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Review Article

Probing pressure, a highly undervalued unit of measure in periodontal probing: a systematic review on its effect on probing pocket depth

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Abstract

Aim: To investigate the influence of probing pressure on the probing pocket depth (PPD) in diseased and healthy periodontal tissue conditions through a systematic review. In addition, to facilitate comparison of the study outcomes, an attempt was made to provide a correction factor that compensates for the different probing pressures used.

Material and Methods: The MEDLINE-PubMed and Cochrane Central Register of controlled trails (Central) were searched up to June 2008 to indentify appropriate studies.

Results: The search yielded 3032 titles and abstracts. In total, five papers fulfilled the eligibility criteria. These studies provided data with probing pressures ranging from 51 to 995 N/cm^2. For the evaluation of the results a distribution was made between diseased and healthy/treated sites. The incremental change in PPD in healthy/treated sites decreased as the pressure increased above 398 N/cm^2. In diseased sites, this phenomenon was already present at pressures above 100 N/cm^2. At healthy/treated sites, a mean increase of PPD of 0.002 mm per increase of 1 N/cm^2 in probing pressure could be calculated whereas at diseased sites this value amounted to 0.004 mm.

Conclusion: The results show that with increasing probing pressure, the PPD increases. The dimensions of the increase are dependent on the periodontal tissue conditions.

Key words: periodontitis; probing force; probing pocket depth; probing pressure; systematic review

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Periodontitis is an inflammatory disease of the supporting tissues of the teeth resulting in the breakdown of the alveolar bone and connective tissue, causing loss of attachment and pathological pocket formation. The depth of this pocket is one of the most important aspects of the diagnosis and treatment of periodontitis. For more than a century, the periodontal probe has been used to assess the probing depth of periodontal pockets (Hefti 1997). J. M. Riggs, an American dentist was the first to describe the periodontal probe in the literature (Riggs 1882). Much later, in the 1920s, the periodontal probe appeared in Europe and was described by a German periodontist, Sachs (1929), using a thin 1.3-mm-wide steel blade. Over the years, several different probe designs have been developed, resulting in a tapered probe tine with a round tip (Ramfjord 1959). At present, this design is still the most popular probe type for a periodontal examination.

Periodontal probing should be accurate and technically simple (Hefti 1997). The current probing methods are subject

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to various errors. Among others, there appears to be a relationship between probing force and pocket penetration (Hassell et al. 1973, Van der Velden 1979, Mombelli et al. 1992). The degree of probe tip penetration into the pocket is also influenced by the presence of inflammation of the periodontal tissues (Armitage et al. 1977, Van der Velden 1980, Fowler et al. 1982, Bulthuis et al. 1998). Even with relatively high forces, the probe tip usually fails to reach the connective tissue attachment in healthy sites (Fowler et al. 1982). In inflamed sites the probe tip generally stops, already with minimal probing pressures, at the level of intact connective tissue fibres or may even penetrate beyond (Bulthuis et al. 1998). Also, the probe tine shape has an effect on the recorded pocket depth (Atassi et al. 1992, Barendregt et al. 1996). The probe tine should be small enough to fit into the periodontal pocket without trauma (Caton et al. 1981). When comparing different probe tine shapes with relatively low probing forces (Atassi et al. 1992, Barendregt et al. 1996) or higher probing forces (Barendregt et al. 1996), more shallow pockets were assessed with a tapered tine. This is most likely due to the tapered shape, that gradually meets more resistance when inserted into the periodontal pocket. Consequently, when evaluating the influence of probing force on the recorded probing pocket depth (PPD), the level of periodontal health and the probe tine diameter are aspects to be taken into account.

In order to be able to compare the results of probing studies using various amounts of probing force, the probe diameter should be taken into account in order to estimate the probing pressure at the tip of the probe. Many publications on clinical studies with PPDs as a parameter for evaluating treatment results fail to report sufficient data on the method used for probing. If studies report methodological aspects, the majority of studies report only the probing force or the dimensions of the conventional probe used. Instead of providing either one, they should report both because it is the pressure at the tip, a result of probing force and probe diameter, that eventually determines probe penetration.

The aim of the present study was to reiterate the influence of probing pressure on the PPD in diseased and healthy periodontal tissue conditions through a systematic review. In addition, to facilitate comparison of outcomes of studies using different probing pressures, an attempt was made to provide a correction factor (CF) that compensates for the probing pressure used.

Material and Methods

Focused question

When using a periodontal probe with a round tapered probe tine in periodontal pockets, what is the effect of different probing pressures on the recorded PPD?

Search strategy

Two internet sources of evidence were used to search for appropriate papers fulfilling the study purpose: The National Library of Medicine, Washington, DC (MEDLINE-PubMed), and the Cochrane Central Register of Controlled Trials (Central; Clinical Trials). The databases were searched up to and including June 2008 using the following terms for the search strategy:
Problem:
([text words] periodontal diseases OR periodontal disease OR
[MeSH terms/all subheadings] ''Periodontal Diseases'')
AND
Intervention:
([text words] periodontal pressure probe OR pressure-probe OR pressure probe OR probe-diameter OR probe diameter OR probing force OR probing-force OR probe-force OR probe force OR resistance to probing OR probe-penetration OR probe penetration OR probing resistance OR probing-pressure OR probing pressure OR periodontal-probing OR periodontal probing)
AND
Outcome:
([text words] Periodontal pocket OR periodontal pockets OR pockets OR gingival pocket OR gingival pockets OR probing depth OR probing-depth OR pocket depth OR pocket-depth OR probing-pocket-depth OR probing pocket depth OR
[MeSH terms/all subheadings] ''Periodontal Pocket'' OR ''Gingival Pocket'')

Screening and selection

The papers were screened independently by two reviewers (H. C. L. & D. S. B.). At first they were screened by title and abstract. Only papers written in the English language were accepted. Case reports, letters and narrative/historical reviews were not included in the search. Papers without abstracts whose title suggested that they were related to the objectives of this review were also selected so that the full text could be screened for eligibility. All reference lists of the selected studies were screened for additional papers. Any disagreement between the two reviewers was resolved after additional discussion. As a second step, after full text reading, papers were selected when they fulfilled the criteria of the study aim.

Eligibility criteria:

- Randomized-controlled trials (RCTs)
- Controlled clinical trials (CCTs)
- Conducted on human subjects
- Use of a tapered probe tine
- Pocket depth recordings with more than 1 probing force used at the same site

The following factors were recorded to investigate the heterogeneity of outcome across studies:

- Subjects
- Periodontal tissue condition
- Sites
- Probes
- Probing pressures
- Extent of probe penetration
- Methodological study quality assessment

The following parameters were investigated as proposed in the Cochrane Handbook of Systematic reviews (http// www.cochrane-handbook.org accessed on 18 December 2008):

(a) allocation concealment
(b) randomization
(c) blindness of the examiner or the patients and
(d) loss to follow-up

Data extraction & analyses

From the papers that met the criteria, data were processed for analysis by HCL, DSB & GAW. The mean PPD in relation to the probing force was extracted. In addition, the probe tip diameter was used to calculate the mean increase in PPD per increase in N/cm^2 probing pressure. Some of the studies provided standard errors (SE) of the mean. If possible, the standard deviations (SD) in these studies were calculated by the authors of the present

Table 1. Overview of the characteristics of the selected studies

Study number (#)	# Author(s) (year) Title	# Subjects/inclusion criteria	Intervention/comparison Study design	# of sites	Conclusion
#I	Bulthuis et al. (1998) (11) Probe penetration in relation to the connective tissue attachment level: influence of tine shape and probing force	22 Untreated severe periodontitis characterized bij moderate to deep pocketing. At least one of the teeth scheduled for extraction had to have severe attachment loss	Probing pocket depth assessment with four different probing forces with comparisons per site. Each probe tine was randomly assigned to a site. RCT	135	For optimal assessment of the attachment level in inflamed periodontal conditions, a tip with a diameter of 0.5 mm and exerting a probing force of 0.25 N may be most suitable
#II	Mombelli et al. (1997) (21) Comparison of periodontal and peri-implant probing by depth–force pattern analysis	11 Systemically and periodontally healthy subjects. In each subject one site, either mesial or distal, on a natural tooth was selected	Five probing forces were used in duplicate to compare tissue resistance in each selected site. CCT	11	With increasing probing force the depth reading increases when attaining probing pocket depth
#III	Barendregt et al. (1996) (12) Clinical evaluation of tine shape of three periodontal probes using two probing forces	12 Patient with moderate to severe periodontitis with a minimum of four teeth per quadrant: all received initial periodontal therapy before entering the study	Randomized duplicate (15 min. interval) probing pocket depth assessment with two different probing forces compared in the same site in three sessions RCT	413	Probing force is of significant importance for the recorded probing depth
#IV	Chamberlain et al. (1985) (18) Significance of probing force evaluation of healing following periodontal therapy	14 Periodontally involved patients demonstrating at least two separate proximal sites with radiographic intraosseous lesions and probing depth $\geqslant 6$ mm; applied treatment was an initial therapy	Pre- and post-treatment periodontal probing with three probing forces in all selected sites with comparison of probing pocket depth per site. CCT	25	Emphasizing the significance of using a known and standardized probing force for evaluation of results following periodontal therapy
#V	Caton et al. (1981) (14) Maintenance of healed periodontal pockets after a single episode of root planning	10 Chronic periodontitis patients with six or more inter-proximal pockets >3 mm. Treatment consisted out of initial periodontal therapy	Three different probing forces to monitor clinical characteristics before and after treatment over a period of 4, 8 and 16 weeks. CCT	128	Clinical changes in periodontal pockets within 1 month after a single period of subgingival root planing combined with improved oral hygiene can be maintained for an additional 3-month time period

RCT, randomized controlled trail; CCT, clinical controlled trail.

review based on the sample size. For a correct analysis the data were divided into diseased sites and healthy/treated sites. In order to compensate the influence of different probing pressures when comparing different study outcomes in either diseased or healthy/treated sites, a CF was computed according to the following formula:

$$\mathrm{CF} = \frac{w_1\bar{x}_1 + w_2\bar{x}_2 + \cdots + w_n\bar{x}_n}{w_1 + w_2 + \cdots + w_n}$$

In this formula is the weight of each study i.e. the number of sites and $\bar{x}_1 \ldots \bar{x}_n$ the mean increase in PPD per 1 N/cm^2 of each study.

Results

Search and selection results

The PubMed search yielded in 2983 papers and the Cochrane search yielded 857 papers. After extracting those papers that were present in both searches, 3032 papers remained to be screened. The screening of the titles and abstracts initially resulted in 13 full articles. A search of the reference lists of the selected studies resulted in one additional paper (Caton et al. 1981). After full-text reading, seven papers had to be excluded because no data on the relationship between probing force and probing depth were reported (Hassell et al. 1973, Abbas et al. 1982, Mombelli & Graf 1986, McCulloch et al. 1987, Sild et al. 1987, Karim et al. 1990, Mombelli et al. 1992). Two papers (Van der Velden 1979, 1980) had to be excluded because they reported data obtained

Table 2. Summary of selected study divided into diseased and healthy/treated sites; mean probing pocket depth (PPD) per probing force/pressure (mm) and standard deviation in parenthesis (if available); increase in PPD (mm) calculation for each increase in probing force in relation to the preceding probing force

Author study number (#)	Forces (*N*)	Diameter (mm)	Pressure* (N/cm^2)	PPD (diseased sites)	PPD increase*	PPD (healthy/ treated sites)	PPD increase*
Bulthuis et al. (1998) (# I)	0.10	0.50	51	2.80 (1.88)	–	–	–
	0.15		76	2.83 (1.81)	0.03	–	–
	0.20		102	3.11 (2.00)	0.28	–	–
	0.25		127	3.14 (2.02)	0.03	–	–
Mombelli et al. (1997) (# II)	0.25	0.40	199	–	–	3.41 (0.49)	–
	0.50		398	–	–	3.92 (0.64)	0.51
	0.75		597	–	–	4.08 (0.72)	0.16
	1.00		796	–	–	4.16 (0.71)	0.08
	1.25		995	–	–	4.21 (0.69)	0.05
Barendregt et al. (1996) (# III)	0.25	0.50	127	–	–	2.40 (1.20)*	–
	0.50		255	–	–	2.70 (1.40)*	0.3
Chamberlain et al. (1985) (# IV)	0.25	0.50	127	5.1 (1.4)	–	4.1 (1.3)	–
	0.50		255	6.1 (1.2)	1.0	4.7 (1.3)	0.6
	0.75		382	6.7 (1.0)	0.6	5.2 (1.3)	0.5
Caton et al. (1981) (# V)	0.15	0.35	155	3.06 (0.44)*	–	2.00 (0.41)*	–
	0.25		259	3.60 (0.51)*	0.54	2.36 (0.41)*	0.36
	0.50		520	3.99 (1.80)*	0.39	2.64 (0.47)*	0.28

*Calculated by the author.

with a parallel probe tine shape. The remaining five papers that fulfilled the selection criteria were processed for data extraction (Caton et al. 1981, Chamberlain et al. 1985, Barendregt et al. 1996, Mombelli et al. 1997, Bulthuis et al. 1998). From one selected study (Mombelli et al. 1997), the original mean data, as assessed around the teeth, were obtained from the author because the paper provided only descriptive data. Also, Barendregt et al. (1996) provided the original mean data, representing measurements with different probing pressures assessed at the same site.

Assessment of heterogeneity

Considerable heterogeneity was observed in the study design, characteristics and outcome variables i.e. selection criteria of the studies, number of subjects, number of sites, the number and magnitude of probing forces/pressures and probe tip diameter. Information regarding the study characteristics is shown in Tables 1 and 2.

Subjects and periodontal tissue condition

The subjects in the five selected studies included both male and female adults with diseased and healthy/treated periodontal tissues. The number of participants varied per study (range 10–22). As shown in Table 2, three studies included data of diseased tissues (Caton et al. 1981, Chamberlain et al. 1985, Bulthuis et al. 1998) while four studies provided data of healthy/treated sites (Caton et al. 1981, Chamberlain et al. 1985, Barendregt et al. 1996, Mombelli et al. 1997).

Sites

A large variation was present in the number of sites that were assessed, ranging from 11 (Mombelli et al. 1997) to 413 (Barendregt et al. 1996) sites.

Probes

All selected studies used probes with a force control or a probing force indicator. In three of the selected studies, a probe tip diameter at the tip of 0.5 mm was used (Chamberlain et al. 1985, Barendregt et al. 1996, Bulthuis et al. 1998). One study (Mombelli et al. 1997) used a probe tip with a diameter of 0.4 mm at the tip and an other study 0.35 mm (Caton et al. 1981).

Probing pressures

Barendregt et al. (1996) and Bulthuis et al. (1998) related their results to probing pressure. The remaining studies used presentation probing forces ranging from 0.10 to 1.25 N in their data. For the present review the probing pressure (N/cm^2) in these studies was calculated based on the probing force and the probe diameter. Over the five studies, the probing pressure ranged from 51 to 995 N/cm^2.

Extend of probe penetration

In the studies of Bulthuis et al. (1998) and Mombelli et al. (1997), an electronic pressure-sensitive probe was used. Bulthuis et al. (1998) used a system (Florida Probe®, Florida Probe Company, Gainesville, Florida. USA) with a precision of 0.1 mm while Mombelli assessed the extent of probe penetration with an accuracy of 0.5 mm. The system of Chamberlain et al. (1985) had calibrated markings on the probe at each millimere and recordings were made to the nearest 0.5 mm. Barendregt et al. (1996) and Caton et al. (1981) describe that they recorded the probing depth to the nearest whole millimtre when the present pressure was reached.

Study quality

Allocation concealment

Becuase of the study design of the selected studies, allocation concealment was not possible. Instead, two other design aspects were investigated: assessment of the inflammatory status of the included subjects and the study design features (Table 1).

Assessment of the inflammatory status

Bulthuis et al. (1998) evaluated the periodontal condition based on manual probing to assess the moderate to deep pocketing around the selected teeth. Mombelli et al. (1997) evaluated the periodontal health based on conventional probing and scored a plaque index (Silness & Löe 1964). Barendregt et al (1996) assessed the inflammatory status based on manual probing after the initial therapy. The sites used for this systematic review from Chamberlain et al. (1985) originated from the study of Renvert et al. (1985). They describe the selection of the sites evaluated as having $<15\%$ plaque, proximal intraosseous lesions and pocket probing depths $\geqslant 6$ mm after initial therapy by manual probing. Finally, Caton et al. (1981) selected patients referred for treatment of chronic periodontitis and evaluated the inflammatory status-based pocket depth and bleeding on probing by manual probing.

Study design

Mombelli et al. (1997) repeated all duplicate probing measurements within 1 week. The PPD assessments in the study of Barendregt et al. (1996) were obtained in three sessions with a 1-week interval. Per session, the assessments were repeated within 15 min. In the study of Chamberlain et al. (1985), the PPD was assessed before and 6 months after treatment. The before-treatment measurements were performed at least 6 months after oral hygiene instruction and root planing. Because they represented deep residual pockets (mean PPD >5.0 mm), they were eligible for this review as diseased sites. From the study of Chamberlain et al. (1985), only the data from the root planing group were used because this was also the treatment modality used in the study of Caton et al. (1981) and Barendregt et al. (1996). Caton et al. (1981) measured the PPD at baseline and 4, 8 and 16 weeks following root planing. For this review, the pocket assessment at baseline and the 16-week assessment were used.

Randomization

Barendregt et al. (1996) and Bulthuis et al. (1998) provided partial randomization in their RCTs. Barendregt et al. (1996) randomized the order of use of tine/force combinations over the patients and sessions. In the study of Bulthuis et al. (1998), the sites to be probed were randomly allocated to each probe tine. Neither study randomized for probing pressure. Additionally, in both studies, the method of randomization is unclear. In all selected studies, logically, the lowest probing pressure was used first when measuring the PPD.

Blinding of examiner or patients

In four of the five selected studies, it was recognized that blinding of the examiners was not possible due to the study design and the probes used. Only in the study of Bulthuis et al. (1998) was the examiner blind for all the recorded measurements due to the use of the Florida Probe®. Blinding of patients was not applicable because they were not actively involved in the study.

Loss to follow-up

In all studies none of the patients/sites were lost to follow-up during the experimental period.

Study outcomes

In Table 2 the results of the five selected studies are presented. The probing forces ranged from 0.10 N (Bulthuis et al. 1998) to 1.25 N (Mombelli et al. 1997), corresponding to probing pressures of 51 and 995 N/cm^2. The PPD in the diseased group ranged from 2.80 mm (Bulthuis et al. 1998) to 6.7 mm (Chamberlain et al. 1985) obtained with a 51 and a 382 N/cm^2 probing pressure, respectively. In the healthy/treated sites, the most shallow PPD was assessed in the study of Caton et al. (1981), which amounted to 2.00 mm, assessed with a probing pressure of 155 N/cm^2. Chamberlain et al. (1985) showed the deepest PPD measured with a probing pressure of 382 N/cm^2 (5.2 mm). Because the heterogeneity of the studies (probing pressure) no meta-analysis could be performed on the pooled data.

In all instances, a higher probing pressure resulted in an increase in PPD. When analysing the data from the study of Mombelli et al. (1997), in healthy sites, the incremental change in PPD decreases as the pressure increases above 398 N/cm^2. This phenomenon was also found in the studies of Caton et al. (1981) and Chamberlain et al. (1985) in both diseased and healthy/treated sites for pressures higher than 255 and 259 N/cm^2, respectively. With relatively low probing pressures in diseased conditions in the study of Bulthuis et al. (1998), the largest increment in PPD was found when the probing pressure increased from 76 to 102 N/cm^2.

In Tables 3a and b, the computations are presented of the CFs for both diseased and healthy/treated sites. This factor amounted, in diseased sites, to a mean PPD increase of 0.004 mm for each increase of 1 N/cm^2 in probing pressure. For healthy/treated sites, the CF was 0.002 mm (Table 3b).

Table 3a. Calculation of the correction factor in diseased sites; mean increase in probing pocket depth per 1 N/cm^2 as result of mean increase of probing pocket depth (PPD) and probing pressure relative to the lowest probing pressure and corresponding PPD

Author Study number (#)	Increase			Weight (w_n) (# sites)	$w_n\bar{x}_n$
	pressure (N/cm^2)	PPD (mm)	PPD per 1 N/cm^2		
Bulthuis et al. (1998) (# I)	25	0.03	0.0012		
	51	0.31	0.006		
	76	0.33	0.004		
		Mean ($\bar{x}_I$)	*0.0037*	*x* 135 (w_I)	= 0.50
Chamberlain et al. (1985) (# IV)	128	1.0	0.008		
	255	1.6	0.006		
		Mean ($\bar{x}_{IV}$)	*0.007*	*x* 25 (w_{IV})	= 0.18
Caton et al. (1981) (# V)	104	0.54	0.005		
	365	0.93	0.0025		
		Mean ($\bar{x}_V$)	*0.0038*	*x* 128 (w_V)	= 0.48
				$\sum w_n\bar{x}_n$	2.0
Correction factor	$\bar{x} =$	$\frac{\sum w_n\bar{x}_n}{w_n}$	$\frac{2.0}{288}$	*0.004*	

The italic is used since these data are the mean data with which the weight is calculated.

Table 3b. Calculation of the correction factor in healthy/treated sites; mean increase in probing pocket depth per 1 N/cm^2 as result of mean increase of probing pocket depth (PPD) and probing pressure relative to the lowest probing pressure and corresponding PPD

Author Study number (#)	Increase			Weight (w_n) (# sites)	$w_n\bar{x}_n$
	Pressure (N/cm^2)	PPD (mm)	PPD per 1 N/cm^2		
Mombelli et al. (1997) (# II)	199	0.51	0.0025		
	389	0.67	0.0017		
	579	0.75	0.0012		
	796	0.80	0.001		
		Mean ($\bar{x}_{II}$)	0.0012	*x* 11 (w_{II})	= 0.013
Barendregt et al. (1996) (# III)	128	0.3	0.002		
		Mean ($\bar{x}_{III}$)	0.002	*x* 413 (w_{III})	= 0.826
Chamberlain et al. (1985) (# IV)	128	0.6	0.005		
	255	1.1	0.004		
		Mean ($\bar{x}_{IV}$)	*0.0045*	*x* 25 (w_{IV})	= 0.113
Caton et al. (1981) (# V)	104	0.36	0.003		
	365	0.64	0.0017		
		Mean ($\bar{x}_V$)	0.002	*x* 128 (w_V)	= 0.30
				$\sum w_n\bar{x}_n$	1.253
Correction factor	$\bar{x} =$	$\frac{\sum w_n\bar{x}_n}{w_n}$	$\frac{1.253}{577}$	*0.002*	

Discussion

The goals of periodontology can be defined in terms of keeping teeth for life, maintaining function, preventing and eliminating pain and discomfort. This can be achieved by aiming for an optimal healthy periodontium that is characterized by the presence of shallow pockets and the absence of inflammation (Van der Velden & Jansen 1981). The periodontal probe is an important tool for the clinical assessment of the periodontal status, diagnosis and treatment planning. To be able to enter the pocket with a periodontal probe, a certain force is needed to overcome the resistance (tonus) of the gingival tissues; not only the force applied but also the dimensions of the probe tip should be considered (Garnick & Silverstein 2000).

Probing force as such has been recognized as an important factor in measuring PPD but little attention has been paid to the issue of probing pressure. Already in 1950 Miller stated the importance of pressure when probing: ''Gentle pressure against the epithelial attachment with the probe passed into the gingival sulcus, or a periodontal pocket, meets with springy resistance of the epithelial attachment''(Miller 1950). In the early 1970s, the term pressure was used by Gabathuler & Hassell (1971) in the title of their publication: ''A pressure-sensitive periodontal probe'', but the paper included only probing force data. Two years later, Hassell et al. (1973) first calculated and published ''light hand pressures'' as proposed by Waerhaug (1952) and Gabathuler & Hassell (1971) which amounted to 20 and 70 ponds/mm^2, respectively. Also, in an attempt to standardize the probing force, Van der Velden & De Vries (1978) introduced ''The pressure probe'' but they also did not use probing pressures to present their data. Other studies during the same time period, dealing with the issue of pocket probing with a force-controlled probe, all mention the probing force and probe diameter without translating this to probing pressure (Armitage et al. 1977, Spray et al. 1978, Robinson & Vitek 1979, Van der Velden 1979, Polson et al. 1980, Hancock & Wirthlin 1981, Fowler et al. 1982). It was not until 1982 that the study results were compared based on probing pressure (Van der Velden 1982). After this publication, numerous studies evaluating the different ''constant-force'' probes for the accuracy and reproducibility still preferred presenting the data in relation to probing force. Some authors acknowledged the importance of the use of probing pressure. Garnick et al. (1989), in a study to evaluate the effect of inflammation and pressure on probe displacement in beagle dog gingivitis, reported four different probing pressures (in N/cm^2 or kPa). In a study of Lang et al. (1991), the title included the term probing pressure but provided only probing force-related data. At the end of their discussion, however, the conclusion was related to probing pressure. Later study results based on probing pressures were presented on the influence of probe tine when assessing PPD (Barendregt et al. 1996). In general, probing force still remained the preferred way for interpretation of study outcomes. Some authors, however, did use probing pressures as a unit of measure. For instance, with the introduction of a new probe design in 2004, proper probing pressure data were presented and discussed in support of the proposed probe design (Vartoukian et al. 2004). Nevertheless, in a recent study on the probe penetration in periodontal and peri-implant tissues in dogs, only probing force and tip diameter were reported (Abrahamsson & Soldini 2006). Therefore, it is reasonable to conclude that the aspect of probing pressure has been greatly undervalued.

A probing pressure is a product of the probing force (N) relative to the tip diameter (mm). The pressure exerted by the probe is directly proportional to the force on the probe and inversely proportional to the surface area at the probe tip (Garnick & Silverstein 2000). Because the surface area of a round probe is determined by πr^2, with r, being the *radius* of the tip, a reduction in the probe diameter will increase the pressure by a proportional amount, that is squared. Therefore, a change in tip diameter has a more profound effect on the pressure than the actual force exerted on the probe (Aguero et al. 1995). For example, if a force of 0.50 N is used on a probe with a diameter of 1 mm, the pressure on the tip of the tine will be 64 N/cm^2. Using the same force on a tip with a diameter of 0.5 mm the pressure will be 255 N/cm^2. Van der Velden (1979) found that with a probing force of 0.75 N in treated residual deep periodontal pockets the probe tip is located at the attachment level. These results were obtained with a probe diameter of 0.63 mm (241 N/cm^2). Using the same probing force other authors (Armitage et al. 1977, Spray et al. 1978, Robinson & Vitek 1979) observed penetration into the connective tissue. However, they used a probe diameter of 0.35 mm. This tip and force combination delivers a probing pressure at the tip of 780 N/cm^2, which explains the difference between the studies.

Because of the fact that in various studies different amounts of probing pressure are used, comparison of for example treatment results becomes difficult. For instance, Badersten et al. (1984), when evaluating the effect of non-surgical periodontal therapy, performed their measurements with a probing force of 0.75 N with a tip diameter of 0.5 mm which amounts to a probing pressure of 382 N/cm^2. The results showed a mean overall PPD of 3.8 mm 12 months after treatment with hand instruments (Badersten et al. 1984). In the study of Kaldahl et al. (1988) a probing force of 0.5 N and a tip diameter of 0.35 mm (519 N/cm^2) was used when testing the effect of four treatment modalities. The mean PPD in sites treated within the non-surgical periodontal therapy modality was 4.26 mm after 12 months (Kaldahl et al. 1988). In order to be able to compare the probing depth after treatment of the two studies, the probing pressure of the Badersten study should be adopted to the level that was used in the Kaldahl study with a corresponding mean PPD increase. This can be achieved using the CF of 0.002 mm increase per 1 N/cm^2 for healthy/treated sites. Thus, the discrepancy of 137 N/cm^2 between the pressures used in the two studies times 0.002 is 0.27 mm. Therefore, if in the Badersten study the same probing pressure was used as in the Kaldahl study, the probing depth would have been 4.07 mm. This probing depth value appears to be in closer range of the 4.26 mm as presented by Kaldahl et al. (1988).

It has been described that with increasing probing force i.e. probing pressure, the recorded probing depth will increase (Robinson & Vitek 1979, Van der Velden 1979, Barendregt et al. 1996), an observation supported by the outcome of this review. Histologic locations of the probe tip considered to be the most relevant in periodontal diagnostics are the base of the periodontal pocket and the most coronal connective tissue attachment (Aguero et al. 1995). Based on the results of the study of Bulthuis et al. (1998) in diseased sites, the tapered probe (tip diameter 0.5 mm) with a 0.25 N force was on average located at this level. In healthy/treated sites in humans, even pressures up to 400 N/cm^2 left the probe tip coronal to this landmark by a mean of 0.73 mm (Fowler et al. 1982). One has to bear in mind therefore that in a number of cases, an over – or underestimation of the true attachment level will still occur when assessing the PPD (Listgarten 1980, Kalkwarf et al. 1986). A high probing pressure is deliberately used in bone sounding to determine the actual alveolar bone level in relation to the location of the gingival margin or the cemento-enamel junction. The tip of the probe is pushed through the supra-alveolar connective tissue to make contact with the bone (Lindhe et al. 2003). This implies that with a certain probing pressure, the increase of probing depth may be physically limited by the alveolar crest. This may explain why with pressures of more than 796 N/cm^2, the increase in PPD is smaller as compared with pressures of 76–597 N/cm^2 probing pressure (Table 2). On the other hand, if too gentle probing forces are applied, the probe tip may not enter the orifice of the pocket (Bulthuis et al. 1998, Barendregt et al. 2006). This could explain why almost no difference in PPD is observed with the very low pressures between 51 and 76 N/cm^2.

Periodontal probing registers resistance of the tissue to the pressure applied by the probe. The greater the pressure, the greater the advancement of the probe into the tissues (Table 2). However, the advancement depends on the resistance of the tissue at the site being measured (Garnick & Silverstein 2000). With a specific pressure, the probe will proceed until a reaction pressure develops from deformation of tissues (Aguero et al. 1995). Tissue pressure that resists probe displacement depends on the tissue morphology including loss of connective tissue attachment and the severity of tissue inflammation. Accordingly, this tissue pressure will vary (Aguero et al. 1995). With treatment, inflammation is reduced and/or tissue attachment is increased, the resistance to probing pressure is increased and the displacement of the probe will be less. The difference in probing depth therefore reflects a reduction of inflammation and the response to treatment (Garnick & Silverstein 2000). Based on the results presented in Tables 3a and b, a clear difference between diseased and healthy/treated tissue is apparent with respect to increase of probing depth. The increase in PPD in relation to pressure increase (N/cm^2) is approximately twice as high in diseased sites.

Conclusion

The results of the present review show that with increasing probing pressure, the PPD increases. The dimensions of the increase are dependent on the periodontal tissue conditions. PPD showed a mean increase of 0.004 mm per increase of 1 N/cm^2 at diseased sites and 0.002 mm at healthy/treated sites. Both can be used as a CF for the comparison of outcomes of studies that have used different probing pressures.

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Clinical Relevance

Scientific rationale for the study: Many factors such as probing force, tip diameter/shape and periodontal health influence probing pocket measurements. Of the aforementioned factors, the probing force seems to be most important. The majority of studies report only probing force while it is the pressure at the tip, the resultant of probing force and probe diameter, that eventually determines probe penetration. Therefore, in a systematic review on the influence of probing pressure on the probing pocket measurements (PPD), an attempt was made to obtain a correction factor (CF) for comparing data obtained with different probing pressures.

Principal findings: The probing pressures in the selected studies, all using tapered probe tines, ranged from extremely low to very high i.e. 51–995 N/cm^2. PPD increased with increasing probing pressure in both diseased and healthy/treated sites. The CF compensating for the influence of the used probing pressure used at healthy/treated sites amounted to 0.002 mm per increase of 1 N/cm^2 in probing pressure whereas at diseased sites this was 0.004 mm.

Practical implications: For a better comparison of the study outcomes obtained with different probing pressures, the CF presented in this study represents a viable tool.