Assessment of the Primary Stability of Dental Implants in Artificial Bone Using Resonance Frequency and Percussion Analyses

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Purpose: *There is no quantitative gold standard instrumentation to assess the quality of implant osseointegration. The purpose of this exploratory study was to evaluate the response of two devices (one based on resonance frequency analysis, the Osstell device, and another that analyzes the percussion energy response, the Periometer) to assess the primary stability of implants embedded in artificial bone models.* ***Materials and Methods:*** *Standard implants were placed into polyurethane blocks of varying densities, and the two mechanical devices were challenged to test the specimen block series. Both analysis of variance and regression analysis were used to examine the output from each device over each series of specimen blocks as well as to directly compare outputs between the two devices.* ***Results:*** *The stability of the implants increased with the foam density for solid block specimens. Linear regression analysis showed significant correlation between the two instruments for testing with monolithic blocks ($r^2 = 0.984$). Both devices also indicated that a hybrid block with the greatest density at the top provided the best implant stability versus a hybrid block with relatively low density at the top of the block. However, resonance frequency analysis readings seemed to be more dependent on the density of the top layer of the hybrid blocks.* ***Conclusion:*** *Osstell and Periometer readings were in good agreement for monolithic blocks, and they were reasonably consistent when blocks of hybrid density were tested.* INT J ORAL MAXILLOFAC IMPLANTS 2013;28:89–95. doi: 10.11607/jomi.2554

Key words: *bone density, dental implant, implant stability, osseointegration*

Primary implant stability is a mechanical phenomenon that is related to local bone quality and quantity and to the type of implant and placement technique used.[1] It is a critical factor in the success of implant integration, since micromotion can lead to failure of osseointegration or fibrous encapsulation of the implant.[2] The evidence regarding the relationship between bone density and primary stability suggests that an objective presurgical assessment of bone density is necessary to determine the influence of surgical protocols.[3] While clinical tools are available to measure implant stability and osseointegration, none is yet considered to be a "gold standard."[4,5] More important, clinical measures are inadequate to judge bone quality with respect to primary stability prior to surgery. Several methods have been used to measure stability and bone quality: histologic analysis, percussion testing, radiologic analysis, removal torque, cutting resistance, and resonance frequency analysis (RFA).[6] Additionally, an instrumented percussion device (Periometer, Perimetrics) provides two pieces of diagnostic information—the loss coefficient and mechanical energy versus time data—that are reportedly able to detect localized defects such as cracks in teeth as well as quantifying implant stability (both primary and secondary).[7,8]

Meredith et al described a noninvasive RFA device (Osstell) that measured implant stability.[9] This portable device measures the characteristic resonance frequency, from which is calculated an implant stability quotient (ISQ).[9–11] ISQs can range between 0 and 100 (measured between 3,500 and 8,500 Hz). It has been reported that a substantial increase or decrease in implant stability can be detected using Osstell that cannot be perceived clinically.[12,13] The repeatability of the Osstell measurements was satisfactory[10,14]; however, some investigators have concluded that RFA is not reliable in identifying mobile implants.[14] In addition,

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Rocci and coworkers concluded that no correlations could be found between any bone morphometric parameters and ISQ values.[15]

One of the simplest methods of evaluating implant stability is by percussion.[1] Outcome measures of tapping, which can be described based on the impact-response theory, are highly dependent on the preceptor or the receiving transducer and signal analysis protocol(s). One quantitative-outcomes approach involves measuring damping, which is the ability of a solid to dissipate mechanical energy.[16] The Periometer (Perimetrics) measures both the structural stability (in bone) and the integrity of dental implants and teeth. Instrumented percussion using the Periometer involves horizontal loading with a percussion rod coupled with an accelerometer to measure the energy return after percussion. A single Periometer measurement takes about 4 seconds. The percussion administered by the Periometer is similar to that for the Periotest (Medizintechnik Gulden). However, there are some important differences between the two systems. First, the Periotest must be held about 1 mm away from the sample during testing,[16] while the Periometer is placed against the sample during testing. This improvement ensures accurate horizontal positioning and helps the operator keep the handpiece steady during testing. The Periometer also has a feature on the handpiece tip that ensures a consistent vertical positioning of the point of percussion on the specimen. Finally, the entire percussion response is analyzed by the Periometer, including mechanical energy amplitude as a function of time. One of the output values of the Periometer is the *loss coefficient*, a damping parameter commonly used in engineering. By contrast, the Periotest measures only the duration of the percussion response and uses this to output a Periotest value, which lies on an arbitrary scale (–8 to +50) and can then be correlated to one of the four integer values of Miller's mobility index (0 to 3). In addition to the loss coefficient, the Periometer also provides an energy return time profile that indicates localized defects, such as incompletely bone-engaged implants. The energy return time profile demonstrates the overall mechanical response of the object being impacted.[7,8] Analysis of these two outputs gives information regarding the attachment of an implant to the bone and the structural stability of the entire implant complex being tested. The Periometer has been demonstrated to distinguish stages of implant integration using clinically relevant mechanical energy.[7] An in vitro study that measured the damping behavior of dental implants embedded in polyurethane foam blocks of various densities concluded that the loss coefficient decreases with increasing density.[7]

The reproducibility of biomechanical testing of implants in cadaver trabecular bone has often been hampered by the mechanical properties of the substrate material.[17] Materials with consistent and controllable mechanical properties similar to those of human cancellous bone, such as polyurethane blocks, can provide an alternative to cadaver bone for many experimental purposes.[18] The polyurethane foam block (Sawbones, Pacific Research Laboratories) has mechanical properties simulating those of human bone.[19,20] It has been used and analyzed in orthopedic and dental research for mechanical testing of the bone-implant interface.[7,19–24] Researchers have also used polyurethane blocks to simulate the Lekholm and Zarb classification for in vitro testing.[23,25]

Several methods are described in the literature for assessing implant stability, which is crucial for osseointegration, but there is no single clinical tool that is considered the gold standard.[4,26] To date, there are no published investigations that have compared the characteristics of the Osstell and Periometer instruments for the assessment of implant stability. Therefore, the purpose of this exploratory study was to evaluate the response of these two devices with implants embedded in artificial bone model material with different densities to simulate the primary stability of implants in a range of clinical scenarios.

MATERIALS AND METHODS

Four solid standard polyurethane blocks with dimensions of 13 × 18 × 4 cm were prepared in four densities: 15 lb/ft^3 (0.24 g/cm^3), 20 lb/ft^3 (0.32 g/cm$^{3)}$, 30 lb/ft^3 (0.48 g/cm^3), and 40 lb/ft^3 (0.68 g/cm^3) (Sawbones, Pacific Research Laboratories). Then, two different types of specimens were created: monolithic and hybrid.

To create the monolithic specimens, four specimens (4 × 3 × 3.5 cm), each from a Sawbones block of uniform density, were cut from larger blocks for initial pilot testing (Fig 1). Implant sites were prepared for four Straumann standard implants (4.8 × 8 mm) using a micromotor hand drill (NOUVAG) in each respective block following the standard Straumann implant protocol. All implants were manually torqued to 35 Ncm using a Straumann torque wrench.

To create the hybrid specimens, three hybrid/laminated blocks were fabricated: one with a 20-lb/ft^3 top layer that was 4 mm thick and a 40-lb/ft^3 base (20/40 lb/ft^3); another with a 40-lb/ft^3 4-mm-thick top layer and a 20-lb/ft^3 base (40/20 lb/ft^3); and a control specimen with a 40-lb/ft^3 top layer and a 40-lb/ft^3 base (40/40 lb/ft^3). Duco cement was used to bond the top layer to the underlying base for each hybrid specimen. The 40/40 lb/ft^3 control specimen was used to verify that the cement would not have a significant effect on the results by comparing its values to those for the monolithic 40 lb/ft^3 specimen. All blocks were fabricated so

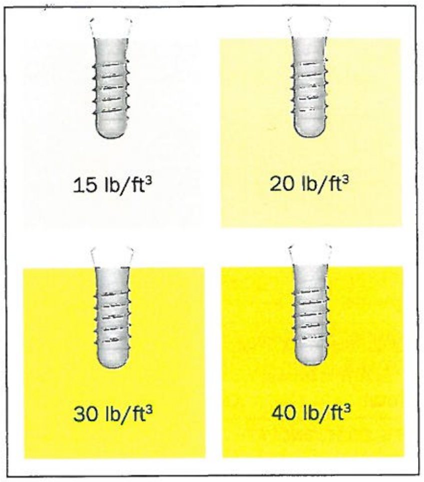

Fig 1 Schematic of the monolithic specimens with simulated bone blocks of different densities: 15 lb/ft^3 (0.24 g/cm^3), 20 lb/ft^3 (0.32 g/cm^3), 30 lb/ft^3 (0.48 g/cm^3), and 40 lb/ft^3 (0.68 g/cm^3).

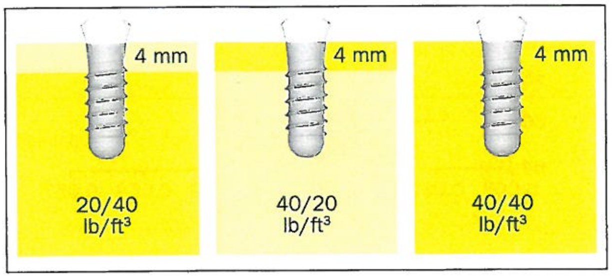

Fig 2 Schematic of the hybrid specimens, each with a 4-mm-thick layer cemented to an underlying block: a 20-lb/ft^3 layer on a 40-lb/ft^3 block (20/40 lb/ft^3), a 40-lb/ft^3 layer on a 20-lb/ft^3 block (40/20 lb/ft^3), and a 40-lb/ft^3 layer on 40-lb/ft^3 block (40/40 lb/ft^3).

Fig 3 Osstell Mentor with Smart Peg and driver.

Fig 4 Periometer with handheld probe and dedicated laptop.

that they all had the same volume (4.5 × 4 × 3.5 cm). Four Straumann Standard implants (4.8 × 8 mm) were placed in each respective block specimen. Implant site preparation was performed as for the monolithic blocks (Fig 2).

Testing Protocol

Two diagnostic devices were challenged to test the monolithic and hybrid specimen series. The first device used was the Osstell Mentor (Osstell) RFA device (Fig 3). This device requires the use of a "smart peg" that is placed on the implant with a special driver; three readings were made buccally and three mesially, as recommended by the manufacturer. This device provides an ISQ, a proprietary number that is related to a derivative of the resonance frequency, which initially has units of frequency (Hz) but is unitless as the provided ISQ.

The second device employed was the Periometer, which is based on percussion energy response analysis (Fig 4). Tests with this device were conducted with the handheld probe percussing a 5-mm regular-neck solid abutment that was attached to the implants. Three readings were made from the buccal side, as recommended by the manufacturer. Loss coefficients and energy return data were tabulated by the Periometer software for each specimen tested.

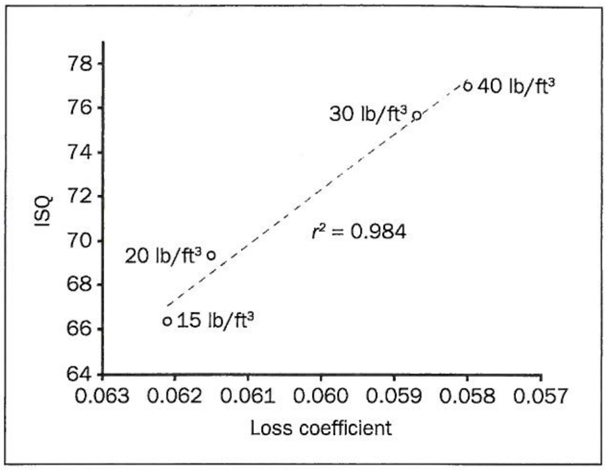

Fig 5 Correlation between the two devices used in the present work for the monolithic specimens. This correlation was significant ($r^2 = 0.984$).

Table 1 Comparison of Periometer Readings for Hybrid Blocks

Comparison	Sum of squares	df	Mean square	F	P
Between groups	.000	3	.000	123.662	.0001
Within groups	.000	32	.000		
Total	.000	35			

P = .0001; ANOVA.
df = degrees of freedom.

Table 2 Comparison of the Osstell Buccal Readings for Hybrid and Monolithic Blocks

Comparison	Sum of squares	df	Mean square	F	P*
Between groups	1,222.750	3	407.583	1,726.235	.0001
Within groups	7.556	32	0.236		
Total	1,230.306	35			

*ANOVA.
df = degrees of freedom.

Table 3 Comparison of the Osstell Mesial Readings for Hybrid and Monolithic Blocks

Comparison	Sum of squares	df	Mean square	F	P*
Between groups	1,182.000	3	394.000	1,576.000	.0001
Within groups	8.000	32	0.250		
Total	1,190.000	35			

*ANOVA.
df = degrees of freedom.

Statistical Analysis

Both analysis of variance (ANOVA) and regression analysis were used to examine output from each device over each specimen block series, as well as to directly compare outputs between the two devices (SPSS 16, IBM; SigmaPlot 9.0, Systat).

RESULTS

Monolithic Specimens

The results generated by both devices for the four monolithic specimens consistently indicated that the stability of the implant increased with the foam density. This finding is consistent with the fact that both the compressive and the shear moduli increase with greater foam density. Linear regression analysis indicated a significant correlation between the two instruments, with an r^2 value of 0.984 (Fig 5).

Hybrid Specimens

Both devices indicated that the hybrid block with the 40/20-lb/ft^3 configuration exhibited the highest implant stability, while the monolithic 20-lb/ft^3 specimen provided the least stability. Both devices also found that the stability of the monolithic 40-lb/ft^3 specimen was statistically the same as the 40/40-lb/ft^3 hybrid control sample. This result confirmed that the cement between the top layer and the base for the hybrid specimens did not significantly alter the measurements of stability. Unexpectedly, the Ostell ISQs for the monolithic 40-lb/ft^3 and 40/40-lb/ft^3 were both significantly lower than that for the 40/20-lb/ft^3 specimen. By contrast, the Periometer indicated that the stability of the monolithic 40-lb/ft^3 and the hybrid control 40/40-lb/ft^3 specimen was statistically the same as the stability of the 40/20-lb/ft^3 specimen. Statistical analysis of the Periometer readings in the hybrid specimens are shown in Table 1. It is not obvious why the Osstell indicated greater stability for the 40/20-lb/ft^3 specimen than for the other specimens that also had 40-lb/ft^3 material at the top portion of the block holding the implant. Additionally, buccal and mesial surfaces of both monolithic and hybrid specimens were read using the Osstell (Tables 2 and 3), and statistically significant differences were found. Table 4 shows the differences observed in a paired *t* test between buccal and mesial readings.

Table 4 Comparison of the Osstell Buccal (b) and Mesial (m) Readings (ISQs) for Hybrid and Monolithic Blocks

					95% CI				
		Mean	SD	SEM	Lower	Upper	*t*	df	*P* (two-tailed)*
Pair 1	ISQ20b × ISQ20m	0.778	0.972	0.324	0.031	1.525	2.401	8	.043
Pair 2	ISQ20/40b × ISQ20/40m	1.444	0.527	0.176	1.039	1.850	8.222	8	.000
Pair 3	ISQ40/20b × ISQ40/20m	1.444	0.726	0.242	0.886	2.003	5.965	8	.000
Pair 4	ISQ40b × ISQ40m	0.222	0.441	0.147	−0.117	0.561	1.512	8	.169

*Paired *t* test.
SEM = standard error of the mean; CI = confidence interval; df = degrees of freedom.

DISCUSSION

The present study is the first of its kind to attempt to compare two mechanical devices for quantitative assessment of implant stability at the time of surgery with potential application in following the course of osseointegration as well: Osstell, an RFA-based instrument for measuring implant stability, and the Periometer, an instrumented percussion method for testing the stability and mechanical integrity of implants and natural teeth. Both instruments have evolved with the goal of providing clinically meaningful data. Neither device has yet received any consensus opinion regarding usefulness or clinical validity. Therefore, this study essentially interrogated both devices by varying both the overall density of bone-simulating substrates and the structures of the substrates. The responses of both devices were compared to gain insight into characteristics of their performance. Initial pilot testing was done (monolithic specimens) to challenge both devices to distinguish among four different foam densities ranging from soft to very hard form (analogous to cancellous type 4 bone to thick cortical type 1 bone), assuming that foam density may be used to represent bone density, which is a main distinguishing characteristic of the classic Lekholm and Zarb bone quality classification.[27] Both devices consistently indicated better implant stability with increasing foam density.

The results indicate that both instruments were generally in agreement and that implant stability increased as block density increased, as indicated by increasing ISQs and decreasing loss coefficients. As shown in Fig 5, a significant linear correlation was observed between the devices over the density range tested.

The Osstell Smart Peg is designed to allow a resonance frequency to be established in the peg-implant complex, and this appears to have been achieved by limiting the connection between the implant and the Smart Peg to a central screw. By contrast, the solid abutment used with the Periometer has both screw and peripheral contact with the wall of the implant, which appears to be a more robust connection for instrumented percussion. It appears that both measures of elastic behavior are consistently related to foam density. For this reason, foam density was used for all subsequent data reporting.

It should be noted that one of the 15-lb/ft^3 monolithic specimens failed while an abutment was being removed from an implant. This failure may be a result partly of the very soft nature of the polyurethane foam of these specimens. Consequently, this lowest-density block was not used in the hybrid testing protocol. Implants were tightened using the Straumann torque gauge to bring the torque resistance back to 30 Ncm following the first round of testing. Implant stability readings for both devices differed between these two rounds of testing but in different directions, with the Osstell device indicating less stability and the Periometer indicating slightly increased stability.

The second round of testing involved the hybrid specimens. This was performed in an attempt to mimic another characteristic of the classic bone quality classification involving the presence of cortical bone along with cancellous bone.[27] Both devices indicated that the highest implant stability was exhibited by the hybrid 40/20-lb/ft^3 specimen. However, there was no significant difference between its value and those of the monolithic 40-lb/ft^3 specimen or the 40/40-lb/ft^3 hybrid control blocks for the Periometer. Based on the expected readings from a "mixtures rule" involving the linear relationships of both devices to block density, the Osstell reading was well above the expected value when the top half of the implant was embedded in the 40/20-lb/ft^3 specimen. One interpretation might be that the resonance frequency increases when the geometric depth of the higher-density support material along the implant is decreased (Fig 6). This geometric effect would give a misleading result, since less

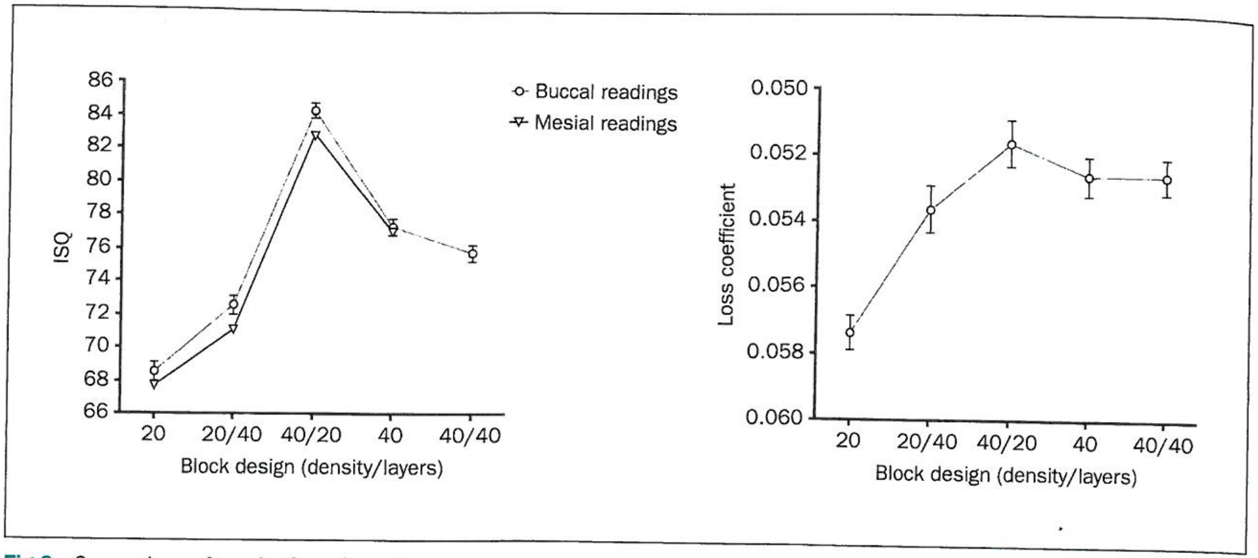

Fig 6 Comparison of results from Osstell and the Periometer for the hybrid and monolithic specimens.

supportive material would seem to produce greater implant stability. This geometric effect would be consistent with the observation that shorter implants inherently exhibit higher ISQs, regardless of the support structure.[28] Statistical analysis (ANOVA) indicated that the ISQs also showed statistically significant differences between buccal and mesial readings. It was not obvious what caused this difference, since the buccal and mesial directions were identical for the present specimens. However, it should be noted that the Smart Peg was removed and reattached between the buccal and mesial measurements. It is possible that some of the bone simulate at the implant surface could have been affected during this reattachment process, which could have led to this discrepancy in the Osstell readings.

The Periometer is interfaced with a dedicated computer that runs application software to process the data. Energy return graphs are processed by the Periometer software saved on the computer. In normal circumstances (analogous to stable implants), there is a uniform bell-shaped response with time, indicating a consistent response from the foam. The shape of the energy return varied for each sample and density, which could be a result of defects at the implant–simulated bone interface. Future research will compare these in a clinical setting and challenge both devices together.

CONCLUSION

Within the circumstances of this study, the null hypotheses were rejected and the following conclusions were made:

1. Implant stability was greater with increasing density of simulated bone.
2. The Osstell and Periometer devices were in good agreement for monolithic blocks, and they were generally consistent for the hybrid-density specimens that were used. However, some inconsistencies in the Osstell readings could not be readily explained.

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