It is generally accepted that in order to be able to deliver optimal treatment a proper diagnosis is a prerequisite. Without this, no effective treatment can be provided for the illness (Hippocrates 460 BC-377 BC). In this respect periodontal diseases are no exception. Although early descriptions of periodontal diseases were only observational in nature, already in 1882 the American dentist Riggs was the first to describe the periodontal probe as a tool in the diagnosis of periodontal diseases (Riggs 1882). Much later, in 1915 Black stated that a flat periodontal probe, 15 mm long with markings every mm, should be used for the examination of clinical pockets present in periodontal diseases as well as during periodontal surgery (Black 1915). In the 1920s, Simonton (1925) described the design of a new instrument to measure pocket depth, which he called the University of California periodontometer. A few years later the periodontal probe appeared in Europe and was described by the German periodontist Sachs (1929) as a thin 1.3 mm wide steel blade. In 1931 Merritt, the designer of a popular clinical probe stated that “no examination of the mouth can be regarded as complete, that does not include the exploration of the gingival crevice ...”. Williams introduced in 1943 in his publication on “Rationalisation of Periodontal Pocket Therapy” a probe design that is still used today in periodontal practice. This rod-shaped probe with a diameter of 1.0 mm was, in contrast to the probe Merrit, calibrated and showed mm markings from 1 to 10 mm without markings at 4 and 6 mm. This to facilitate the reading of shallow pockets (1-3mm) and medium pockets (about 5 mm) and deep pockets (7mm and more) (Williams 1943). Modifications of Williams’ probe were described by many authors. The best known examples are probably the probes of Goldman-Fox, Nabers, Dellich, Cross and Gilmore. In the late 1950s, Goldman et al., Orban et al., and Glickman (1958) supported in their textbooks on periodontal disease the use of the Williams probe, being “a tapered rod-like blade which has a blunt rounded tip”. This probe design, also used by Ramfjord (1959) when he developed indices for the prevalence and incidence of periodontal disease, is at present still the most popular probe type for periodontal examination.

Structure of the periodontal tissues

One important question concerning periodontal probing has been what the recording with a periodontal probe actually reflects. Schroeder et al. (1971) suggested that periodontal probing does not record the depth of the anatomic sulcus or pocket. They pointed out that probing may result in tissue penetration by
the probe with consequent overestimation of the actual sulcus or pocket depth. The true description of the periodontal pocket has been a point of discussion for a long time. It was believed that the capillary space between the gingival epithelium and the enamel extended to the cemento-enamel junction from the time the tooth had erupted into the oral cavity (Black 1915). This concept was rejected by Gottlieb (1921), who found microscopic evidence for existence of an organic connection of gingival epithelium to the enamel surface, which he called "epithelansatz" (epithelial attachment). Thus, in periodontal health, only a shallow sulcus existed close to the free border of the gingiva. Gottlieb's theory was challenged, when Waerhaug published his monograph "The gingival pocket" (1952), in which he reintroduced Black's concept of 1915 and denied the existence of an epithelial attachment. In his experiments, with inserted steel blades and plastic strips, he claimed to observe that the bottom of the sulcus was situated consistently at the cemento-enamel junction. Therefore he concluded that all epithelium belongs to the lining of the clinical pocket, and that the gingiva was forming an adherent epithelial cuff. These challenging statements by Waerhaug caused a reaction resulting in a series of studies, which refute the results of his experiments (Orban et al. 1958, Stern 1962). These studies showed that the gingival epithelium apical to the sulcus is, in fact attached to the enamel surface. Of great importance for our current knowledge has been the major work by Schroeder & Listgarten (1971). With help of Electron Microscopic techniques they revealed that in humans the epithelium apical to the sulcus is connected to both the tooth surface and the gingival lamina propria by a basal lamina and hemidesmosomes. They called this structure the junctional epithelium. This part of the epithelium is composed of nonkeratinizing cells with their long axis oriented parallel to the tooth surface. The dentogingival junction appears to be stronger than the intercellular attachment of the epithelium. Insertion of probes in a periodontal pocket causes penetration within the junctional epithelium, leaving the innermost epithelial cells attached to the tooth surface. They reported that in nearly all specimens epithelium was present between the probe tip and connective tissue.

In all, a healthy intact periodontal complex is described as the gingiva being composed of a dense lamina propria which is covered on the oral side by the gingival oral epithelium, a stratified, squamous, keratinizing epithelium which extends from the mucogingival junction to the gingival margin. This epithelium continues as the gingival sulcular epithelium, which lines the lateral wall of the shallow gingival sulcus and overlaps the coronal portion of the junctional epithelium. The latter is sandwiched between the tooth surface and the gingival lamina propria. Just apical to the last cell of the junctional epithelium immediately at the cemento-enamel junction the first anchoring connective tissue fibers are present. Thus
the bottom of a sulcus is situated at the most coronal level of the epithelial attachment and the bottom of the pocket at the most coronal level of the connective tissue attachment. Listgarten (1972) also stated that it is better to distinguish between clinical and histological sulcus depth. To minimize confusion it is easier to reserve the term sulcus for histological and pocket for clinical measurements (van der Velden 1979).

**Parameters influencing periodontal probing**

Probing assessment of a pocket depth is influenced by several variables, one of which is manual dexterity and tactility of the examiner performing the measurements. Variables such as site and angle of insertion (Tibbets 1969; Listgarten 1980; Isidor et al. 1984; Watts 1989), accuracy of reading the millimeter markings (Magnusson et al. 1988) are also factors mainly determined by the examiner. Other factors are patient cooperation and anatomical variations of the site examined; for example root curvature, malpositioned teeth, furcation sites (Moriaty et al. 1988, 1989), remaining calculus and overhanging restorations. Listgarten (1972) indicated that the extent of tissue penetration of a periodontal probe may be related to a variety of factors such as probing pressure applied, thickness of the probe, contour of the tooth surface and the degree of inflammatory cell infiltration with accompanying loss of collagen fibers.

**Probing force**

Studies investigating the probing forces used during periodontal probing have shown that a wide range of forces are applied by clinicians. Clinicians exerted between 0.05 to 1.35 N, with a tendency to apply lighter forces in the anterior and higher forces in the posterior region of the mouth. Also different probing forces are used at different sites around teeth, i.e. the lightest force at the mid-facial aspect, followed by mesial and heaviest force on distal aspects (Gabathuler & Hassell 1971, Hassell et al. 1973 & Freed et al. 1983). In attempts to minimize the influence of the variations in probing force, several constant force probes have been devised. Armitage et al. (1977) developed a coiled spring pressure probe, which could apply forces between 0.15 N and 0.35 N and was based on a Michigan probe No. 1 with a diameter at the tip of 0.35 mm. Because of the bulkiness of the design of this probe system, only measurements in the anterior region of the mouth were possible. Vitek et al. (1979) failed in an attempt to improve this probe and subsequently
constructed a new constant force probe. It consisted of a leaf spring controlled periodontal probe, capable of delivering constant, unidirectional forces to a tip over a range of adjustable loads. Tromp et al. (1978) attached a constant force torque spring (0.15 N) wound on two cylinders in reversing winding mode, in between the probe tine and the handle of an ordinary metal periodontal probe. The first commercially developed force controlled periodontal probe was introduced by Polson et al. (1980). First named the “Electronic pressure-sensitive periodontal probe” and later published as the Vine Valley Probe (Vine Valley Research, Middlesex, New York) consisted of 2 parts: a hand piece having the size and shape of a large fountain pen, and a small electronic control box having a knob for pre-setting the desired probing force. Through increasing the current passing through the electromagnetic coil in the hand piece, the force needed to open an air gap in the hand piece when probing, also increased. As the preset force was reached an audible indicator “beep” was heard. This electronic pressure probe made probing possible with a constant force at any level between 0.10 N and 1.00 N. The probe had a tip diameter of 0.35 mm (Polson et al. 1980). Simons et al. (1987) introduced a commercially version of the probe of Tromp et al. (1978), the Brodonic®. It is a hinged constant force probe with the coiled spring in the hand-piece of the probe. The probing force can be changed through adjusting the coiled spring and is attained when the handle is tilted as far as the hinge opens. A possible disadvantage is the need to rotate the handle during measurements to keep the probe aligned parallel to the tooth axis. A variation on this simple design was proposed by Hunter (1994). The Hunter Probe® and later named the Vivacare TPS Probe® has a rigid metal tip which is designed as a hemisphere with a diameter of 0.5 mm with a special spring mechanism which controls the probing pressure. It was compared for its precision with a manual probe (Mayfield et al. 1996). The manual probe proved in this study to be more reproducible. As possible explanation might be variation in force delivery to the probe tip. Bergenholtz et al. (2000) showed a significant difference in force delivery over 12 tips with a range of 0.84N. A periodontal probe based on another principle was developed by Van der Velden and de Vries (1978). This probe consisted of a cylinder and piston (diameter 0.63 mm) assembly connected to a variable air pressure system. The probing depth could first be read on a millimeter scale within the probe handle and later recorded by a digital voltage meter (Van der Velden 1980). The advantage of this setup was that a wide range of probing pressures could be exerted and the absence of visual recordings. Another automated periodontal probe was introduced by Gibbs et al. (1988). This instrument, the Florida probe®, is equipped with a probe (diameter 0.40 mm) which runs through a sleeve and during the probing depth
measurements the sleeve is placed at the gingival margin. The probe tip is connected to a movable arm, which transfers the movement of the probe tip to a displacement transducer with digital readout. The data are then transferred automatically to the computer when a foot switch is pressed. At present the Florida Probe®, Vivacare TPS probe® and the Hawe Neos Click-Probe® are the only commercially available pressure probes for use in daily practice. The Click-Probe® is mainly used for probing around implants with a plastic tip (diameter 0.45mm) and has a force delivery system through a magnet which will disconnect when a probing force is used of 0.20N.

**Probing in periodontal health and disease**

With the introduction of constant force probes, it has become possible to evaluate at which probing force the measurement most accurately assesses the bottom of the histological pocket i.e. the most coronal connective tissue attachment. To clarify relationships between probe tip and connective tissue attachment levels, a great number of investigations have been performed. In order to be able to compare the results of various studies on this topic, it is necessary to convert the large variation of probing forces and probe tip diameters into “probing pressure”. This is the probing force per surface area at the tip of the probe and can be described in N/cm$^2$ or kPa (1 kPa = 0.1 N/cm$^2$).

Armitage et al. (1977), in an experiment carried out on beagle dogs, tested clinically healthy sites, inflamed sites after experimental gingivitis and sites exhibiting periodontitis. Methyl metacrylate probes with a diameter of 0.35 mm were inserted with a force of 0.25 N, i.e. a probing pressure of 2210 kPa. The probe tip was luted to the tooth and block sections processed for histology. Results indicated that the relationship of the probe tip to the most apical extension of the junctional epithelium varied. This depended on the degree of inflammation of the gingival tissues. In gingival health, the probe consistently reached a point coronal to the apical termination of the junctional epithelium at the cemento enamel junction by approximately 0.4 mm. In experimental gingivitis specimens, the probe tip fell short of the CEJ by 0.1 mm. At the periodontitis sites the probe tip passed beyond the apical termination of the junctional epithelium by a mean distance of 0.25 mm. The observations were the first to demonstrate a relationship between the degree of inflammation and the level of probe penetration. Later histological observations confirmed the findings of Armitage et al. (1977). No probe penetration beyond the apical termination of the junctional epithelium was observed in periodontally healthy monkey teeth (Hancock et al. 1981).
Polson et al. (1980) confirmed in humans, that in clinically healthy sites the probe tip is always located coronal to the apical end of the junctional epithelium.

In gingivitis the apical termination of the junctional epithelium is still at the CEJ whereas the location of the gingival margin may be 1-5 mm coronal of the CEJ. In case of minor gingivitis (Gingival Index score 1, Löe & Silness 1963), the inflammatory infiltrate is restricted to the coronal portion of the gingival tissues. In presence of severe gingivitis (GI=3) the location of the inflammatory infiltrate may include the whole gingival or only the coronal part of the gingival dependent on the height of the gingiva in question. Using probing pressures of 1650 - 2600 kPa, histological studies have shown that only in the presence of an inflammatory infiltrate extending to the apical termination of the junctional epithelium the probe tip may be located apical from the CEJ. In the presence of mild gingivitis or severe gingivitis in the coronal part of the gingiva, the probe tip will stop coronal from the CEJ (Caton et al. 1981, Anderson et al. 1991).

Therefore, due to the specific location of the inflamed connective tissue in relation to the probe tip, the probing technique used in gingivitis may be a critical factor.

In untreated periodontitis the inflammatory infiltrate is always located on the inner side of the pocket wall as well as apical from the apical termination of the junctional epithelium. In both treated and non-treated sites Van der Velden & Jansen (1981), using six different probing pressures (480, 800, 1600, 2400, 3220 and 4020 kPa), found in beagle dogs that with increasing probing pressures, the location of the probe tips changed from a position coronal to the attachment level to a position apical to the attachment level. When using probing pressures of 1600 kPa and less, the tips appeared to end more apically than in the relatively healthy sites. When pressures greater than 2400 kPa were used, in both groups, the tips ended always apical to the connective tissue attachment through compression of the connective tissue. Using a probing pressure of 2680 kPa Garnick et al. (1980) determined in humans the position of the tip of the periodontal probe in an inflamed situation and 1 week after scaling. In the inflamed tissues the tip extended to the base of the junctional epithelium or slightly beyond. Similar results were found one week after scaling, possibly due to the short healing period. These authors concluded that the position of the probe tip was determined by condensation of the connective tissue, tissue edema and alveolar bone rather than through the epithelial attachment.

Based on the formentioned studies a lighter probing pressure is assumed to be more suitable to indentify the base of the (histological) sulcus, i.e. the most coronal cells of the junctional epithelium. Both
the degree of inflammation of the gingival tissues and the probing pressure determine whether or not the probe tip will reach the apical termination of the junctional epithelium. Once the tip reaches this location, the degree of periodontal inflammation in that area will determine whether the tip penetrates the connective tissue.

**Probe diameter and tine shape**

As the penetration of the probe tip is based on the resistance of the periodontal tissues to probing, it is likely that the diameter and the shape of the probe tine are of influence on the probing depth measurements. Keagle et al. (1989) evaluated force-displacement curves for probes with different diameters in healthy and inflamed tissues. Based on their experiments in dogs, a probe with a diameter of 0.6mm proved to be most discriminatory for the different levels of gingival inflammation. With increasing severity of inflammation the 0.6mm probe tip progressed accordingly deeper into the pocket whereas the larger diameter probe tips (0.7 and 0.8mm) on average failed to penetrate the pocket deeper with increasing GI score.

The first study published on the influence of the tine shape was the study of Atassi et al. (1992). They suggested that a parallel-sided tine measured a deeper probing depth than a tapered tine using the same probing pressure in inflamed moderately deep sites. If a difference was present, the parallel-sided tine yielded a deeper measurement but the mean difference was not statistically significant.

**Reproducibility of periodontal probing measurements**

Due to the large number of variables that influence periodontal probing, improving the reproducibility of periodontal probing is largely dependent on minimizing the influence of these variables e.g. probing pressure, periodontal health and precision and readout of the millimeter markings on the probe. Winter (1979) and Van der Velden (1978) evaluated the millimeter markings of commercially available periodontal probes. A great variation between the different probe tines occurs not only in the accuracy of the millimeter markings but also in the diameter between the different tines within a production batch (Van der Zee et al. 1991). Therefore throughout the longitudinal studies standardization of tine characteristics is
important and therefore the same probe should be used throughout the whole study. This will enhance
the accuracy and reproducibility of periodontal probe dependent measurements. Another variable which
influences reproducibility is the potential errors made with visual recording of the millimeter markings on
the probe tine. Magnusson et al. (1988) performed a comparison between the Florida Probe® with an
electronic readout (Gibbs et al. 1987) and a standard manual probe. The potential errors associated with
charting by a second person were eliminated through the direct data entry into the computer in case of the
Florida Probe®. In this study it was concluded that the reproducibility of the measurements obtained with
the electronic probe was significantly higher to that obtained with the manual probe. The assumed
advantage of the pressure controlled probe over a conventional periodontal probe was also tested in a
study by Kalkwarf et al. (1986). They compared a manual and a pressure controlled periodontal probe prior
to instrumentation, following subgingival debride-
ment or periodontal surgery at more than 25,000 sites
with initial probing depths of 2 to 15 mm. The pressure controlled probe was set at 0.50 N and was applied
to a probe with a diameter at the tip of 0.35 mm (5200 kPa). Pilot trails indicated that a probing pressure of
2600 kPa was not sufficient to provide reproducible measurements in the deeper sites (PPD ≥ 6mm)
encountered during this investigation. The pressure controlled probe produced significantly deeper
readings on the facial and lingu
al aspects of teeth regardless of the stage of periodontal therapy and in the
group with probing depths ≥ 6mm. In a comparison to a conventional Meritt-B probe without standardized
force and a constant pressure probe of 0.75 N (with a blind electronic pocket depth read out 0.1 mm
increments), no significant difference in reproducibility of approximal pocket depth measurements, either
in shallow or deep pockets, could be determined (Van der Velden & de Vries 1980). Using the Meritt-B
probe, all three examiners found deeper mean probing pocket depths. As a possible explanation the
authors suggest that in most cases the tip of the pressure probe failed to reach the bottom of the deepest
pocket in the interproximal area, due to loss of tactility by the examiner operating the pressure probe. This
also suggests that the sensitivity of pocket depth measurements to one decimal is of minor importance.
Mullally & Linden (1994) compared a pressure-controlled probe with a conventional probe at mesial and
distal sites in relatively shallow sites. The highest levels of agreement were found between both
examinations with the electronic pressure-controlled probe. Thus, a tendency towards better
reproducibility of probing measurements was noted after using a standardized force, but the difference
was not in all studies statistically significant (van der Velden & de Vries 1980; Badersten et al. 1984). Both
manual and pressure controlled probing are capable in reproducing approximately 90% of the recordings
within ± 1.0 mm difference. This was found for intra-examiner as well as inter-examiner comparisons of 2 examiners (Badersten et al. 1984).

Assessment of loss of attachment

Through accurate monitoring of the pocket depth and attachment level, a possible loss of attachment can be determined in its earliest stage and is essential in providing the patient with the most optimal level of periodontal care. In periodontal health the collagen fibrous attachment reaches up to the cemento-enamel junction (CEJ) (Schroeder et al. 1997). In the presence of loss of connective tissue attachment, the first anatomical landmark to be assessed to monitor changes in the attachment level is the cemento-enamel junction. 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). However for monitoring disease progression based on the attachment level measurements in large epidemiological studies, the CEJ is the reference point of choice (Pihlstrom et al. 1992). Therefore determining the accurate position of the CEJ is the first step in achieving an accurate probing attachment level measurement.

Due to 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 surrogate attachment level measurement. Osborn et al. (1990) introduced the Florida Disk Probe® were the occlusal surfaces or the incisal edge of the tooth serves as a reference for the relative attachment level (RAL instead of CAL). This probe is the original Florida Probe® equipped with a disk. The disk rests during measurement on the occlusal surface of the examined tooth. In the study by Osborn et al. (1990) this probe was compared with a conventional probe, the Michigan probe, for the intra- and inter-examiner reliability. They found that the differences of measurements of the Florida Disk Probe® were in 93 to 95% of the cases within 1.0 mm, and in 100% within 2.0 mm. They concluded that only when double passes were performed (reproducibility of 100% within 1.0 mm) the use of the Florida Disk Probe® offered advantages over the conventional probe. However, as discussed by the authors, when the occlusal surface or the incisal edge is restored or altered in the course of the investigation, this reference for the relative attachment level is no longer valid.
CHAPTER 1

General aim of the present thesis

In addition to its traditional role as an instrument for estimating pocket depths, the periodontal probe has also been used to quantify gingival inflammation (Löe 1967, Mühlemann & Son 1971), dental plaque (Silness & Löe 1964), and to estimate the degree of periodontal clinical attachment loss (Glavind et al. 1967). In assessing gingival inflammation, the way how the pressure is exerted on the gingival tissue may be of great importance. Therefore the purpose of the study presented in CHAPTER 2 was to compare 2 indices, i.e., the Eastman interdental bleeding (EIB) index in which the bleeding is provoked by inserting a wooden interdental cleaner between the teeth from the facial aspect and the bleeding on marginal probing (BOMP) index bleeding, where bleeding is provoked with a probe running along the inner side of the gingival margin.

Loss of attachment as determined from the cemento-enamel junction (CEJ) to the most coronal connective tissue attachment is essential for monitoring disease progression. The purpose of the study in CHAPTER 3 was to test the accuracy and precision with which the CEJ can be assessed in both deciduous and permanent teeth, using 3 commercially available periodontal probes with different tip endings.

It is apparent from the existing literature that probe penetration, assuming that forces are controlled, depends on the degree of inflammation in the adjacent soft tissue, probe tine diameter and also tine shape. The resistance offered by the periodontal tissues when probing, will increase as the dimensions of the probe tine increases. Therefore, the purpose of the research presented in CHAPTER 4 was to evaluate the influence of the tine shape of 3 different periodontal probes (parallel-sided, tapered, WHO) on the measured probing depth.

In presence of periodontitis the probe tip will pass beyond the apical termination of the junctional epithelium. Trauma to the most coronal part of the connective tissue attachment due to scaling and root planing may result in loss of attachment (Badersten et al. 1984; Claffey et al. 1988; Lindhe et al. 1982). Therefore an accurate assessment of the most coronal connective tissue level in untreated periodontitis is of importance. In CHAPTER 5 the purpose of the study was to investigate in untreated periodontitis the influence of tine shape and probing force on probe penetration in relation to the attachment level as determined microscopically.
As probing pocket depth increases, access for subgingival debridement becomes more difficult (Rateitschak-Pluss et al. 1992). In inflamed situations probing measurement tend to overestimate the actual pocket depth and subgingival instrumentation may result in connective attachment loss (Claffey et al. 1988). The study presented in CHAPTER 6 aims to test whether a slim ultrasonic insert reaches a more apical position when penetrating a periodontal pocket compared to the working blade of a conventional Gracey curette in both untreated periodontitis and periodontal maintenance patients.

Despite the possible advantages of pressure probes, the conventional periodontal probe still is the most frequently used probe in daily periodontal practice. One of the reasons being that for periodontal diagnosis, tactile information of the periodontal defect and root anatomy is important. This aspect is of less importance in maintenance patients with relatively shallow pockets. Therefore the aim of the study described in CHAPTER 7 was to test in periodontal maintenance patients whether the systems for pressure control that have been commercially developed contribute to more reproducible probing depth measurements as compared with a manual probe.

As increasing probing pressure results in a deeper pocket after treatment (Mombelli et al. 1992), interpretation of the treatment results may become difficult since many studies have suggested different probing pressures in assessing the probing pocket depth before and after treatment of periodontal diseases. In CHAPTER 8 an attempt is made to provide a correction factor that compensates for the probing pressure employed as an aid for the comparison of outcomes of studies using different probing pressures.
References


