An Improved Impact Technique for Monitoring Percutaneous Implant Integrity

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Purpose: *The purpose of this study was to investigate the validity of the current Periotest system when measuring implant systems and to present a new system to monitor implant interface integrity.* ***Materials and Methods:*** *The new system records an impact accelerometer signal and utilizes software for data analysis to determine the resonance frequency of an implant-abutment system. The new system uses the handpiece from the Periotest to acquire an impact signal but makes no use of the rest of the device. Tests were completed to determine the repeatability of the new system along with the effects clinical variables such as abutment torque, angulation of the handpiece, striking height, and distance handpiece is held from the abutment have on the measurement results. Accuracy of the current Periotest method as well as the new system was independently evaluated through the use of an abutment with a strain gauge attached.* ***Results:*** *The new system for impact testing is shown to have greater accuracy than that of the Periotest device. Additionally, the effects of handpiece distance from abutment and torque (when above 15 Ncm) were found to be negligible while angulation of the handpiece and striking height affected the resonance frequency of the new system.* ***Conclusion:*** *The results of the in vitro testing indicate that greater resolution and accuracy can be achieved from an impact test that utilizes a clinical measurement protocol and independent analysis of the impact accelerometer signal.* *Int J Oral Maxillofac Implants 2008;23:263–269*

Key words: *biomechanics, clinical assessment, diagnosis, impact test, implant interface, implant stability, resonance frequency analysis*

For implants to survive and function, the interface between the bone surface and the implant must be able to support the loads that are transferred from the implant to the surrounding bone structure. Although implant survival rates are high in many applications, implant failures do occur. However, identification of the early stages of failure is challenging.[1,2] Additionally, there are currently a variety of opinions concerning the effect that early loading has on osseointegration. As a result, there is an ongoing clinical need to monitor the integrity of the implant-bone interface from placement through the serviceable life of the implant.

Recent research consensus reports have questioned the clinical validity and relevance of 2 common mechanical systems, the Osstell and the Periotest, used in evaluating the stability of implants.[3,4] These concerns appear to be due to a lack of evidence detailing the sensitivity and precision of the instruments along with a lack of explanation for inconsistent results shown in literature.[5–10]

When using the Periotest the inconsistent and insensitive results reported may result from both the techniques used to analyze the impact accelerometer signal and from clinical variations that occur during measurements. The goal of the present work was to investigate the validity of the current Periotest system measurements and to present a new system for impact testing designed specifically for implants. The new system independently collects and analyzes impact accelerometer data to determine the resonance frequency of the implant-abutment system. The focus of the study was on 4 specific areas:

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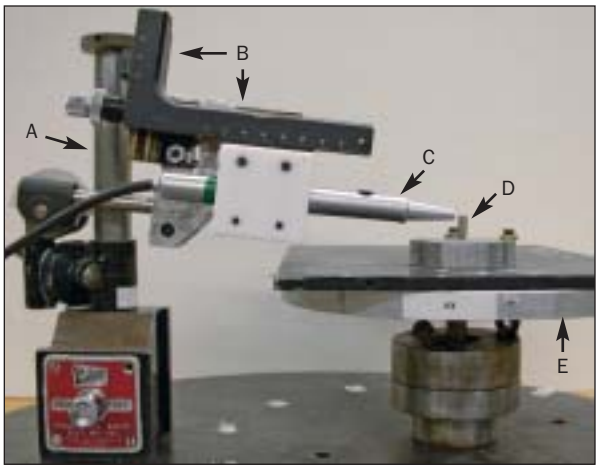

Fig 1 Bracket system to hold the acclerometer handpiece and control the horizontal, vertical, and angular displacements. *(A)* Vertical support, *(B)* 2-axis micrometer, *(C)* handpiece, *(D)* implant/abutment, and *(E)* platform.

1. Evaluation of the Periotest system accuracy when measuring implants.
2. Assessment of the new system's signal processing to increase measurement accuracy.
3. Determination of the resonance frequency from the impact accelerometer signal. Using resonance frequency allows for a continuous measurement scale that is directly related to the impact dynamics.
4. Investigation of the effects of critical clinical parameters on the new system when utilizing a handheld impact device.

MATERIALS AND METHODS

In Vitro Experimental Apparatus

To simulate a range of implant applications, 2 different implants, a 3.75 × 4-mm flanged extraoral implant (Baha; Cochlear Canada, Toronto, ON, Canada) and a 4 × 10-mm intraoral implant (Brånemark system; Nobel Biocare, Göteborg, Sweden) were mounted in 41-mm diameter disks of Photoelastic FRB-10 plastic (Measurements Group, Raleigh, NC). Implants were placed into the disks using drills and taps equivalent to the in vivo placement protocol. The 4-mm implant was inserted into a disk of 5-mm thickness, while the 10-mm implant was placed in a 10-mm-thick disk. Both implants were secured to the disks with epoxy cement (5 Minute Epoxy; Devcon, Danvers, MA) to ensure as uniform an interface as possible. FRB-10 was chosen, as its elastic modulus of 9.3 GPa is within the range reported for cortical bone and dense cancellous bone (1.3 to 25.8 GPa).[11]

Standard abutments with lengths of 3, 5.5, and 10 mm (Nobel Biocare) were coupled to the implants as required using a torque wrench (DIB 038, Nobel Biocare) with a torque of 20 Ncm unless otherwise specified. The FRB disks were then mounted in a circular steel base that was in turn mounted to a stand, which also held the accelerometer handpiece (Fig 1).

The accelerometer handpiece (Periotest, Medizintechnik Gulden, Eschenweg, Modautal, Germany) was mounted on a custom-built adjustable stand that allowed for vertical, horizontal, and angular rotation of the handpiece.[12] The holder had 2 micrometer attachments (Vickers Instrument, York, England) to control the horizontal and vertical displacement. Handpiece angulation was determined using a standard bevel gauge (not shown).

Accuracy of Accelerometer Signal Measurements

To independently monitor the motion of the implant-abutment system, a strain gauge was mounted on a 5.5-mm abutment and connected to the 4-mm implant (details on the type of strain gauges used and strain equipment setup are outlined in a thesis by Swain[13]). An impact was then initiated by aligning the accelerometer handpiece so that the top rim of the abutment was struck. Impact data was collected from the strain gauge, the impact signal used by the Periotest device in calculating a Periotest value, and from the accelerometer signal coming directly from the handpiece utilized in the new system.

To evaluate the accuracy of the impact accelerometer signals over a range of implant-abutment systems, impact data were collected for 3 different systems:

- 4-mm implant with a 10-mm abutment to simulate a less stiff system
- 10-mm implant with a 3-mm abutment to simulate a stiff system
- 10-mm implant with a 10-mm abutment to simulate an intermediate case

Alternate Accelerometer Signal Processing

The accelerometer signal recorded directly from the handpiece utilized in the new system was collected with an Instrunet analog/digital model 100 sampling system (GW Instruments, Somerville, MA) with a sampling rate of 167 kHz connected to a Toshiba Satellite A10 laptop computer (Toshiba, Tokyo, Japan). The collected accelerometer signal was then filtered with a moving average filter to avoid any phase shift or distortion in the signal.[14] The contact time (defined as the time between zero crossings of the accelerometer signal shown by points A and B in Fig 2) was then calculated. This contact time could then be compared to the contact time calculated from the accelerometer signal utilized by the Periotest unit in the calculation of Periotest values (shown as the time between points A and C in Fig 2).

Calculation of Impact Resonance Frequency

The impact resonance frequency was determined from the accelerometer signal collected directly from the handpiece. The impact resonance frequency was determined from the contact time using

$$\text{Freq} = \frac{1}{2 \cdot (\text{contact time})}$$

Evaluation of Clinical Variables

The experimental apparatus was used to evaluate the repeatability of the new system and its sensitivity to several clinical variables. The tests included *(1)* repeatability of measurements, *(2)* handpiece distance from the abutment, *(3)* abutment torque, *(4)* striking height (position along the abutment where contact is made), and *(5)* angulation of handpiece.

Unless otherwise stated, the handpiece was set at an angle of 5 degrees from an axis perpendicular to the 3.75 × 4-mm extraoral implant fitted with a 5.5-mm abutment torqued to 20 Ncm. The distance between the striking rod and the abutment was set to 1.5 mm, and strikes occurred on the superior rim of the abutment.

Repeatability and Reproducibility of the New Measurement System. To evaluate the repeatability and reproducibility of the measurement system, 7 sets of 5 consecutive recordings were completed on the 4-mm implant with a 5.5-mm abutment. Between each set of 5 recordings, the handpiece and stand were moved and then realigned to strike the rim of the abutment in an attempt to replicate the previous set of recordings.

Effect of Handpiece Distance from Abutment. The handpiece instructions recommend that it be held a distance of 0.5 to 2.0 mm from the object being measured. To determine the effect of variations in this distance, 5 recordings at distances of 0.5, 1.0, 1.5, 2.0, and 2.5 mm from the 4-mm implant/5.5-mm abutment system were completed.

Effect of Abutment Torque. To determine the effect of abutment torque on the resonant frequency, a 5.5-mm abutment was torqued to the 4-mm implant system at 5, 10, 15, 20, and 25 Ncm. Five consecutive recordings were made at each of these values. Torque values were determined using a TorsionMaster Testing System (MTS Systems, Eden Prairie, MN).

Effect of Vertical Striking Height. To allow for a greater variation in striking height, the 5.5-mm abutment was replaced by a 10-mm abutment. The abutment was attached to the implant with a torque of 20 Ncm. Recordings were completed by striking the superior rim of the abutment and then lowering the handpiece distances of 0.5, 1, 1.5, 2, 3, 4, 5, and 6 mm. Five recordings were completed at each height.

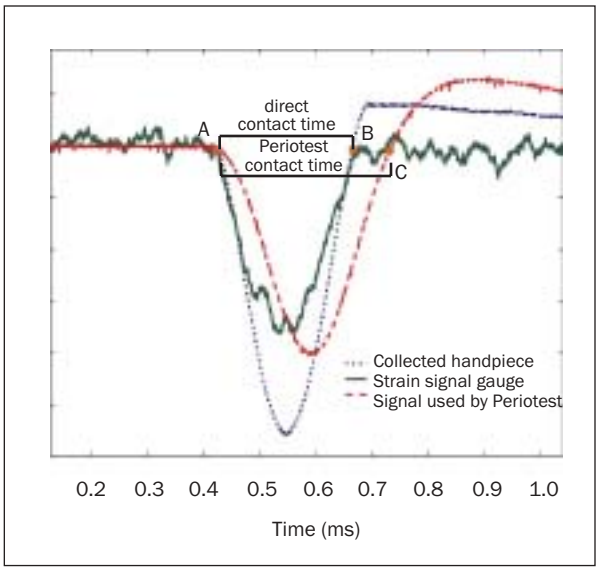

Fig 2 Strain gauge signal, collected handpiece signal, and signal used by the Periotest when striking a 4-mm implant with 5.5-mm abutment. This plot demonstrates that the impact signal used in calculating the Periotest value does not accurately reflect the implant motion.

Angulation of Handpiece. The handpiece instructions recommend an angulation of ±20 degrees from the horizontal. To determine the effect angulation has on the resonant frequency, 5 consecutive recordings were completed at 0, 1, 2, 3, 4, 5, 10, 15, and 20 degrees (with 0 degrees corresponding to having the handpiece perpendicular to the abutment). The angulation of the handpiece was controlled using a standard bevel gauge. Figure 1 shows the handpiece with an angulation of 5 degrees.

RESULTS

Accuracy of Accelerometer Signal Measurements

An example of the impact signals simultaneously recorded from the strain gauge, the handpiece accelerometer, and the Periotest is illustrated in Fig 2. The Periotest rod begins contact with the abutment at point A, as indicated by all 3 signals. The contact time based on the strain gauge signal matches the contact time determined by the collected handpiece signal (difference between points A and B) used in the new system almost identically, while the Periotest unit signal shows a significantly longer contact time (difference between points A and C).

The difference in contact time between the accelerometer signal collected with the new system directly from the handpiece and the signal used by the Periotest in the calculation of the PTV is demon-

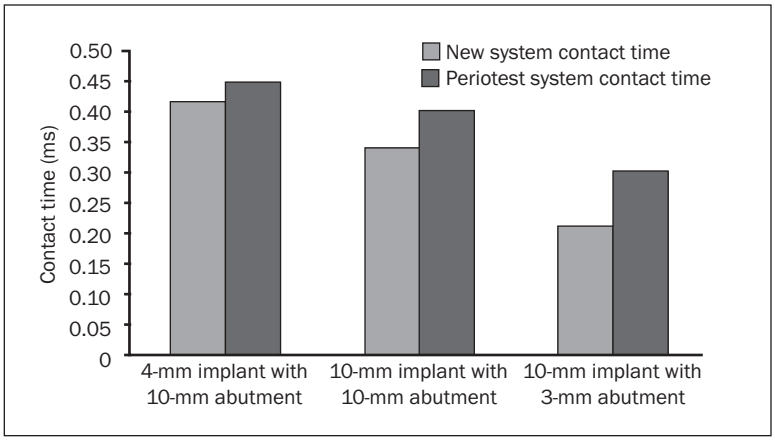

Fig 3 Comparison of contact times in milliseconds of the signal used in the new system and that used in the Periotest unit.

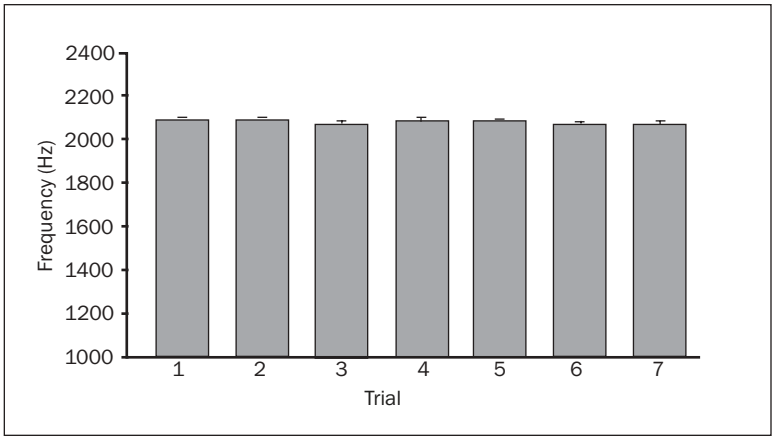

Fig 4 Measurements on the repeatability and reproducibility of the experimental setup. Each bar represents the average of 5 recordings. The error bars on each column (and subsequent plots) indicate 1 standard deviation of the recordings.

strated for different implant-abutment systems in Fig 3. As the stiffness of the implant-abutment systems increased, the difference in contact times between the accelerometer signals increased, with the largest difference occurring with the 10-mm implant with a 3-mm abutment (the stiffest implant-abutment system).

Repeatability and Reproducibility of the New Measurement System

The results of the repeatability and reproducibility measurements are shown in Fig 4. The mean resonance frequency across all trials (7 trials of 5 measurements within each trial) was found to be 2083 ± 12 Hz. Within a single trial, the largest standard deviation was 12 Hz. Of the 7 trials, the lowest average value was 2070 ± 12 Hz (trial 7), and the highest average value was 2095 ± 3 Hz (trial 1).

Effect of Handpiece Distance from Implant System

Figure 5 shows the results of variations in the distance between the handpiece and abutment. The mean value for recordings with the handpiece 0.5 mm from the abutment was 2098 ± 2 Hz, while the mean value at 2.5 mm away was 2082 ± 6 Hz.

Effect of Abutment Torque

The effect of abutment torque on frequency measurement is shown in Fig 6. The recorded frequencies were significantly lower for the abutments attached with 5 and 10 Ncm of torque than for those attached with at least 15 Ncm. The 5-Ncm torque (which was noticeably loose) had the lowest resonance frequency value of 1293 Hz and the largest standard deviation of 43 Hz. The mean resonance frequencies were 2084 ± 9 Hz for 15 Ncm, 2085 ± 7 Hz for 20 Ncm, and 2086 ± 7 Hz for 25 Ncm.

Effect of Vertical Striking Height

Figure 7 illustrates the very significant effect that striking height is known to have on the resonance frequency. Although there was very little change in the frequencies when the handpiece was moved up to 1.5 mm from its initial position, there was a noticeable difference between the 1.5 mm and 2 mm positions and with subsequent changes.

Angulation of Handpiece

As mentioned previously, the handpiece instructions recommend an angulation of ± 20 degrees from the horizontal. Figure 8 demonstrates that as handpiece

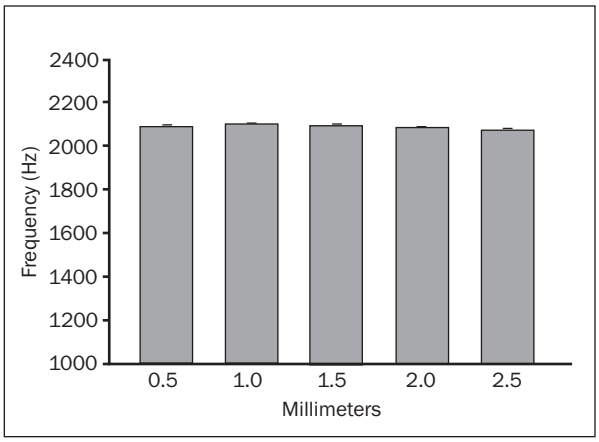

Fig 5 Effect of handpiece distance from abutment on resonant frequency. No noticeable difference between distances was observed.

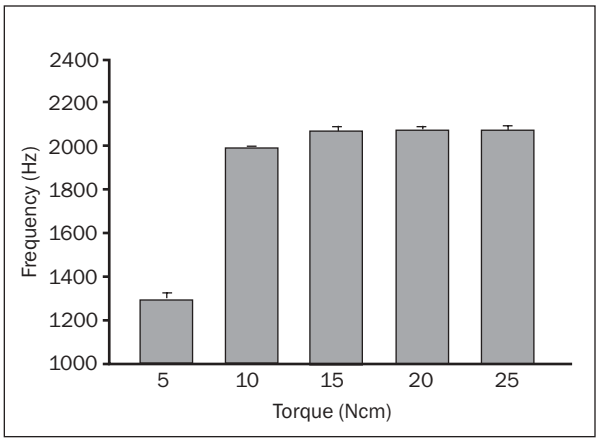

Fig 6 Effect of abutment torque on the resonant frequency of a 5.5-mm abutment with a 4-mm implant. Beyond a torque of 15 Ncm no noticeable difference was observed.

angulation increased from 0 to 20 degrees, the resonance frequency of the system increased from 2178 ± 19 Hz to 2236 ± 10 Hz. The results at 0 degrees were noticeably different from the values recorded at 1 degree, while the results were more consistent between 1 degree and 5 degrees.

DISCUSSION

The analysis of the accelerometer signals collected in addition to the impact signal from the strain gauge mounted on the abutment (Fig 2) demonstrates that the accelerometer signal collected from the handpiece and that collected from the strain gauge had similar contact times, while the accelerometer signal used by the Periotest had a longer contact time. Additionally, the difference in the contact times between the accelerometer signal independently collected from the handpiece, which is utilized in the new system, and the Periotest signal were not always the same. The difference increased for more rigidly supported implants. The results in Fig 3 demonstrate that as the stiffness of the implant-abutment systems increased, the differences in contact times between the new system and the Periotest increased. For a 4-mm implant with a 10-mm abutment, the contact time for the accelerometer signal used by the Periotest was 8% larger than the signal collected directly from the handpiece. For a 10-mm implant with a 3-mm abutment, the Periotest signal had a 40% larger contact time. These results suggest that the accelerometer signals used in the Periotest calculations can have significant and varying amounts of distortion. As a result, to be as effective as possible in detecting clinically relevant changes in implant interface properties, a more precise interpretation of the signal is required. With the new system the analysis of the

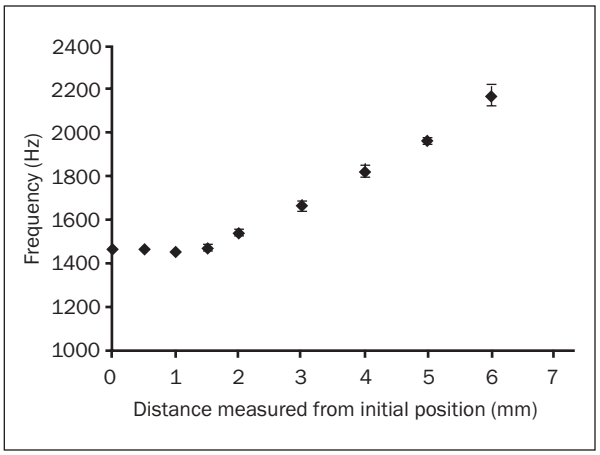

Fig 7 Effect of striking height on resonant frequency. The resonant frequency increased significantly as the abutment was hit farther from the top. This highlights the importance of controlling where the rod strikes when using the instrument.

impact accelerometer signal from the handpiece provides a more accurate representation of the actual motion of the implant-abutment system and thus provides a more accurate measure of the resonance frequency, which can be related to the stiffness of the system. In addition to increased accuracy, by determining the resonance frequency, the new system provides a continuous range of frequencies and greater resolution than the Periotest value scale utilized by the Periotest. For implant-abutment systems with Periotest values ranging between –8 and 0, there is very limited measurement resolution whereas with the new system the resonance frequency will have a continuous range of values from 1300 Hz to 2700 Hz, with higher frequencies corresponding to more stable implants, thereby providing greater resolution with which to monitor changes of the implant-abutment interface.

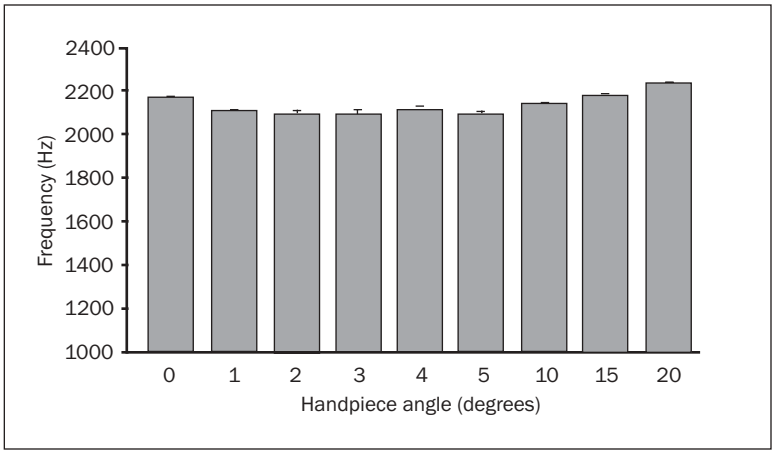

Fig 8 Effect of angulation on the resonant frequency measurements. If angulation is kept between 1 and 5 degrees, there is very little change in the measurements.

Coupled with the need for a more precise signal analysis, the results show that adherence to a strict clinical protocol is required to yield reproducible results. One of the advantages of the use of an impact technique, its flexibility, is also a potential disadvantage (ie, if the technique is used incorrectly, it may yield inconsistent results). This is believed to be one of the reasons for the large variations in results reported in the literature.[15] Figure 4 demonstrates the degree of repeatability and reproducibility that can be achieved when important clinical variables are held constant with the new system. However, when the handpiece is held by hand, these variables become much more difficult to control. This highlights the importance of adhering to a clinical protocol to maximize the precision of the measurements.

The results of variations in the clinical parameters show that, as expected, the position at which the impacting rod strikes the abutment (striking height) can have a pronounced effect on the resonance frequency. However, Fig 7 also demonstrates that there was effectively no change in the resonance frequency when the rod was moved up to 1.5 to 2.0 mm from its initial position. Since the impacting rod is 2 mm in diameter, and the impacting rod was aligned to hit the rim of the abutment in its original position, there is a 2 mm "window" over which the flat tip of the impacting rod will strike the corner of the abutment. Figure 7 shows that as long as a portion of the handpiece impact rod strikes the rim of the abutment, there will be little effect on the resonance frequency measurement.

The distance between the handpiece and the abutment had little influence on the resonance frequency. As long as the distance from the handpiece and abutment was between 0.5 and 2.5 mm, there were practically no differences in the resonance frequency. When the handpiece angulation was kept within the range of 1 to 5 degrees, no substantial differences were evident. The differences between the 0-degree and 1-degree recordings were caused by differences in the point of impact. When the handpiece is placed perpendicular to the striking surface, it is not certain which part of the 2-mm diameter rod is striking the abutment. If the lower edge of the rod strikes the abutment (angle slightly less than 0 degrees), this results in a higher frequency measurement than if the top part of the rod had struck the abutment (angle slightly more than 0 degrees). Effectively, there is a change in striking height, as the rod may be striking different locations along the abutment due to the slight difference in angulation. To eliminate this variability, a small angulation of the handpiece is required. However, as angulation increased past 10 degrees, there was a trend of increasing natural frequency.

The torque applied to the abutment when mounted to the implant also had an effect on the resonance frequency. At torque values of 10 Ncm and below, the reduced stiffness of the joint caused a reduction in the resonance frequency of the system. This effect has been reported previously based on Periotest values.[16] For torques greater than 15 Ncm, the resonance frequency remained essentially unchanged. While it appears that torques above 15 Ncm produce consistent measured frequencies, this was only true for the limited number of implant-abutment systems tested, and may not be the case for all implant-abutment systems.

Based on the tests conducted, the new system seems preferable to measurement with the Periotest. Independent analysis of the impact accelerometer signal collected by the new system directly from the handpiece more closely represented the actual motion of the implant-abutment system. The accelerometer signal used in calculation of a Periotest value was found to contain a distortion in the contact time. Calculating the resonance frequency of the implant and connected abutment with the new system allowed for a continuous variation in frequency instead of the limited resolution provided by the Periotest value.

Based on the tests conducted, the following recommendations can be made to ensure handpiece impact recordings obtained are as accurate and as relevant as possible:

1. It appears that the distance of the impacting rod from the abutment prior to striking will not affect the resonance frequency measurements if it is kept within 0.5 to 2.5 mm.
2. The torque applied when mounting a standard 5.5-mm abutment appears to have little effect on the resonance frequency for torques greater than 15 Ncm.
3. As the effect of striking height on the resonance frequency was found to be considerable, it is recommended that the impacting rod always strike the superior rim of the abutment, a point that is clinically easy to identify and one that allows a ±1 mm variation, when centered, without significantly changing the results.
4. The ± 20-degree handpiece angulation recommended by the instructions is too large for implant-abutment systems. The angle of the impacting rod to the abutment should be kept in the range of 1 to 5 degrees from the perpendicular to the abutment axis. If the handpiece is horizontal (0 degrees), controlling the exact point of contact becomes difficult. For handpiece angulations greater than 10 degrees, there was a trend of increasing resonance frequency.

Although these recommendations will maximize accuracy and repeatability during resonance frequency analysis of an implant-abutment system with a handheld impact test, it should be emphasized that resonance frequency alone does not provide a direct measure of the bone properties at the implant interface (degree of osseointegration). The resonance frequency is a measure of the implant stability, which is influenced by the properties of the bone surrounding the implant but is not a direct measure of these properties. However, the resonance frequency can be related to the supporting bone stiffness and damping properties through the use of an analytical model to interpret the impact accelerometer signal.[17]

CONCLUSION

A new system of measuring bone-implant integrity has been developed based on impact accelerometer measurements. The new system provides greater accuracy and measurement resolution than the Periotest. However, to ensure repeatability of the measurements with the new system, a clinical protocol must be followed to control variables when the system is used to record implant stability.

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REFERENCES

1. Adell R, Lekholm U, Rockler B, Brånemark P-I. A 15-year study of osseointegrated implants in the treatment of edentulous jaw. Int J Oral Surg 1981;6:387–416.
2. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants. A review and proposed criteria for success. Int J Oral Maxillofac Implants 1986;1:11–25.
3. Aparicio C, Lang NP, Rangert B. Validity and clinical significance of biomechanical testing of implant/bone interface. Clin Oral Implants Res 2006;17:2–7.
4. Hobkirk JA, Wiskott HWA. Biomechanical aspects of oral implants: Consensus report of Working Group I. Clin Oral Implants Res 2006;17:52–54.
5. Meredith N, Book K, Friberg B, Jemt T, Sennerby L. Resonance frequency measurements of implant stability in vivo. Clin Oral Implants Res 1997;8:226–233.
6. Nedir R, Bischof M, Szmukler-Moncler S, Bernard JP, Samson J. Predicting osseointegration by means of implant primary stability. Clin Oral Implants Res 2004;15:529–539.
7. Glauser R, Sennerby L, Meredith NI, Rée A, Lundgren A, Gottlow J, Hämmerle C. Resonance frequency analysis of implants subjected to immediate or early function occlusal loading. Clin Oral Implants Res 2004;15:428–434.
8. Olivé J, Aparicio C. The Periotest method as a measure of osseointegrated oral implant stability. Int J Oral Maxillofac Implants 1990;5:390–400.
9. Ichikawa T, Miyamoto M, Horisaka Y, Matsumoto N. Clinical evaluation of Periotest for two-piece apatite omplants. Int J Oral Maxillofac Implants 1994;9:461–467.
10. van Steenberghe D, Tricio J, Naert I, Nys M. Damping characteristics of bone-to-implant interfaces: A clinical study with the Periotest device. Clin Oral Implants Res 1995;6:31–39.
11. Guo XE. Mechanical properties of cortical bone and cancellous bone tissue. In: Cowin SC (eds). Bone Mechanics Handbook, ed 2. Boca Raton: CRC Press, 2001:10–19.
12. Derhami K, Wolfaardt JF, Faulkner G, Grace M. Assessment of Periotest device in baseline mobility measurements of craniofacial implants. Int J Oral Maxillofac Implants 1995;10:221–229.
13. Swain R. Development and Modeling of an Impact Test to Determine the Bone-Implant Interface Properties of Osseointegrated Implants [thesis]. Edmonton, Alberta, Canada: University of Alberta, 2006:24–41.
14. Oppenheim AV, Willsky AS, Young IT. Signals and Systems. Upper Saddle River, NJ: Prentice Hall, 1983: 413–420.
15. Faulkner G, Giannitsios D, Lipsett W, Wolfaardt J. The use and abuse of the Periotest for 2-piece implant/abutment systems. Int J Oral Maxillofac Implants 2001;16:486–494.
16. Faulkner G, Wolfaardt JF, Chan A. Measuring abutment/implant joint integrity with the Periotest instrument. Int J Oral Maxillofac Implants 1999;14:681–688.
17. Swain R, Faulkner G, Raboud D, Wolfaardt J. A dynamic analytical model for impact evaluation of percutaneous implants. J Biomech Eng [in press].