

BONE DENSITY: ITS INFLUENCE ON IMPLANT STABILITY AFTER UNCOVERING

Harold F. Morris, DDS, MS
Shigeru Ochi, PhD
Patricia Crum, DDS, MPA
Ira Orenstein, DDS
Richard Plezia, DDS, MS

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Harold F. Morris, DDS, MS, is codirector at the DVA Dental Clinical Research Center and staff prosthodontist at the VA Medical Center, 2215 Fuller Road, Ann Arbor, MI 48105.

Shigeru Ochi, PhD, is codirector and biostatistician at the DVA Dental Clinical Research Center and VA Medical Center, Ann Arbor, MI.

Patricia Crum, DDS, MPA, is chief of dental service at the VA Medical Center, Ann Arbor, MI, and associate professor in the Department of Periodontics, Prevention, and Geriatrics at the University of Michigan, Ann Arbor, MI.

Ira Orenstein, DDS, is staff dentist at the VA Medical Center, Bronx, NY, and Columbia University School of Dental and Oral Surgery, New York, NY.

Richard Plezia, DDS, MS, is chief of dental service at the John Dingell VA Medical Center, 4646 John R Street, Detroit, MI.

Primary implant stability and bone density are variables that have long been considered to be essential to achieving predictable osseointegration and long-term clinical survival. Although the dentist can control most factors associated with implant survival, bone density is the one factor that cannot be controlled. Measuring implant stability would assist in determining if an implant has integrated and is ready for the fabrication of the final prosthesis. Changes in implant stability in each type of Bone Quality (BQ-1, -2, -3, and -4), which may occur with time, have not been studied. Such information could help identify well-integrated implants and identify changes associated with impending implant failure. Several studies have used the Periotest instrument to study implant stability. Use of the Periotest implant stability will be studied during each phase of implant treatment for each bone density, and a range for clinically satisfactory integration will be suggested. Implant stability changes over time, and the changes are different for each bone density as the bone surrounding the nonhydroxyapatite implant becomes denser. This is clearly demonstrated in a postmortem histological specimen. The changes in implant stability (Periotest Values [PTVs]) are more apparent in BQ-1 and BQ-2 bone and less apparent in BQ-3 and BQ-4 bone. The Periotest is capable of providing valuable information concerning favorable or unfavorable changes in the bone-implant interface after uncovering. In addition, it can help identify when an implant is ready to be loaded. A new range of PTVs (-5 to -2) is suggested for monitoring the status of implants. Implants with PTVs more positive than -2 would indicate a bone-implant complex that may be marginal.

INTRODUCTION

In general, the long-term clinical success of osseointegrated endosseous implants is related to a couple of factors: (1) the status of the bone-implant interface and (2) the density of the surrounding bone (ie, the bone-implant complex). Implant stability, as mea-

sured by the Periotest as Periotest Values (PTVs), reflects the status of this bone-implant complex. Reliable measurements of stability would assist the clinician in determining implant integration before fabrication of the final dental restoration. After delivery and loading of the final restoration, reliable



FIGURE 1. Periotest instrument for measuring implant stability. The plunger rod within the handpiece is electromagnetically accelerated; when it strikes a firm object, the plunger rebounds into the handpiece. The time that the plunger remains in contact with the object is returned to the Periotest, and the central processing unit converts this time into a Periotest Value (PTV). PTV calibration ranges from -8 to $+50$ PTVs. The more rigid the object, the more negative the PTVs, and flexible objects provide more positive values. Range for integrated implants is -5 to -2 PTVs. Between -2 and $+2$, implant may appear clinically stable but suggests a marginal bone-implant complex.

measurements may well be equally important in monitoring the status of the bone-implant complex to identify early signs of problems. Such information would also contribute to a better understanding of bone response to dental implants after uncovering. If early signs of problems within this complex could be measured, they would permit early intervention and research to develop new and innovative corrective treatments.

Some reports suggest that primary implant stability may be directly related to the bone quality and quantity, the implant design, and the site preparation.¹ Other reports speculate that greater contact between the implant and the bone may be more favorable, but this relationship is not well understood.² Although bone density at the time of implant placement is generally

accepted as being important to immediate implant stability, the influence of each of the 4 bone densities on early and long-term implant stability has not been well documented.

One study reported that in dense bone, implant stability decreases slightly with time, despite clinical evidence of osseointegration and increased bone-implant contact.³ However, another study reported that in soft bone there is an increase in implant stability with time.⁴ Scientific data from an independent clinical study are needed to demonstrate any changes in the stability measured with the Periotest or other methods. Ideally, such research should include the testing of large numbers of implants and be supported by postmortem specimens obtained from humans.

The dental implant community has

long sought a noninvasive method that could assess implant stability. It should be capable of providing a reliable, indirect, noninvasive measurement of the bone quality and quantity associated with this complex, as well as any changes in this complex after clinical loading. It is reasonable to assume that a change in implant stability represents measurable changes within the bone-implant complex. The stability data recorded over time may actually document changes in which the implant becomes increasingly more stable or less stable. Buser⁵ provided some insight into the potential favorable or unfavorable bone responses around the implant to clinical loading when loading is below, within, or exceeding normal physiological limits. Loading the bone below physiological limits may result in atrophy, whereas loading above physiological limits may precipitate fracture failures with eventual loss of the implant (ie, The Carter Hypothesis). Loading within acceptable limits serves to stimulate bone, which can respond by becoming denser.

To be of practical value, an instrument used to measure implant stability should be noninvasive, be nontraumatic, be easy to use in the clinical environment, exhibit a clinically meaningful level of sensitivity, and be reproducible. In 1986, Schulte⁶ described the Periotest (Figure 1) in detail. It was developed initially to assess bone atrophy and inflammatory periodontal conditions around natural teeth.⁷ It has been used successfully to study changes in tooth mobility and implants for large numbers of implants and natural teeth for a period of 60 months.⁸

The Periotest device consists of a metal case containing a central processing unit, a digital read-out screen, and artificial speech (Figure 1). The case is connected by a cord to a handpiece that contains a percussion rod, which is electromagnetically accelerated when the unit is activated. When the rod comes into contact with a solid object, it strikes the object and rebounds. The more rigid the bone-im-

plant complex, the shorter the time the plunger remains in contact with it and the faster it rebounds.

The duration of contact between the rod and the object being tested is returned to the central processing unit (CPU) in the Periotest case. The CPU converts the electrical output from the handpiece into a PTV. The operator gets both a digital readout and an audible readout of the PTVs. The instrument is calibrated to a range of PTVs from -8 to $+50$, with the more negative values indicating greater stability and the more positive values indicating less stability. Teerlinck et al⁹ reported that the PTVs for 30 patients with implants that were determined to be osseointegrated fell within a range from -4 PTVs to $+2$ PTVs. Olive and Aparicio¹⁰ also reported a similar range of PTVs for osseointegrated implants. PTVs of $+9$ or greater were associated with implants that had failed and required removal.

In 1997, Meredith et al¹¹ introduced the so-called Resonance Frequency Analysis technique. As are the Periotest and other methods for measuring stability, the device is based on the assumption that the amount of bone-to-implant contact determines how the implant vibrates when tested.

Although bone density is consistently referred to as being important to the long-term clinical performance of dental implants, limited scientific information addresses the influence of each bone density on long-term survival. And although the dental surgeon can control most factors associated with improving the chances for clinical success, bone density is the one factor over which the surgeon has no control.

Branemark and Zarb¹² described 4 Bone Qualities (BQ-1, -2, -3, and -4) found in the edentulous jawbone. BQ-1 is composed of homogeneous compact bone, which has been described to be like hard wood, when preparing the implant site. BQ-2 has a thick layer of compact bone surrounding a dense core of trabecular bone, which has been described as having the quality of a

Implant Site	Q-1 Bone (%)	Q-2 Bone (%)	Q-3 Bone (%)	Q-4 Bone (%)
Maxillary anterior	0.5	24	59	16
Maxillary posterior	1.5	23	53	23
Mandibular anterior	20	64	14	1.8
Mandibular posterior	8.8	56	33	2.6

hard pine. BQ-3 has a thin layer of dense cortical bone around a dense core of dense trabecular bone and feels like a soft wood (eg, balsa wood). BQ-4 bone represents the less dense bone and has a thin layer of cortical bone around a core of low-density trabecular bone, which feels like Styrofoam. Misch¹³ also defined the 4 bone types relative to the surgical protocol, healing, treatment plans, and progressive loading time periods that were optimal for each bone type. In 1997, Truhlar et al¹⁴ reported on the distribution of the bone quality (density) in which 2910 implants (Table 1) were placed in a randomized, prospective, scientific clinical study. The percentage of each bone density found in each jaw region was very similar to percentages reported by others.¹⁵⁻¹⁷

The purpose of this paper is to report scientific clinical data related to the following questions: (1) what PTVs would suggest that the implant is integrated, (2) are there changes in the bone-implant complex after a normal healing period, (3) are there changes within the bone-implant complex in response to stimulation during loading, (4) what is the influence of each bone density on implant stability and what changes in implant stability over time are normal, and (5) are these data supported by human postmortem histological specimens? Currently, little information exists concerning the influence of bone density on the stability of endosseous dental implants at uncovering and after loading of the prosthesis.

MATERIALS AND METHODS

A total of 30 Periotest units were purchased on the open market. Of these

instruments, 6 were randomly selected for testing to study the reproducibility within the same instrument and among the 6 instruments. A series of standardization test devices were fabricated and tested in vitro. They consisted of 2 types: (1) blocks of wood of different densities in which 2 implants of the same design were placed; and (2) a metal membrane, which consisted of various metal types and thickness to alter the flexibility of the membrane, was placed over a hollow section at the ends of a metal cylinder. Each end was covered with a similar metal membrane but with different thickness to produce very different rigidity. The wooden-block and metal-membrane test samples were all coded for future reference.

The dimensions of the 4 blocks of wood that were the test specimens were 5.0 cm in depth, 10.0 cm wide, and 10.0 cm long. The materials for the blocks were selected to simulate the various bone densities: simulated BQ-1 bone was made from a dense hard wood, BQ-2 bone was made with a slightly less dense wood, BQ-3 bone was a soft wood, and BQ-4 bone was a very soft wood. Two actual implant-fixture sites were prepared in each block of wood 3.8 cm apart. One implant was placed into the prepared site, which had been filled with a thin layer of epoxy cement (to simulate an implant that was integrated), whereas the other implant was seated without anything between the implant and the wood (to simulate nonintegration). The instrument was activated, and the PTVs were recorded with the test specimen's reference code.

The clinical investigators were trained in the intraoral use of the Per-

TABLE 2
Mean PTVs for each bone density at each follow-up visit*

Bone Quality	3 mo	6 mo	9 mo	12 mo	18 mo	24 mo	36 mo	48 mo	Total
BQ-1	-3.51	-4.34	-4.17	-4.67	-4.42	-4.79	-4.34	-4.34	-4.34
BQ-2	-3.40	-3.28	-3.62	-3.57	-2.67	-4.00	-3.76	-3.61	-3.61
BQ-3	-3.23	-2.77	-2.62	-2.57	-2.88	-2.76	-2.78	-2.62	-2.78
BQ-4	-1.55	-1.70	-2.20	-2.88	-2.47	-1.89	-2.18	-2.18	-2.04

*PTVs indicates Periotest values; BQ, bone quality. There is an increase in the density of the bone surrounding the endosseous implant in response to functional stresses. This change in density is different for each of the bone densities. BQ-1 shows the greatest increase in stability (negative PTVs = greater stability, the more negative the PTV the greater the stability of the bone-implant complex); BQ-2 shows a similar change, but it takes longer for the final stability to develop; BQ-3 shows little or no negative (increase in stability over time) change in PTVs; and BQ-4 shows the least change in implant stability.

iotest device during a three-day training meeting before activation of the study. A total of 3006 implants were placed during the study.¹⁸ For all clinical measurements of implant stability, the tip of the plunger rod from the Periotest's handpiece was carefully positioned above the soft-tissue margin, and the Periotest was activated (Figure 2A). Implant stability was tested 3 months after uncovering and at 6, 9, 12, 18, 24, 36, and 48 months. BQ for each implant was determined during the placement of the implant by using radiographs and tactile sensations. Although some subjectivity was involved in assessing a BQ at the time of implant placement, the PTVs for the implants correlated well with the BQ classification for the bone in that area.¹⁹

POSTMORTEM HISTOLOGICAL SPECIMEN

The comprehensive clinical study design allowed for the opportunity to obtain postmortem specimens for histological analysis to support clinical findings. One patient, who was entered into the study, had a fixed partial denture restoration planned and fabricated for the mandibular posterior jaw region. The patient was later diagnosed with cancer after the implants had been in place and functioning for a period of 24 months. At the time of entry into the study, the patient signed a con-

sent form that permitted donation of bone-implant complex for histological analysis in the event of his death. The bone quality in this area was recorded as BQ-2.

RESULTS AND DISCUSSION

The mean PTVs were pooled for all implants placed in all bone densities and were tested. The PTVs varied slightly (range -3.06 PTVs to -3.40) during the 48-month observation period (Figure 2C) at each evaluation visit. The greater the negative number, the better the stability of the bone-implant complex, whereas any trend toward positive values would indicate a less stable bone-implant complex. At 3 months after uncovering, the mean PTV for all implants was -3.2, indicating that all implants exhibited good stability. At 6 months, their stability had changed slightly to -3.1 PTVs; at 12 months, -3.2 PTVs; at 18 months, -3.3 PTVs; at 24 months, -3.4 PTVs; at 36 months, -3.3 PTVs; and at 48 months, -3.2 PTVs. These variations in stability were neither clinically nor statistically significant.

Bone is a viable, living tissue that responds to stimulation by developing a more dense bone structure when the stimulation remains within normal physiological limits.¹⁹ The histological specimen obtained during this study (Figure 2B) provides a rare opportunity to view what appears to be a favorable bone response in a human his-

tological specimen. This specimen was obtained as part of the same study that was gathering clinical implant stability and survival data. It clearly shows a dense bone formation around the periphery of the implant in response to microstrains that occurred during a 20-month period of normal clinical function. Restoring and functionally loading the implant involves stimulating the bone surrounding the dental implant, which should lead to a gradual increase in the density of the bone-implant complex. The concept of "progressive loading" capitalizes on this physiological response to increase the bone density and improve the ability of the implant to withstand functional stresses and promote long-term clinical survival.

This response, however, does not occur to the same degree for all implants in all bone densities as shown by PTVs recorded for each bone density over time (Table 2, Figure 2D). The denser the bone surrounding the implant site at the time of implant placement, the greater the contact between the implant surface and the trabecular bone. During loading, the functional microstrains will stimulate the trabecular bone. If this falls within a physiologically acceptable range for that bone density, the bone responds by increasing its density.⁵ Roberts²⁰ has referred to this response as microremodeling. The extent of this favorable bone response for each bone density is reflected in the PTVs recorded over the 48 months. Favorable bone response over time is indicated by the PTVs becoming more negative, indicating an increase in the rigidity of the bone-implant complex.

The most dense BQ (BQ-1) appears to reach an optimal PTV between 6 and 12 months (Table 2) after uncovering. The mean PTV for BQ-1 was -4.3 PTVs. BQ-2 is less dense than BQ-1 and had a mean PTV of -3.6 PTVs for all evaluations during the 48 months. Stability of the bone-implant complex in BQ-2 reached an optimal PTV over a slightly longer period of

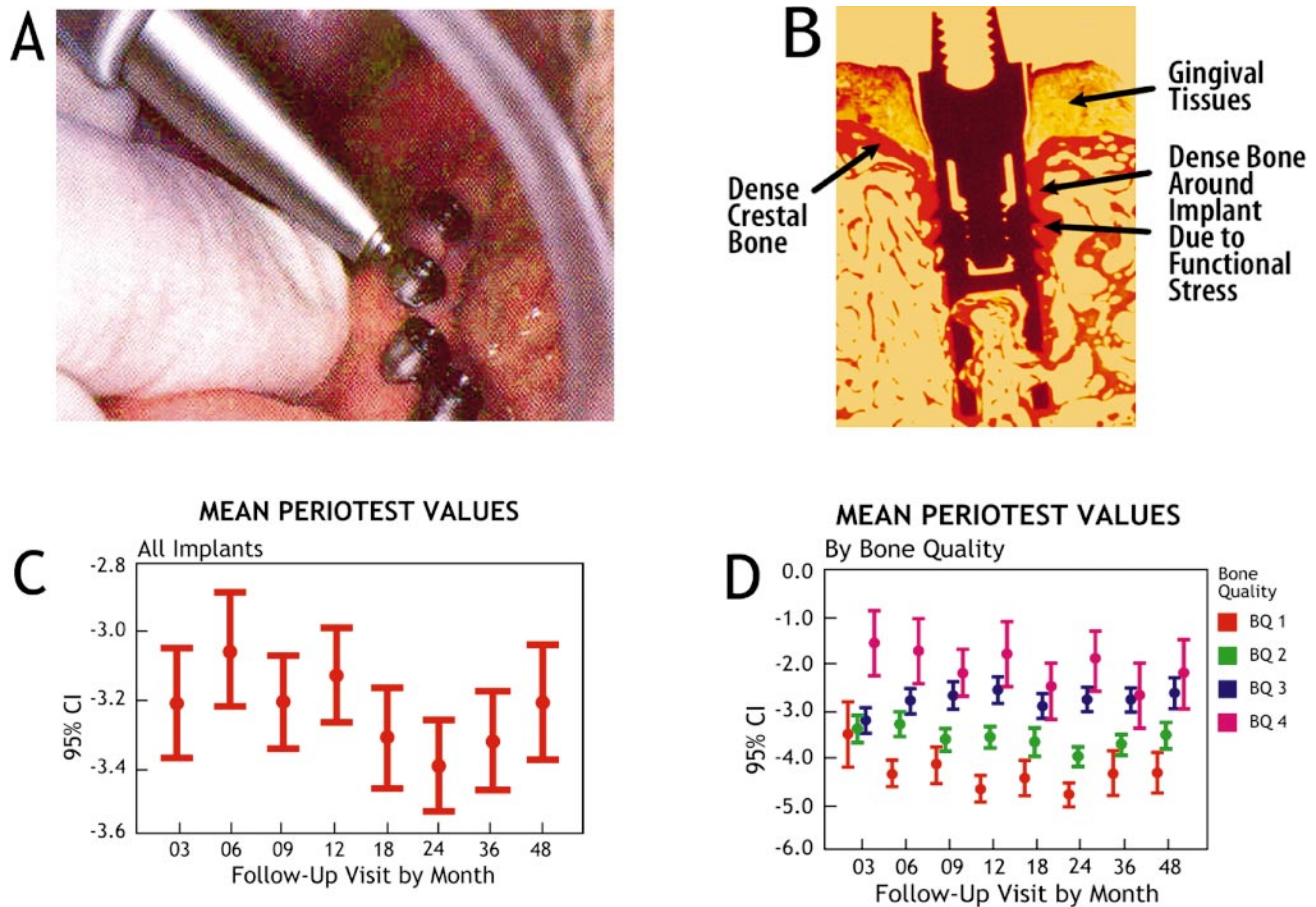


FIGURE 2. (A) Periotest instrument: The plunger rod from the handpiece is positioned slightly above the soft tissue, and the Periotest is activated. (B) Postmortem specimen: The implant is a titanium alloy and was loaded clinically for a period of about 20 months. Note the dense cortical bone at the crest of the specimen and surrounding the dental implant around most of its periphery. This dense layer of bone can be explained by The Carter Hypothesis, which states that bone responds to loading within normal physiological limits by forming increased density of bone. This increase in bone density occurs over a period of time and is documented by the changes in the PTVs recorded for each bone density at each follow-up visit. Roberts²⁰ refers to this as microremodeling of bone. (C) All implants placed: Mean Periotest Value (MPTV); confidence interval (CI) = 95% for Periotest Values (PTVs). For each follow-up visit: At 3 months, MPTV = -3.21; at 6 months, MPTV = -3.06; at 12 months, MPTV = -3.22; at 18 months, MPTV = -3.40; at 24 months, MPTV = -3.40; at 36 months, MPTV = -3.33; and at 48 months, MPTV = -3.21. Differences are not statistically significant. (D) Changes in PTVs over time for each of the 4 bone densities. CI = 95% for PTVs. The 95% CIs are shown above for each of the visits and for each Bone Quality (BQ). BQ-1 is shown in red. At 3 months after uncovering, the mean is about -3.8 PTVs (rigid), and it gradually decreases over time to about -4.5 PTVs (more rigid) at 48 months. BQ-2 is shown in green. At 3 months, the mean is about -3.5 PTVs (rigid), which also gradually decreases over time to -3.8 PTVs but at a slower rate than the increased in rigidity noted for BQ-1. Dark blue represents BQ-3. At 3 months, the mean is about -3.2 PTVs, which appears to become less rigid until the mean at 48 months is about 2.8 PTVs. BQ-4 is shown in pink. At 3 months, after uncovering, the mean is about -2 PTVs and remains around -2 over the 48-month period.

time. The mean PTV recorded for BQ-3 over the 48-month period was -2.8 PTVs. The optimal PTV for BQ-3 was reached between 6 and 18 months. The changes in the PTVs over time do not suggest a major increase in the density of the bone surrounding the implant or that the stability of bone-implant complex is decreasing. The PTVs for BQ-4 are significantly less negative than those of the other bone densities,

which suggests that the bone-implant complex does not improve (PTVs become more negative) with any appreciable amount and may, in fact, be slightly worsening (PTVs become more positive) during long-term functional loading. The optimal stability is evident between 9 and 18 months. The differences in the mean PTVs (stability) is statistically significant for each of the bone densities (Figure 2D).

CONCLUSIONS

The conclusions that one can draw from these results in relation to the goals of this study are the following:

What PTVs would suggest that the implant is integrated? PTVs for implants that appear to be clinically osseointegrated fall within -4 (very stable) and -2 (stable and functional). This range is more critical than the range of -4 to

+2 PTVs reported by Teerlinck.⁹ Any implant with PTVs more positive than -2, should be viewed with some concern, because the bone-implant complex may be marginal and the long-term prognosis for implant survival may be questionable. This is particularly true if the implant is placed in poor bone density or subjected to a functional overload.

What are the changes within the bone-implant complex after loading? Three months after uncovering of the implants, in BQ-1 and BQ-2 there is a general decrease in the PTVs (PTVs become more negative) when the implant is exposed to the oral environment and after loading of the prosthesis. This indicates a positive response (bone density increasing) of the bone to clinical loading. There is a less evidence of this favorable bone response in BQ-3 and BQ-4. BQ-3 appears to remain relatively consistent, whereas there is an indication that the bone-implant complex changes very little if the implants are not overloaded.

What is the influence of bone density on implant stability, and what changes would be considered to be normal responses? There is a correlation between the bone density in this study and the mean PTVs recorded for each bone density. As the bone density increases, the PTVs become more negative (indicating a more rigid bone-implant complex). The PTVs for the 48-month period for BQ-1 range from -3.51 to -4.79 with a mean of -4.34 PTVs; for BQ-2, the mean was -3.61 PTVs; for BQ-3, the mean was -2.78 PTVs; and for BQ-4, the mean was -2.04 PTVs. After loading, the stability of implants in BQ-1 continues to become more negative until a PTV of about -4 is reached. Implants in BQ-2 show similar changes in stability, whereas implants in BQ-3 tend to show no significant positive or negative changes. PTVs associated with implants in BQ-4 tend to become slightly more positive, which suggests possible early breakdown may be starting within the bone-

implant complex as a result of overloading.

Are these observations supported by histological specimens? The histological structure around the implant in the postmortem specimen provides graphic evidence that the bone around the implant responds favorably by increasing its density when subjected to physiologically acceptable levels of loading. This is seen when comparing the bone immediately surrounding the implant with the bone that is farther from the implant.

The Periotest device appears to represent an instrument capable of detecting changes in the bone-implant complex over time in large, well-controlled clinical studies. This instrument may also be of particular value in monitoring the performance of implants that are immediately functionally loaded, provided that the implants are tested numerous times and with only short intervals between the tests. Detecting early signs of a breakdown within the bone-implant complex early enough to allow the necessary intervention would be problematic, because this would require almost weekly testing to provide the number of data points necessary to demonstrate trends.

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