

CLINICAL TESTS OF AN ULTRASONIC PERIODONTAL PROBE

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Abstract. A new ultrasonic periodontal probe has been developed that offers the potential for earlier detection of periodontal disease activity, non-invasive diagnosis, and greater reliability of measurement. A comparison study of the ultrasonic probe to both a manual probe, and a controlled-force probe was conducted to evaluate its clinical effectiveness. Twelve patients enrolled into this study. Two half-month examinations were conducted on each patient, scheduled one hour apart. A one-way analysis of variance was performed to compare the results for the three sets of probing depth measurements, followed by a repeated measures analysis to assess the reproducibility of the different probing techniques. These preliminary findings indicate that manual and ultrasonic probing measure different features of the pocket. Therefore, it is not obvious how the two depth measurements correspond to each other. However, both methods exhibited a similar tendency toward increasing pocket depths as Gingival Index scores increased. Based on the small sample size, further studies need to be conducted using a larger population of patients exhibiting a wider range of disease activity. In addition, studies that allow histological examination of the pocket after probing will help further evaluate the clinical effectiveness of the ultrasonic probe. Future studies will also aid in the development of more effective automated feature recognition algorithms that convert the ultrasonic echoes into pocket depth readings.

INTRODUCTION

A new type of ultrasonic periodontal probe has been developed which makes non-invasive, painless probing possible [1]-[3]. The purpose of this investigation was to compare the depth measurements for the ultrasonic probe with manual and computerized constant-force probing.

The current "gold standard" for the measurement of periodontal disease activity is loss of probing attachment. Unfortunately, small increases in attachment loss may remain undetected due to the inherent errors in current probing techniques. A loss of over 2 mm must occur before further loss of attachment can be reliably diagnosed as having taken place at a site [4]-[6]. Most investigators agree that an alteration of 2 to 3 mm is an indicator of a significant anatomic change [7].

The ultrasonic periodontal probe offers the potential to detect much smaller increments of anatomic change in pocket depth, thereby promising earlier detection of tissue breakdown and faster intervention. Additionally, this technology eliminates operator variability in pressure, placement and angulation; operator errors in visual interpretation of millimeter markings; and misrecording of measurements.

The ultrasonic probe works by projecting a narrow, high-frequency (10-15 MHz) ultrasonic wave into the gingival sulcus/periodontal pocket, and then detecting echoes of the returning wave. The time series return signal can then be converted into a depth measurement by multiplying time of arrival of the return signal by the speed of sound in water (1500 m/s) and dividing by two (since the signal travels into the pocket and back). The inherent resolution of these depth measurements is determined by the wavelength of the wave entering the pocket, which for a 10 MHz wave traveling in water is 0.15 mm.

Ultrasound technology has been used successfully as a standard diagnostic tool in many areas of medicine since the late 1950's. According to the American Institute of Ultrasound in Medicine: "There are no confirmed biological effects on patients or instrument operators caused by exposure from present diagnostic ultrasound instruments." Digital subtraction radiography is the only other imaging technique that can hope to offer a similar ability to diagnose small anatomical changes resulting from periodontal disease activity. However, it exposes patients to harmful ionizing radiation, and can only detect bone loss, not breakdown in the periodontal ligament [8]-[9]. Studies have shown that alveolar bone loss lags periodontal ligament breakdown significantly, delaying diagnosis and slowing interventional therapy [10]-[12].

The ultrasonic probe will also eliminate the need for antibiotic prophylactic premedication prior to probing in those patients who are at risk of developing bacteremias from dental procedures. It is also expected that this procedure will be painless, much faster than manual probing, and yield more useful patient information by providing a graphical representation of changes in pocket depth.

METHODS AND MATERIALS

Twelve subjects enrolled into this study presented with at least 24 teeth and varying levels of periodontal health. 162 teeth provided 972 independent measurements. Health histories were reviewed. Subjects enrolled did not require antibiotic premedication before dental treatment. The study involved one patient visit in which two periodontal examinations were performed 1 hour apart. The appointment scheduling was long enough apart so that the operator could not recall probing measurements, but short enough to avoid tissue changes between visits. The Institutional Review Board of Old Dominion University approved this study protocol.

To reduce inter-examiner variability, a single practicing dental hygienist with over 30 years of experience was used. To avoid examiner bias, the examiner was not permitted to view pocket depth recordings on the screen for either computerized probe. The examiner was trained and calibrated with the manual probe to simulate probing force in the range of 20-30 grams of pressure.

Quadrants to be treated were randomly assigned. Three probing methods were evaluated: ultrasonic, computerized controlled-force, and manual probing. The order of the probing method and quadrant to be treated were randomly assigned using simple randomization. Periodontal measurements were performed at six sites per tooth: disto-buccal, mid-buccal, mesio-buccal, disto-lingual, mid-lingual and mesio-lingual.

The Gingival Index (GI) of Loe and Silness [13] was used at the beginning of the appointment to assess the severity of gingival tissues adjacent to selected teeth. A score from 0-3 was assigned using the following criteria:

0: Absence of inflammation.

1: Presence of mild inflammation, slight color change, slight edema, and no bleeding on probing.

2: Presence of moderate inflammation, moderate redness, and edema with bleeding on probing.

3: Presence of severe inflammation, marked redness and edema, and tendency toward spontaneous bleeding.

Bleeding indices were not captured since bleeding would not be a comparable indicator with the ultrasonic probe.

The comparison probes used in this study were a computerized controlled-force probe and the UNC-12 manual probe. The computerized probe system¹ is a constant force automated probing system. The system includes a control unit, two memory cards, handpiece, printer, footswitch, and disposable probe tips. The computerized probe utilizes a plastic filament, with a rounded tip diameter of 0.54 mm. The probe measures depths from 0.0 mm to 10.0 mm in 0.5 increments, with approximately 30 grams of force. To operate the computerized probe, a flexible filament fiber was inserted between the gingiva and the tooth surface. The probe filament was gently depressed until the tip reached the base of the sulcus/pocket and the probe tip was in contact with the gingival margin. At the point of contact the foot pedal was depressed to capture the data. Manual probing measurements were determined with new, same batch UNC-12 probes² with a tip diameter of 0.45 mm and calibrated markings every millimeter for 12 mm with colored reference points at 5 and 10 mm.

The ultrasonic probe was operated using a portable computer system, which included a pulser/receiver card³ (to power the ultrasonic transducer), an analog-to-digital converter⁴ (for digitizing the ultrasonic signals), and a software-based instrumentation and analysis package.⁵ The probe itself included a 10 MHz transducer with a 2 mm-diameter active area.⁶ The transducer was housed within a stainless steel handpiece at the base of a hollow conical tip. The tip was designed to narrow the ultrasonic beam profile to 0.5 mm and to provide an area for water to sustain the ultrasonic wave and carry it into the periodontal pocket [14]. The water flow rate through the ultrasonic probe was controlled through a pressure gauge that was set below 5 pounds per square inch (just strong enough to produce a steady flow without turbulence). During the first 6 examinations, the pressure gauge was controlled manually, while a foot pedal control was incorporated into the system for the final 6 examinations. The foot pedal allowed the hygienist to control the flow of water more easily as the probe was moved from site to site. It also allowed hands-free control of the computer data acquisition software, which shortened examination time.

During the exam, the ultrasonic probe was held in a vertical position, almost parallel to the long axis of the tooth. In addition, the hygienist looked for two visual cues to determine if the probe tip was in the correct position—slight blanching of the gum tissue and complete coupling of water into the periodontal pocket (no water squirted back out of the pocket during probing). Under these conditions, a high-quality signal was almost always acquired. In the few cases where a poor quality signal was obtained—usually due to poor probe positioning or insufficient water flow—the hygienist was instructed to repeat the measurement at that site. Once the proper probing position was determined, the **FIGURE 1**. The processed returns used for visual interpretation (left) and the smoothed version used for automated feature recognition algorithm (right).

¹ Probe One: American Dental Technologies, Corpus Christi, Texas

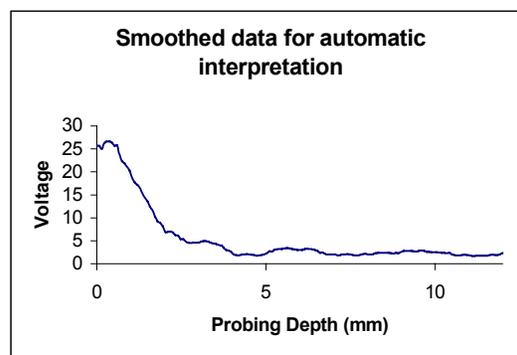
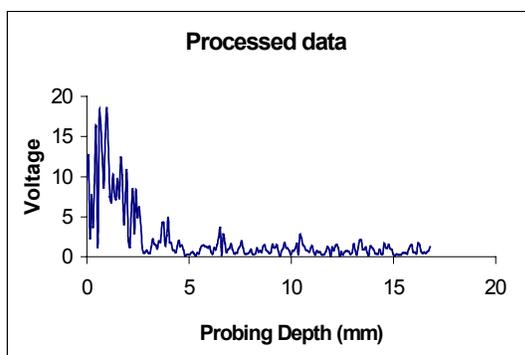
² HuFriedy Manufacturing Company, Chicago, Illinois

³ Matec SR9000, Matec Instruments, Hopkinton, Massachusetts

⁴ CompuScope 2156: Gage Applied Sciences, Inc., Montreal, Canada

⁵ LabView v. 5.1: National Instruments, Austin, Texas

⁶ Valpey-Fisher: Hopkinton, Massachusetts



ultrasonic probe was held in place for approximately 3 seconds to acquire a series of ultrasonic traces that were digitized and saved in the computer for later analysis.

RESULTS

A signal processing technique based on peak-picking and smoothing algorithms was used to analyze the ultrasonic data [14]. To obtain pocket depth data, a processed signal for each probing site was visually examined by five individuals experienced in ultrasound signal analysis. These observers identified a pocket depth at the point where the return signals were no longer prominent. It is believed that this transition point corresponds to the point where connective tissue attaches to the tooth cementum. At this point, the connective tissue strongly attenuates return signals off the tooth surface, so features beyond this depth no longer produce significant ultrasonic returns.

Several observers were used to determine how consistently several different individuals could identify the ultrasonic pocket depth, and to compare their performance to an automated feature recognition software algorithm. This automated feature recognition algorithm, which was employed after further smoothing of the signal, used a thresholding technique based on the average value of the return signal (Figure 1). The probing depths obtained from the ultrasonic probe were then statistically compared to the manual probing depths, the controlled-force probing depths, and the Gingival Index scores. Several different statistical analysis techniques were used to compare the ultrasonic depth measurements with the manual probing and controlled-force probing depths, including a graphical method that plots the difference between two corresponding measurements against their mean value [15] and a method based on orthogonal regression [16]. Standard analysis techniques such as correlation, paired-*t* tests and linear regression analysis were not undertaken, since the criticisms of these techniques outlined by Altman and Brand [17] applied to this analysis.

While these techniques provided some useful analysis, a one-way analysis of variance in which the manual probing data were treated as an ordinal variable (rather than a continuous variable), provided the most insight into the data. The manual probing data could be treated as an ordinal variable because it is obtained on a gross scale (1mm increments over a range from 1 to 7 mm) compared to the ultrasonic data (0.1mm increments over the same range). By treating the manual probing data as an ordinal variable, comparisons across a group—all ultrasonic measurements taken at sites with a particular manual probing value (1,2,3,etc.)—are possible.

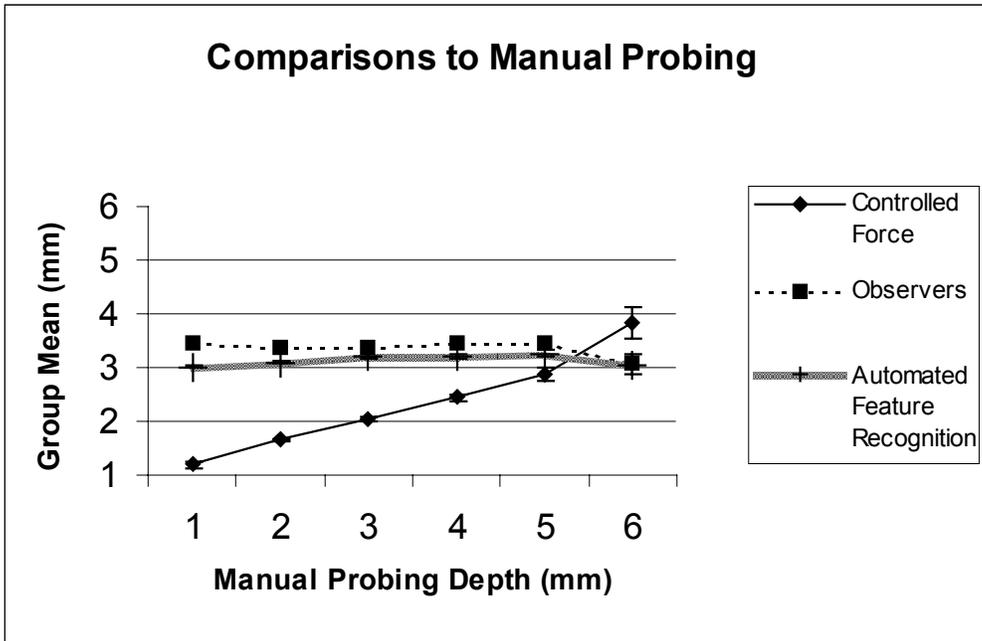


FIGURE 2. A comparison of ultrasonic and controlled-force probing depths to manual probing. This comparison was obtained by performing a one-way ANOVA for ultrasonic and controlled-force probing measurements, grouped on the manual probing depth values. Controlled-force and ultrasonic probing using an automated feature recognition algorithm gave p -values of less than 0.0001. Observer-based interpretation of the ultrasonic probing depths gave a p -value of 0.0006.

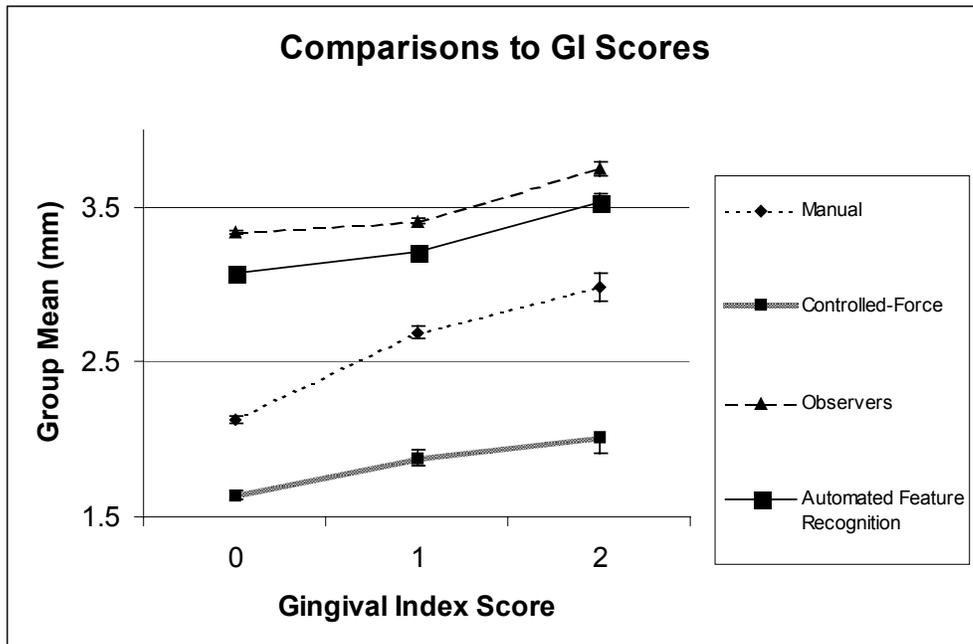


FIGURE 3. A comparison of all three probing methods to Gingival Index scores. The comparison was obtained using a one-way ANOVA grouped on gingival index. The p -value for each ANOVA was less than 0.0001.

TABLE 1. Variance component estimates obtained using a repeated measures analysis. The variance due to error provides a measure of the reproducibility of the different probing techniques. Although manual probing and ultrasonic probing (when coupled with an automated feature recognition software algorithm) produce similar error variances, ultrasonic probing has a lower overall variance. This may be an indication of bias in the manual probing measurements.

Sources of Variance	Manual	Controlled Force	Ultrasonic: Observers	Ultrasonic: Automated Feature Recognition
Total Variance	0.80	0.68	0.64	0.23
Error (Residual)	0.15	0.39	0.36	0.14
Site-to-Site	0.45	0.23	0.00	0.01
Tooth-to-Tooth	0.18	0.04	0.03	0.00
Patient-to-Patient	0.02	0.02	0.13	0.08
Observer	--	--	0.16	--

The results of this analysis can be seen in figure 2, which shows that the controlled-force probing depths tended to increase as the manual probing depths increased. The ultrasonic data exhibit no such tendency, however, as the mean value for the ultrasonic depths did not vary significantly as the manual probing depth increased. However, due to the well-chronicled inaccuracies in manual probing, it is possible for ultrasonic probing to accurately monitor periodontal attachment levels without corresponding to manual probing depths. As a result, a one-way analysis of variance was also performed against Gingival Index scores, which is shown in figure 3. From this figure, it appears that ultrasonic probing depths may, in fact, track periodontal attachment levels, since ultrasonic depths tend to increase with increasing GI scores.

Finally, the probing depth data were analyzed to assess the reproducibility of the measurement techniques. To do so, a repeated measures analysis was performed, in which each of the data sets were modeled to separate out variation due to error (the variation that would occur if the same measurement were repeated again under the exact same conditions) from variation due to other factors. These factors included variation across patients, tooth numbers, probing locations, and observers (for the ultrasonic data only). As can be seen from table 1, the reproducibility of manual probing and ultrasonic probing with automated feature recognition is comparable (as indicated by their similar values for variance due to error). However, manual probing has a much larger total variance, because manual probing has much larger site-to-site and tooth-to-tooth variance components. This either indicates a bias in manual probing (perhaps due to a site- or tooth-specific change in angulation or probing pressure) or a failure to detect important variations in probing depth on the part of ultrasonic probing. Two observations, however, point to a bias in manual probing. First, ultrasonic probing has a larger patient-to-patient variance, where one would expect variance due to differences in overall gingival health. Second, controlled-force probing, which is designed to eliminate variations in probing force, has lower site-to-site and tooth-to-tooth variance than manual probing.

DISCUSSION

From these results, manual and ultrasonic probing depths do not appear to correspond to each other. However, manual probing does not measure the depth of an anatomical feature, but rather resistance to probing force, whereas ultrasonic probing more likely corresponds to echoes off an anatomical feature.

During manual probing, the junctional epithelium is typically perforated and connective tissue stops the probe tip from further penetration. In healthy gingiva the histological sulcus depth (the true "pocket depth") is about 0.5 mm deep, but the probe tip normally penetrates to a depth of up to 2.5 mm (the "probing depth"). If gingivitis or periodontitis are present, the tip of the periodontal probe may penetrate through connective tissue (causing bleeding) until resistance is met at the first intact collagen fibers that insert into the cementum. Thus, the difference between probing depth and pocket depth may be even greater for patients with periodontitis [18].

Due to the significant difference between probing depth and true pocket depth, manual and controlled force probing measurements are not likely to correspond to the transitions from sulcus to junctional epithelium or from junctional epithelium to connective tissue. Thus, in healthy patients the manual probing measurements will usually fall somewhere between the bottom of the sulcus and the bottom of the junctional epithelium. In addition, as periodontitis progresses, the anatomy becomes more complicated and manual probing is even less likely to match a specific anatomical feature.

Thus, comparisons of the ultrasonic probing depths to some other standard would be highly desirable. During this study, the Gingival Index was used as this standard, and the results of this comparison indicate promise for ultrasonic probing. However, the patients examined during this trial generally exhibited good gingival health (GI scores of 0-2), so these results cannot be extrapolated to patients exhibiting greater disease activity.

The indications of better reproducibility seen in table 1 further demonstrate that ultrasonic probing may have merit as a diagnostic tool. Therefore, future studies are planned to include a larger proportion of patients with greater levels of disease activity. These studies should include comparisons of ultrasonic probing with anatomical pocket depths (examination prior to flap and en bloc surgery, followed by histological examination). In addition, more investigation into the automated feature recognition software algorithm is needed. Although automated feature recognition has a lower variance due to error than the other probing techniques, an adaptive thresholding algorithm in which artificial intelligence techniques are used to determine the optimal smoothing and thresholding parameters for each trace may further improve the reproducibility of ultrasonic probing. To be effective, this learning algorithm will need to be developed using a larger data set from patients exhibiting a wider range of disease activity.

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