to the gingival margin presented by examiners with the three probes in permanent and deciduous teeth (standard deviation in parenthesis)

	Merritt-B	% agreement	CPITN	% agreement	TPS	% agreement
Permanent teeth						
Examiner 1	−0.06 (0.55)*	99	−0.01 (0.69)	99	−0.04 (0.56)	99
Examiner 2	−0.09 (0.87)*	91	0.08 (0.88)	98	−0.12 (0.75)*	96
Examiner 3	−0.18 (0.82)*	95	−0.24 (0.79)*	93	−0.13 (0.83)*	94
Examiner 4	0.04 (0.85)	93	−0.08 (0.91)	90	0.10 (0.84)*	92
Repeated measures†	*p<0.001*		*p<0.05*		*p<0.001*	
Overall % agreement		95		95		95
Deciduous teeth						
Examiner 1	−0.04 (0.54)	99	−0.11 (0.66)*	98	−0.09 (0.66)	98
Examiner 2	0.04 (0.74)	96	−0.13 (0.77)*	94	−0.13 (0.63)*	98
Examiner 3	0.07 (0.67)	97	−0.06 (0.69)	97	0.04 (0.66)	99
Examiner 4	−0.02 (0.59)	99	0.03 (0.74)	94	0.08 (0.77)	95
Repeated measures†	*NS*		*p<0.05*		*p<0.01*	
Overall % agreement		98		96		98

% agreement is expressed as the difference between the first and the second assessment within the range of −1 to +1 mm.

*Post-testing using the Student's *T*-test, significant differences between duplicate measurements ($p<0.05$).

†The overall effect of the examiner on the reproducibility of the duplicate measurement using the first and the second assessment. A negative value represents a deeper measurement in the second assessment.

Table 3. Inter-examiner reproducibility: the mean (in mm) of the duplicate estimations per examiner of the distance from the gingival margin to the cemento-enamel junction (CEJ) for each of the three probes in permanent and deciduous teeth (standard deviation in parentheses)

	Merritt-B	CPITN	TPS
Permanent teeth			
Examiner 1	3.15 (0.64)^{2,3,4}	3.00 (0.70)^{2,3,4}	2.73 (0.70)^{2,4}
Examiner 2	2.10 (0.75)^{1,3,4}	2.00 (0.77)^{1,3,4}	1.87 (0.63)^{1,3,4}
Examiner 3	2.50 (0.68)^{1,2,4}	2.33 (0.67)^{1,2,4}	2.66 (0.69)^{2,4}
Examiner 4	2.81 (0.63)^{1,2,3}	2.54 (0.68)^{1,2,3}	2.29 (0.54)^{1,2,3}
ANOVA	$p<0.001$	$p<0.001$	$p<0.001$
Deciduous			
Examiner 1	3.32 (0.53)^{3,4}	2.98 (0.46)^{2,3}	2.54 (0.49)^{2}
Examiner 2	3.42 (0.73)^{3,4}	2.78 (0.66)^{1,3,4}	2.34 (0.55)^{1,4}
Examiner 3	2.67 (0.57)^{1,2,4}	2.34 (0.54)^{1,2,4}	2.43 (0.60)^{4}
Examiner 4	3.13 (0.47)^{1,2,3}	2.98 (0.44)^{2,3}	2.62 (0.52)^{2,3}
ANOVA	$p<0.001$	$p<0.001$	$p<0.001$

Post hoc testing; superscript numbers indicate significant differences between examiners ($p<0.05$).

probe. Post-testing showed no significant difference between the two assessments for all examiners with the Merritt-B probe. With all three probes, examiners 3 and 4 gave the most reproducible results among the four examiners. The overall percentage of agreement for differences between −1 and +1 mm was for the Merritt-B probe and 98% for the TPS probe. The CPITN probe showed 96% agreement.

Inter-examiner reproducibility

All examiners assessed the same site in duplicate with the same probe. Based on the mean distance from the gingival margin to the CEJ for each of the three probes per examiner, the inter-examiner reproducibility was evaluated (Table 3). In both permanent and deciduous teeth, the examiner had a significant effect on the recorded location of the CEJ. In permanent teeth, the assessments of the CEJ by the four examiners ranged from 1.87 mm with the TPS probe by examiner 2 to 3.15 mm assessed by examiner 1 with the Merritt-B probe. In the deciduous teeth, examiner 2 with the TPS probe and examiner 3 with the CPITN probe gave the lowest mean value of 2.34 mm. The highest mean value of 3.24 mm was recorded by examiner 2 with the Merritt-B probe.

In permanent teeth, the inter-examiner correlations for the paired assessments with the Merritt-B probe of the four examiners ranged from 0.37 to 0.53 (Pearson's correlation). The CPITN probe showed a comparable correlation between the examiners, ranging from 0.36 to 0.52, and the correlation for the TPS probe ranged from 0.25 to 0.48. The inter-examiner correlations in the deciduous teeth with the Merritt-B probe were higher than those in permanent teeth, ranging from 0.40 to 0.60. The CPITN and the TPS showed lower correlation ranges (0.08–0.48 and 0.12–0.44, respectively).

Accuracy

To test the accuracy of the three probes, the mean difference between the microscopically assessed position of the CEJ and the mean clinical assessment of the CEJ relative to the gingival margin was calculated (Table 4). Based on repeated measures analysis, all probes differed in their assessment of the CEJ. In permanent teeth, the Merritt-B probe was the most accurate (−0.05 mm), showing no significant difference with the microscopic assessment. Both the CPITN probe and the TPS probe (0.11 and 0.19 mm, respectively) assessed the CEJ more coronally than the actual position.

In deciduous teeth, the Merritt-B probe was most accurate in relation to the microscopic assessment (−0.02 mm). Both the CPITN probe and the TPS probe stopped coronal of the CEJ (0.35 and 0.63 mm, respectively). Comparing the accuracy of the different probes between the permanent and the deciduous teeth, no significant difference was observed using the Merritt-B probe. In deciduous teeth, the CPITN probe and the TPS probe assessed the CEJ more coronally than the true position compared with the permanent teeth (0.35 *versus* 0.11 mm and 0.63 *versus* 0.19 mm, respectively.).

Figure 2a–c shows the accuracy of the three probes based on the frequency distributions of the difference between the microscopically assessed position of the CEJ and the mean CEJ assessment relative to the gingival margin. In permanent teeth, with the Merritt-B probe, 33% of the measurements corresponded with the microscopic assessment of the CEJ, while in 26%, the probe tip was 0.5 mm apical and in 18% 0.5 mm coronal of the CEJ. In all, 95% of the measurements were within the interval of −1 to +1 mm. In deciduous teeth,

Table 4. Accuracy: the mean difference (in mm) between the microscopic assessment and the mean measurement (in mm) of the location of cemento-enamel junction (CEJ) with the three probes, for each of the four examiners, in permanent and deciduous teeth (standard deviation in parentheses)

	Merritt-B	CPITN	TPS
Permanent teeth	−0.05 (0.68)^{c,t}	0.11 (0.59)^{*,m,t}	0.19 (0.58)^{*,m,c}
Examiner 1	−0.57 (0.67)*	−0.42 (0.67)*	−0.15 (0.63)*
Examiner 2	0.49 (0.85)*	0.58 (0.82)*	0.71 (0.73)*
Examiner 3	0.11 (0.88)*	0.24 (0.78)*	−0.07 (0.88)
Examiner 4	−0.23 (0.82)*	0.04 (0.73)	0.29 (0.68)*
Deciduous teeth	−0.02 (0.51)^{c,t}	0.35 (0.52)^{*,m,t}	0.63 (0.46)^{*,c,t}
Examiner 1	−0.20 (0.51)*	0.14 (0.55)*	0.57 (0.58)*
Examiner 2	−0.29 (0.67)*	0.34 (0.68)*	0.78 (0.55)*
Examiner 3	0.45 (0.75)*	0.78 (0.73)*	0.68 (0.68)*
Examiner 4	−0.02 (0.56)	0.14 (0.61)*	0.49 (0.61)*
Permanent versus deciduous	NS	$p<0.001^{\dagger}$	$p<0.001^{\dagger}$

*Paired *T*-test comparing the mean probe assessment with the microscopic assessment. A negative value represents a deeper probing measurement than the microscopic assessment.
^{m,c,t}ANOVA for differences between probes; significant differences between probes ($p<0.001$) (m, Merritt-B; c, CPITN; t, TPS).
†ANOVA comparing permanent teeth and deciduous teeth.

the Merritt-B corresponded in 41% of the measurements with the microscopically assessed position of the CEJ. In 99%, the difference was within the −1 to +1 mm interval.

The measurements with the CPITN probe in permanent teeth were in 36% in accordance with the microscopically assessed position of the CEJ. In 24%, the probe tip was 0.5 mm apical and in 21% 0.5 mm coronal to the CEJ. In all, 91% of the measurements were within the interval of −1 to +1 mm. In deciduous teeth, the CPITN probe corresponded in 29% of the measurements to the actual position of the CEJ. In 59%, the CEJ was estimated coronal of the CEJ.

The TPS probe assessments in permanent teeth corresponded exactly in 35% of the measurements with the actual position of the CEJ, while in 36%, the assessment was 1 mm coronal to the CEJ. In all, 93% of the measurements were within the interval of −1 to +1 mm. In deciduous teeth, the TPS probe corresponded in 41% of the measurements to the CEJ while in 37% the CEJ was estimated more coronally.

Discussion

The most important clinically detectable change during periodontal breakdown is loss of connective tissue attachment relative to its original location at the CEJ. The CEJ can serve as a fixed reference point but cannot be identified easily, especially when it is still covered by gingival tissue. Therefore, clinical evaluation of the accuracy of CEJ assessments has the impracticality of not being able to obtain the true value without extraction or a surgical intervention (Hug et al. 1983). In the literature, clinical studies claiming to test accuracy (Janssen et al. 1988, Karpinia et al. 2004) fail to do so. Based on the study design presented, without a true value, the data presented only represent the reproducibility of the methods tested. The ''in vitro'' study design of the present study provides an optimal situation for obtaining the true value and therefore testing the accuracy of the three probes used. Factors influencing the accurate estimation of the CEJ, such as the presence of calculus and restorations, were avoided by selecting teeth without restorations and by careful cleaning of the teeth.

Hug et al. (1983), estimating the CEJ, also showed, in both intra- and inter-examiner comparisons, a low reproducibility. The intra-examiner reproducibility of probing measurements from the stent to the gingival margin showed the highest reproducibility (Watts 1987). The stent to the CEJ showed the least reproducibility, with measurement errors within ±1 mm. Clark et al. (1987) compared the intra-examiner reproducibility for probing depth and attachment level when measuring from a custom occlusal stent or the CEJ. Increased reproducibility was observed with attachment-level measurements using the stent. The level of intra-examiner agreement for CEJ measurements was 72% within ±1 mm. Because of the limitations of a custom occlusal stent for epidemiological field studies, they stated that the traditional CEJ method seems to be the only possible option. In the present study, the intra-examiner reproducibility in assessing the CEJ in the permanent teeth was 95% for all probes within ±1 mm of difference. This result is comparable to Badersten et al. (1984). They showed an intra-examiner reproducibility of 90% within ±1 mm. Based on the data of the present study in the deciduous teeth using the Merritt-B probe, the intra-examiner reproducibility was even higher. In 98%, the assessments were between −1 and +1 mm and showed no significant differences between the four examiners using the Merritt-B probe. In all, the intra-examiner reproducibility in the present study is good and the Merritt-B probe performed best in the deciduous teeth.

Analysis of the inter-examiner reproducibility showed significant differences between all four examiners. This is also apparent from the Pearson correlation coefficients. In comparison, Clark et al. (1987) reported a Pearson correlation coefficient of 0.59 for the inter-examiner reproducibility between the 2 examiners when assessing the CEJ in a subgingival position. In the present study, the highest correlation in the permanent teeth was 0.53 between examiners 1 and 2. The lowest correlation was found for the TPS probe between examiners 3 and 4 (0.25). In the literature, no studies are available comparing the inter-examiner correlation in deciduous teeth. It is clear from these data that all examiners differed in assessing the CEJ, and the inter-examiner reproducibility is relatively poor.

When improving the accuracy and the reproducibility of CEJ probing measurements, one of the variables is the probe itself. In the literature, several designs have been used with one common feature, i.e. a distinct sharp edge at the probe tip for improved tactility. Compared with a conventional probe tip, the modified design by Hug et al. (1983) was not able to increase the accuracy, while Watts (1989) showed an improved reproducibility for the modified Cross calculus probe with an offset scale. Karpinia et al. (2004) and Preshaw et al. (1999) used a probe with, at the tip, a diameter of 1.25 mm for CEJ assessments. Despite showing reproducible measurements, the large diameter at the tip suggests limited subgingival

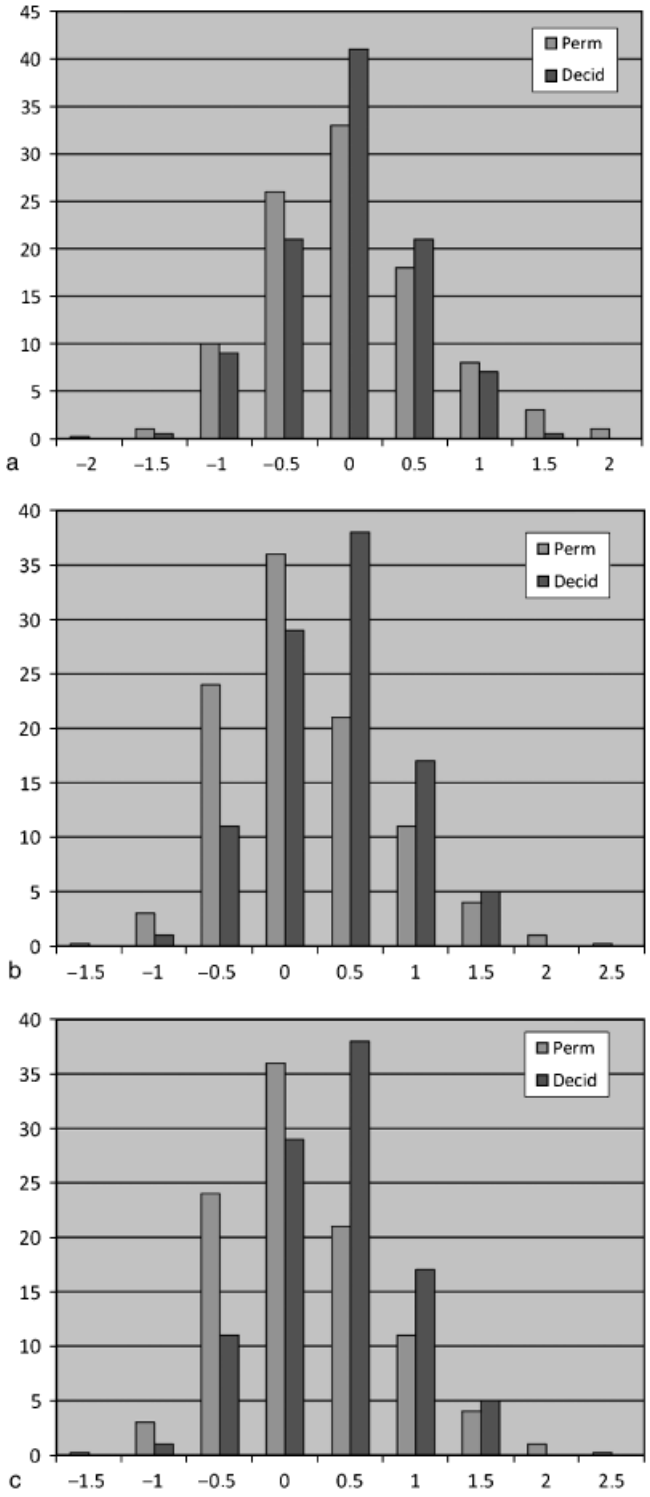

Fig. 2. (a–c) Frequency distribution of the difference between the cemento-enamel junction (CEJ) estimation with the Merritt-B probe as compared with the microscopic assessment with 0.5 mm increments in permanent and deciduous teeth.

access. The TPS probe used in the present study has a rim surrounding the side of the ball with a 0.5 mm diameter. The manufacturer claims that this aids in the detection of the CEJ (Mayfield et al. 1996). As the TPS probe, the spherical ball-like tip design of the WHO probe might also provide better tactility. In this study, the TPS probe and also the CPITN probe estimated the location of the CEJ on average more coronally. The conventional Merritt-B probe proved to be the most accurate in assessing the actual position of CEJ. The same difference in accuracy is observable in the deciduous teeth. Again, the TPS probe and the CPITN probe positioned the CEJ more coronally than the actual position. Based on the results of this study, we may conclude that the probes tested in this study, with a specific design suggested to improve the tactility, do not lead to more accurate measurements.

It can be speculated that, due to the enamel surface texture being close to the CEJ as described by Schroeder & Scherle (1988), assessment of the CEJ becomes difficult. The enamel of the permanent tooth surface close to the CEJ appears either smooth or micropitted, with perikymata running more or less parallel to the CEJ. Along the latter, nodules and patches of irregular size and form occur as well (Schroeder & Scherle 1988). The higher tactility of the TPS probe and the CPITN probe may have indicated the irregular surface texture to be the CEJ. The same phenomenon might be true for the deciduous teeth. Together with the surface texture, the globosity (Ceppi et al. 2006) may have induced more probing errors with the TPS probe and the CPITN probe.

Conclusions

The Merritt-B probe was found to provide the most accurate assessment of the subgingival location of the CEJ relative to the gingival margin in both permanent and deciduous teeth. The intra-examiner reproducibility was good in deciduous teeth with the Merritt-B probe. The inter-examiner reproducibility was relatively poor in both permanent and deciduous teeth. Examiners assessing the CEJ should be trained to perform repeated measurements to increase reproducibility for valid recordings.

Acknowledgements

The authors sincerely thank Esther Reijerse and Marion van Dijk for their help in performing the CEJ measurements.

References

Armitage, G. C., Svanberg, G. K. & Loë, H. (1977) Microscopic evaluation of clinical measurement of connective tissue attachment

levels. *Journal of Clinical Periodontology* **4**, 173–190.

Badersten, A., Nilveus, R. & Egelberg, J. (1984) Reproducibility of probing attachment level measurements. *Journal of Clinical Periodontology* **11**, 475–485.

Barendregt, D. S., Van der Velden, U., Reiker, J. & Loos, B. G. (1996) Clinical evaluation of tine shape of 3 periodontal probes using 2 probing forces. *Journal of Clinical Periodontology* **23**, 397–402.

Bulthuis, H. M., Barendregt, D. S., Timmerman, M. F., Loos, B. G. & Van der Velden, U. (1998) Probe penetration in relation to the connective tissue attachment level: influence of tine shape and probing force. *Journal of Clinical Periodontology* **25**, 417–423.

Ceppi, E., Dall'oca, S., Rimondini, L., Pilloni, A. & Polimeni, A. (2006) Cemento-enamel junction of deciduous teeth: SEM-morphology. *European Journal of Paediatric Dentistry* **7**, 131–134.

Clark, D. C., Chin Quee, T., Bergeron, M. J., Chan, E. C., Lautar-Lemay, C. & de Gruchy, K. (1987) Reliability of attachment level measurements using the cemento enamel junction and a plastic stent. *Journal of Periodontology* **58**, 115–118.

Fowler, C., Garrett, S., Crigger, M. & Egelberg, J. (1982) Histologic probe position in treated and untreated human periodontal tissues. *Journal of Clinical Periodontology* **9**, 373–385.

Glavind, L. & Loë, H. (1967) Errors in the clinical assessment of periodontal destruction. *Journal of Periodontal Research* **2**, 180–184.

Hassell, T. M., Germann, M. A. & Saxer, U. P. (1973) Periodontal probing: investigator discrepancies and correlations between probing force and recorded depth. *Helvetica Odontologica Acta* **17**, 38–42.

Hug, H. U., Van 't Hof, M. A., Spanauf, A. J. & Renggli, H. H. (1983) Validity of clinical assessments related to the cemento-enamel junction. *Journal of Dental Research* **62**, 825–829.

Janssen, P. T. M., Drayer, A., Faber, J. A. J. & Palenstein Helderman, W. H. (1988) Accuracy of repeated single versus averages of repeated duplicates of probing depth measurements. *Journal of Clinical Periodontology* **15**, 569–574.

Karpinia, K., Magnusson, I., Gibbs, C. & Yang, M. C. (2004) Accuracy of probing attachment levels using a CEJ probe versus traditional probes. *Journal of Clinical Periodontology* **31**, 173–176.

Marks, R. G., Low, S. B., Taylor, M., Baggs, R., Magnusson, I. & Clark, W. B. (1991) Reproducibility of attachment level measurements with two models of the Florida Probe. *Journal of Clinical Periodontology* **18**, 780–784.

Mayfield, L., Bratthall, G. & Attstrom, R. (1996) Periodontal probe precision using 4 different periodontal probes. *Journal of Clinical Periodontology* **23**, 76–82.

Mombelli, A., Muhle, T. & Frigg, R. (1992) Depth-force patterns of periodontal probing. Attachment-gain in relation to probing force. *Journal of Clinical Periodontology* **19**, 295–300.

Osborn, J., Stoltenberg, J., Huso, B., Aeppli, D. & Pihlstrom, B. (1990) Comparison of measurement variability using a standard and constant force periodontal probe. *Journal of Periodontology* **61**, 497–503.

Pihlstrom, B. L. (1992) Measurement of attachment level in clinical trials: probing methods. *Journal of Periodontology* **63**, 1072–1077.

Preshaw, P. M., Kupp, L., Hefti, A. F. & Mariotti, A. (1999) Measurement of clinical attachment levels using a constant-force periodontal probe modified to detect the cemento-enamel junction. *Journal of Clinical Periodontology* **26**, 434–440.

Reddy, M. S., Palcanis, K. G. & Geurs, N. C. (1997) A comparison of manual and controlled-force attachment-level measurements. *Journal of Clinical Periodontology* **24**, 920–926.

Schroeder, H. E. & Listgarten, M. A. (1997) The gingival tissues: the architecture of periodontal protection. *Periodontology 2000* **13**, 91–120.

Schroeder, H. E. & Scherle, W. F. (1988) Cemento-enamel junction – revisited. *Journal of Periodontal Research* **23**, 53–59.

Theil, E. M. & Heaney, T. G. (1991) The validity of periodontal probing as a method of measuring loss of attachment. *Journal of Clinical Periodontology* **18**, 648–653.

Van der Velden, U. (1979) Probing force and the relationship of the probe tip to the periodontal tissues. *Journal of Clinical Periodontology* **6**, 106–114.

Van der Velden, U. & Jansen, J. (1980) Probing force in relation to probe penetration into the periodontal tissues in dogs. A microscopic evaluation. *Journal of Clinical Periodontology* **7**, 325–327.

Watts, T. (1987) Constant force probing with and without a stent in untreated periodontal disease: the clinical reproducibility problem and possible sources of error. *Journal of Clinical Periodontology* **14**, 407–411.

Watts, T. L. (1989) Visual and tactile observational error: comparative probing reliability with recession and cemento enamel junction measurements. *Community Dentistry Oral Epidemiology* **17**, 310–312.

Watts, T. L. P., Beards, C. F., Ewing, P. D. & Leeman, S. (1995) Periodontal disease activity: development strategy for investigation by means of accurate 3-dimensional clinical assessment. *Journal of Clinical Periodontology* **22**, 201–207.

Address:
D. S. Barendregt
Department of Periodontology
Academic Centre for Dentistry Amsterdam
Amsterdam
The Netherlands
E-mail: dick.barendregt@dsbb.nl

Clinical Relevance

Scientific rationale for the study: The CEJ is the reference point of choice for evaluating CAL. Often, difficulties are experienced in accurately locating this anatomical landmark. It can be questioned whether the specific designs of commercially available periodontal probes improve the accuracy of subgingival CEJ assessment.

Principal findings: Increasing the tactility through the design of the TPS probe and CPITN probe did not lead to a more accurate subgingival assessment of the CEJ. The Merritt-B probe proved to be the most accurate in assessing the correct subgingival position of the CEJ in both permanent and deciduous teeth.

Practical implications: The use of the conventional Merritt-B probe offers the most accurate subgingival CEJ assessments when compared with the TPS probe and the CPITN probe.