Influence of Implant Geometry and Surface Characteristics on Progressive Osseointegration

Nico C. Geurs, DDS, MS[1]/Robert L. Jeffcoat, PhD[2]/Edwin A. McGlumphy, DDS, MS[3]/
Michael S. Reddy, DMD, DMSc[4]/Marjorie K. Jeffcoat, DMD[5]

Purpose: *Although no currently available technique for the measurement of osseointegration is entirely satisfactory, 3 clinical variables can be reasonably associated with the process: probing depth, micromobility, and crestal bone height. Micromobility can be quantified to some extent with the use of the Periotest, a commercially available instrument. In this investigation, the influence of surface characteristics and geometry upon Periotest value (PTV) and probing depth measurements was studied.* ***Materials and Methods:*** *In a multicenter trial, 120 healthy edentulous patients received 5 or 6 implants in the anterior mandible and were followed for 3 years. A total of 634 implants were placed. Every patient received at least 1 implant of each of 3 types: threaded titanium plasma-sprayed (TPS), threaded hydroxyapatite-coated (HA), and cylindric HA-coated. A randomization schedule assured that approximately equal numbers of each type of implant were placed and that they were uniformly distributed over the arch.* ***Results:*** *Of the 4 tested combinations of dependent and independent variables, the only statistically significant ($P < .05$) effect was that of coating on PTV. At 1 year after prosthetic restoration, the mean PTV for HA-coated threaded implants was −5.36 ± 1.24, compared with −4.86 ± 1.70 for TPS implants. This difference steadily declined in magnitude and significance, until, after 3 years, the groups were indistinguishable.* ***Discussion:*** *This study agrees with the previous observations that HA coating tends to accelerate the initial rate of osseointegration. The absence of a difference between threaded and cylindric implants confirms that the PTV responds to micromobility near the surface, on a scale much smaller than such gross geometric features.* ***Conclusion:*** *On the basis of these results, one may conclude that HA-coated implants exhibit a more rapid decrease in micromobility than do TPS implants of identical geometry.* (INT J ORAL MAXILLOFAC IMPLANTS 2002;17:811–815)

Key words: *dental implants, hydroxyapatites, micromobility, multicenter study, osseointegration, surface properties*

While the measurement of osseointegration is fundamental to implant research, no clinical test is yet generally acknowledged to be entirely satisfactory. Gross rates of survival or success, though often reported in the literature, have little power to discriminate among groups of modern implants, whose success rates typically exceed 90%. Destructive techniques, including histomorphometry[1,2] and mechanical pull-out and torque-out tests,[3,4] are more direct but are rarely suitable for use in human patients.

Three clinical variables can be reasonably associated with instantaneous assessment of osseointegration status: probing depth (PD), micromobility,[5,6] and crestal bone height (BH).[7,8] All can be used in situations where destructive techniques would be unacceptable. Both PD and BH measure anatomic changes associated primarily with the degree of bony support (length or area of the surface in contact with bone) rather than its quality (the thickness and composition of the attachment). By contrast, at least one aspect of micromobility (a measure of nonlinear response) has been shown to correlate

[1]Associate Professor, Department of Periodontology, University of Alabama (UAB) School of Dentistry, Birmingham, Alabama.
[2]Research Professor, UAB School of Dentistry, Birmingham, Alabama.
[3]Associate Professor, Department of Prosthodontics, The Ohio State University College of Dentistry, Columbus, Ohio.
[4]Professor, Department of Periodontology, UAB School of Dentistry, Birmingham, Alabama.
[5]Rosen Professor and Chair, Department of Periodontology, UAB School of Dentistry, Birmingham, Alabama.

Reprint requests: Dr Nico C. Geurs, Department of Periodontology, UAB School of Dentistry, 1530 3rd Avenue South, SDB 412, Birmingham, AL 35294-0007. Fax: +205-934-7901. E-mail: ngeurs@uab.edu

with the quality of osseointegration, independent of the overall bone height.[9]

Periotest (Siemens, Bensheim, Germany) is an instrument designed to quantify tooth or implant mobility. Originally intended for use on natural teeth,[10] the Periotest has sufficient range to detect the much lower mobility associated with osseointegrated implants.[11,12] In clinical use, the device's handpiece probe is positioned perpendicular to the long axis of the tooth or implant. Its tip is held about 1 mm distant from a point roughly centered on the buccal surface of the tooth or implant. When a switch is pressed, a light rod is impelled repeatedly against the tooth or implant surface. By monitoring the motion of the rod as it strikes and rebounds, the instrument computes the dynamic properties of the rod/tooth system, which are in turn related to the mobility of the tooth within its supporting structures. This information is summarized in the Periotest value (PTV), an arbitrary continuous quantity presented as a signed integer, where higher numbers denote higher mobility. Periotest measurements can be performed with good reproducibility.[13]

The present analysis is limited to Periotest micromobility and probing pocket depth as osseointegration-related outcomes. The authors' hypothesis is that the design of an implant influences the time course of its osseointegration over a considerable period after placement and restoration. To test this hypothesis, a study was designed in which 2 primary design-related independent variables were each controlled at 2 levels: geometry (threaded or cylindric) and coating (titanium plasma-sprayed [TPS] or hydroxyapatite-coated [HA]).

MATERIALS AND METHODS

At 2 clinical centers, 120 healthy edentulous patients received 5 or 6 mandibular endosseous root-form implants (Steri-Oss, Nobel Biocare USA, Yorba Linda, CA) supporting a fixed/detachable prosthesis. Three basic design families—TPS/threaded, HA/threaded, and HA/cylindric—were employed; no cylindric TPS implants were tested. A randomization schedule ensured that every patient received at least 1 implant from each family and that implants of each type were uniformly distributed over the arch. For the surgical placement, full-thickness flaps were reflected and the mental foramina were located bilaterally. The most distal implant osteotomies were located 5 mm anterior to the mental foramina, and the space between these implants was measured. Depending on the available space, to allow an inter-implant space of at least 3 mm, either 5 or 6 implant osteotomies were prepared in any given patient. All osteotomies were prepared according to the manufacturer's specifications, and 5 or 6 root-form implants were placed. The implant length, diameter, and placement details were determined by the clinicians according to the requirements of each patient.

After a healing period of 4 months, a second-stage surgery was performed to uncover the implants. Healing abutments of 3, 5, or 7 mm were chosen depending on soft tissue thickness.

After a further healing period of 4 weeks, the prosthetic phase was begun with the selection of permucosal extensions placed into the implants with a torque of 35 N/cm. The implants were restored with a fixed/detachable restoration having distal cantilevers to the mesial of the first molar. A total of 634 implants were placed in this fashion. The study constitutes a randomized, balanced, incomplete block design with respect to coating and geometry.

At placement of the prosthesis, baseline data were collected, including gingival index (GI), PD, recession (REC), relative attachment levels (RAL), and PTV. Probing depth and attachment levels were measured using a controlled-force modified Florida probe (Florida Probe, Gainesville, FL). The standard Florida probe tip was modified to have a rounded tip and Williams marking as described by Reddy.[14,15] To make the Periotest measurements, the prosthesis was first removed to give access to the isolated implant abutments. The Periotest instrument was then used in accordance with manufacturer's instructions, where the point of impact was standardized to be a point 1 mm from the coronal extent, and the angle of incidence was perpendicular to the buccal surface of the implant or abutment. The instrument was actuated repeatedly until it displayed the same value twice in succession; this repeated PTV was recorded. This process was repeated at each subsequent annual recall visit. Annual calibration exercises were performed to ensure that the examiners at the different centers were well calibrated. Standardized radiographs were also taken at each examination, but these have not yet been measured in sufficient numbers to allow meaningful comparisons on the basis of radiographic bone height.

Data Analysis

A 3-year analysis was carried out, including only those patients for whom complete examination results of the specified types were available for baseline and all 3 years. Each implant was classified according to its geometry (either CYL [cylindric] or THD [threaded]) and its surface treatment (either TPS or HA). The study design inherently cancelled any effects related to patient identity or location of the implants.

Table 1 Summary of Results and Statistical Analysis

	PTV				PD			
	HA-coated		Threaded		HA-coated		Threaded	
Year	THD (n = 110)	CYL (n = 111)	TPS (n = 109)	HA (n = 110)	THD (n = 117)	CYL (n = 118)	TPS (n = 116)	HA (n = 117)
0								
Mean	–5.236	–5.342	–4.229	–5.236	2.457	2.558	2.462	2.457
SD	1.165	1.164	2.030	1.165	0.588	0.685	0.559	0.588
P (Tukey HSD)	.996		.000032		.645		1.000	
1								
Mean	–5.355	–5.279	–4.862	–5.355	2.276	2.263	2.225	2.276
SD	1.238	1.706	1.702	1.238	0.641	0.616	0.628	0.641
P (Tukey HSD)	1.000		.0187		1.000		.989	
2								
Mean	–5.691	–5.820	–5.303	–5.691	2.064	2.154	2.055	2.064
SD	1.073	0.936	1.647	1.073	0.608	0.604	0.533	0.608
P (Tukey HSD)	.987		.142		.769		1.000	
3								
Mean	–5.445	–5.784	–5.431	–5.445	2.119	2.272	2.190	2.119
SD	1.617	1.115	1.468	1.617	0.557	0.516	0.553	0.557
P (Tukey HSD)	.271		1.000		.134		.924	
MANOVA								
F	1.12		.8676		1.831		.0062	
P	.2911		.00358		.1773		.9373	

Multivariate analysis of variance (MANOVA) was used to compare implants grouped by surface characteristic and geometry. Separate analyses were carried out for PTV and PD measured with the Florida Probe. Each analysis was balanced, in that HA-coated cylinders were compared only to HA-coated threaded implants and HA-coated threaded implants were compared only to TPS threaded implants. There were approximately 110 implants in each cell. PTV, though coarsely quantified, is actually a continuous variable, and parametric methods are therefore justified.

A post hoc significance test, Tukey honest significant difference, was applied. The results are shown in Table 1.

RESULTS

A total of 8 implants (1.3%) were lost in the first year, prior to prosthetic loading. The remaining 626 were loaded, functional, and showed no clinical signs of failure at 3 years.

Of the 4 tested combinations of dependent and independent variables, the only statistically significant effect ($P < .05$) was that of coating on PTV. For the TPS group, a clear temporal trend toward lower PTV (ie, less mobile implants) was evident (Fig 1). The HA-coated group showed little or no change over the same time period. At the initial time point (t = 0, the time of prosthetic placement, typically 5 months after implant placement), the HA-coated group showed a mean PTV that was significantly lower (ie, less mobile) than that recorded in the TPS group. This difference steadily declined in magnitude and significance until, at t = 3 years, the groups were indistinguishable. Although it is tempting to speculate as to whether the 2 curves merged or crossed at that point, the 3-year data do not provide an answer.

Figure 2 is the corresponding plot for PD. The 2 coating groups were statistically indistinguishable ($P > .9$). Both showed a gradual decrease in PD over the first 2 years and a partial reversal in the third year.

Figures 3 and 4 show the effects of geometry on PTV and PD, respectively. From these data, it may be concluded that, in the present experiment, geometry had no statistically significant effect on either outcome variable. While there was a suggestion that the curves might have been diverging at t = 3 years, no trend could be extrapolated with confidence.

Implant size and location in the arch did not have a statistically significant influence on the PTV.

DISCUSSION

Of all the variables in this experiment, only the PTV provided statistical discrimination between uncoated and HA-coated implants. Since PTV is a

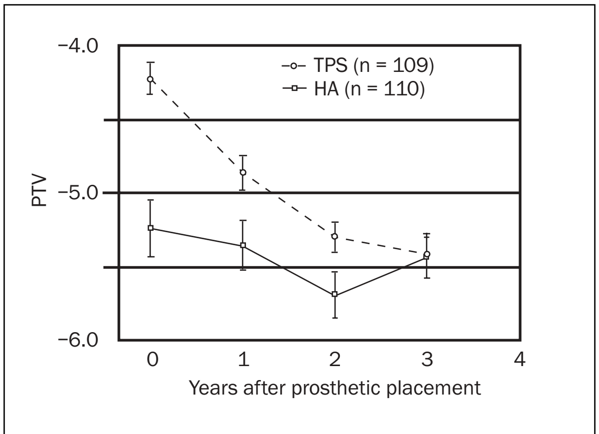

Fig 1 The effect of implant surface coating on PTV. MANOVA: F = 8.676, *P* = .00358.

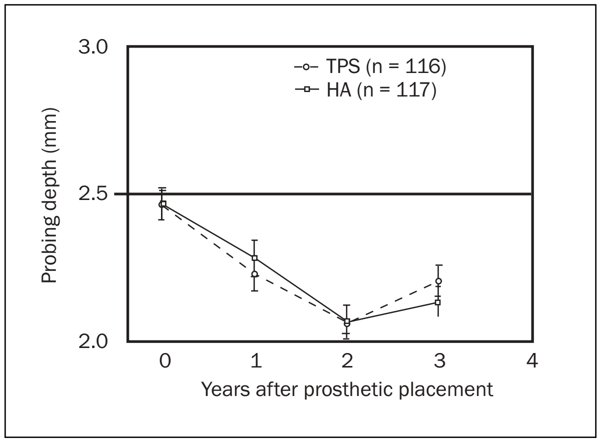

Fig 2 The effect of implant surface coating on PD. MANOVA: F = .0062, *P* = .9373.

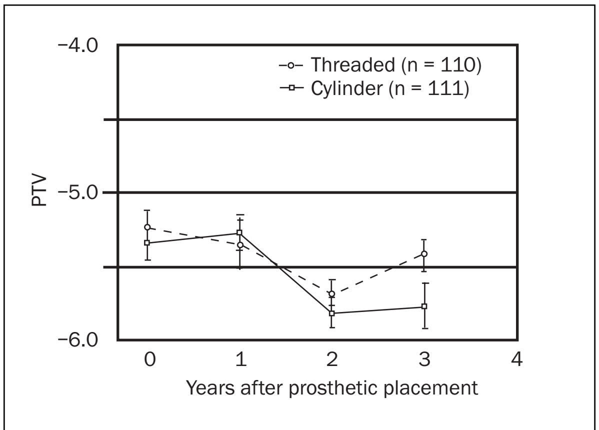

Fig 3 The effect of implant geometry on PTV. MANOVA: F = 1.120, *P* = .2911.

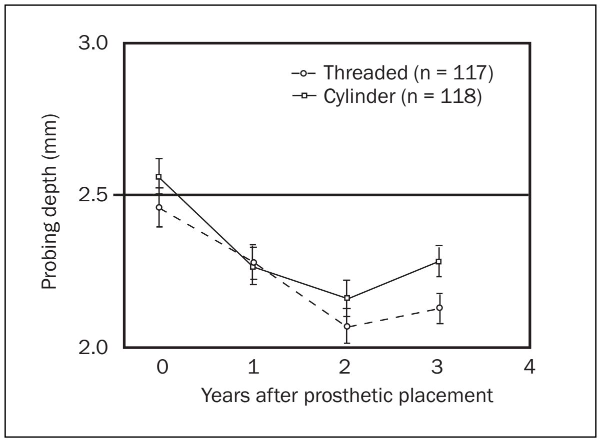

Fig 4 Effect of implant geometry on PD. MANOVA: F = 1.831, *P* = .1773.

measure of mobility, the trends in Fig 1 show that HA-coated implants undergo a more rapid initial decrease in micromobility than their uncoated counterparts; both groups approached the same asymptotic level within 3 years after placement. On the other hand, the mobility of thread-stabilized implants did not differ significantly from that of cylindric implants.

These results are qualitatively consistent with past studies suggesting earlier (if not necessarily superior) integration of HA-coated implants when compared with TPS controls. Roynesdal and coworkers,[16,17] for example, found that HA-coated cylindric implants had lower PTV than TPS or titanium threaded implants after 2 years. These differences, however, were apparent only for the HA-coated implants and the threaded titanium implants.

The observed difference in PTV early in the healing process may result from more extensive bone-to-implant contact. In a histologic comparison of HA-coated and as-machined titanium implants retrieved from dogs,[18] the former exhibited a greater amount of implant-to-bone contact early in healing. Such increased healing capacity has been attributed to the chemical composition of the HA rather than its micro-roughness.[19] When compared to titanium and TPS implants, HA-coated implants have also been found to withstand greater amounts of reverse torque 6 months after placement in baboons.[3]

Although the 2 coatings in this experiment were associated with distinctly different patterns of mobility, the difference is only evident when one compares the mean response of the respective patient groups. For any individual patient, the current Periotest instrument yields measurements that are too coarsely graduated to be useful for following the normal progression of osseointegration. This is not a fundamental limitation of the method, however; with refined instrumentation, micromobility measurements could provide valuable information for the clinical management of individual implant cases. Several investigators have recently described other instruments to quantify micromobility: for example, Ramp and Jeffcoat[20] used a hand-held contact probe to estimate linear and non-linear dynamic parameters as a function of lateral preload. Meredith[21] measured resonant frequency by means of a vibrational exciter temporarily affixed to the implant. Jeffcoat and coworkers[22] have designed a miniature impedance-sensing package to be placed within the implant itself. All of these, like the Periotest, are based on the idea that mobility can be conveniently and accurately measured by dynamic means.

While it is obvious that gross mobility is associated with implant failure, it appears that no study (including this one) has demonstrated a definitive correlation between mobility and other measures of osseointegration among successful implants in human patients. The PTV is reported to have a high specificity, but it lacks sensitivity as a test for peri-implant disease.[12] Recent animal experiments[20] have, however, shown micromobility to be well correlated with the total amount of bone in contact with the implant, measured histologically.

CONCLUSIONS

Micromobility appears to measure differences in implant behavior that are undetectable by more conventional means. In this experiment, HA-coated implants consistently exhibited a more rapid early decrease in mobility than did otherwise identical TPS implants. Future refinements in instrumentation may make micromobility measurements both informative and easily obtained in a clinical setting.

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