The Use and Abuse of the Periotest for 2-Piece Implant/Abutment Systems

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While the Periotest continues to be used in assessing the integrity of implants, there are numerous reports of its inconsistencies. To understand more precisely what the Periotest is actually measuring, a mathematical model was developed that illustrates the effect that various geometric and clinical parameters have on the Periotest value (PTV). In addition, the model was validated with an in vitro experiment. Results of the mathematical model are shown to correlate with those obtained from the experimental test. The PTV is very sensitive to the position at which the Periotest impacts the abutment and to angulation of the handpiece. It was shown that a change in position of 1 mm in striking height can produce a difference in PTV of between 1 and 2. Since the angulation of the handpiece can produce a difference in striking position of 2 mm, it must be controlled as well. The model also showed that the Periotest can detect changes in bone height of 0.5 mm. (INT J ORAL MAXILLOFAC IMPLANTS 2001; 16:486–494)

Key words: *biomechanics, dental implantation, dental implants, Periotest*

There has long been a need for convenient, commercially available, noninvasive diagnostic tools to evaluate the viability of the bone-implant interface.[1] Traditional techniques such as manual mobility assessment and radiography have shown implants to appear clinically integrated, but subsequently, failure may occur. Moreover, the traditional techniques have not been helpful in early discrimination of loss of mechanical integrity at the abutment-implant interface versus changes in status of the bone-implant interface.

As a result of the above need, several mechanical tests have been proposed for determination of the mechanical integrity of the bone-implant interface. These include applying a reverse torque to the implant, mechanical impedance techniques, resonance frequency analysis, and the Periotest (NIVA, Charlotte, NC). The reverse torque technique, in which a removal torque is applied, can be influenced by many variables and is potentially a destructive test.[2] Proposed mechanical impedance methods include the use of an impact hammer and a steady-state vibration technique.[3,4] A somewhat similar approach is used in the resonance frequency analysis, which uses a small transducer that is screwed onto the implant or abutment to compare the resonant frequency of the implant and transducer to the base values obtained at the time of placement.[5] This evaluation is reported to be convenient and require minimal time to administer.

One of the best-documented techniques is the Periotest, which is similar to the impact impedance method and which uses a small rod to impact a natural tooth in much the same way as the manual tapping mobility test.[6,7] Subsequently, the Periotest has been applied to implant/abutment systems. The signal from an accelerometer mounted to the impacting rod is used to determine a contact time, which is then related to the Periotest value (PTV). In essence, it measures mainly the natural frequency and to a lesser extent the damping characteristics of the tooth or bone-implant interface. None of these

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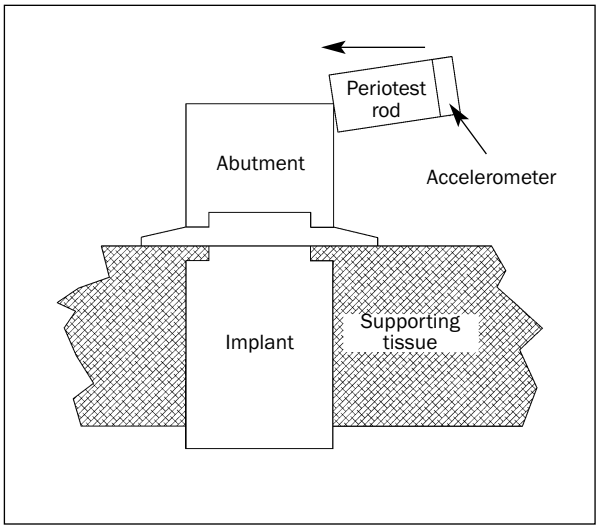
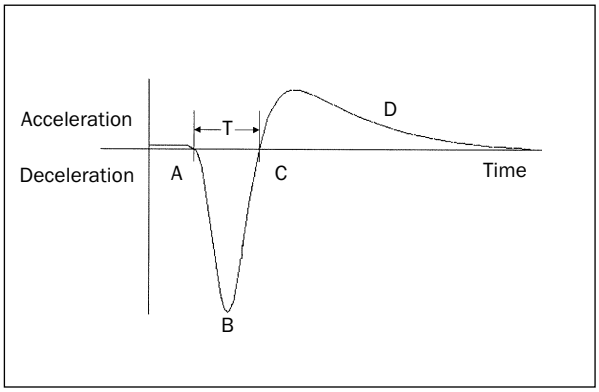


Fig 1 *(Left)* Schematic of Periotest and implant system.

Fig 2 *(Below)* Typical Periotest accelerometer signal.



mechanical techniques are currently in widespread clinical use, since their ability to provide the resolution and confidence in the diagnosis of the integration of an implant is still under active consideration.

The Periotest, while providing a rapid means of measuring the mobility of natural teeth, has been found to be inconsistent, especially for implants.[8–11] Some of the cited studies have shown that large variations of the PTV can occur for clinical variables. These include the position at which the rod impacts the implant, the angulation of the handpiece, and sensitivity to the physiologic variables (integration of the implant and changes in bone thickness), which are of great interest. However, Aparicio reported in an 8-year longitudinal study that the PTV did show a strong correlation to the degree of osseointegration.[10] In addition, a recent in vitro study showed that loosening of the abutment-implant interface could also be diagnosed using the PTV before manual detection was possible.[12] It appears that the Periotest instrument is convenient and easy to use and potentially yields useful information. However, this flexibility and the clinical variables to which the Periotest is sensitive can easily mask the diagnoses being sought.

The purpose of this paper was to discuss a mathematical model of the Periotest impacting the implant/abutment combinations in both intraoral and extraoral applications and to use this model to understand the effect that certain clinical variables and physical parameters have on the PTV. In addition, the model will be validated with an in vitro test to compare the predictions of the model with actual measurements. While there have been previous mathematical models of the Periotest and implant, some of these have been too simple to explain the effects of many of the clinical and physical parameters on the results obtained.[12,13] Elias developed a more complex model in conjunction with the use of the mechanical impedance technique.[14] In the following, a description of a new mathematical model of the Periotest during impact with an implant/abutment model is given. The results of this model, which include the effects of many of the significant clinical variables, are then discussed. The detailed mathematical development of the model and the formulae used in the discussion are derived in detail in the Appendix. The predictions of the model are used to estimate the changes in PTV for variations in clinical and histologic parameters.

DESCRIPTION OF THE PERIOTEST AND IMPLANT/ABUTMENT MODEL

The essence of the instrument and the testing procedure are shown in Fig 1 and include a tapping rod that is caused to impact the implant/abutment assembly. The rod, with its attached accelerometer, is given a velocity by a propulsion coil and is essentially moving at a constant velocity immediately prior to impacting the surface of the implant/abutment or tooth. A typical signal from the accelerometer at impact is shown in Fig 2, which shows that the rod first rapidly slows (from point A to B).

During this period, the implant/abutment unit would have its upper portion displacing to the left

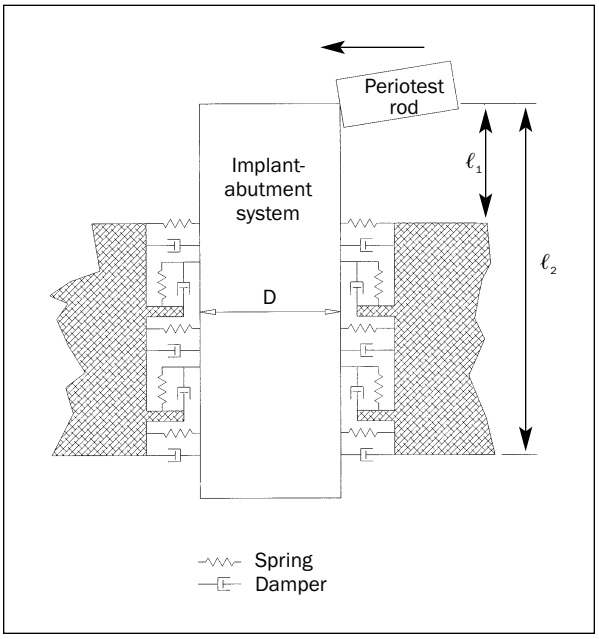


Fig 3 Proposed mathematical model of Periotest and implant system.

in Fig 1. The maximum displacement would occur approximately when the deceleration is at a maximum (point B) and the upper portion of the tooth or implant and rod begins to move back to the right. It is assumed that, during deceleration (region A-B-C), the rod and implant/abutment unit are in contact. Once the acceleration to the right begins, the rod and abutment are most likely no longer in contact and the signal is describing the motion of the rod alone (times after point C in Fig 2). The PTV is directly related to the time (T), denoted as the *contact time*, during which the deceleration occurs and the rod and implant/abutment are in contact. These contact times are in the order of less than a millisecond. The instrument is designed to administer 16 of these impacts in 4 seconds, average the contact times, and calculate the PTV, which is related to T by PTV = 50 T – 21.3 (Equation 1), where T is in milliseconds.[6] For a PTV of 0, the contact time T is 0.426 milliseconds, while for a PTV of –4 it is 0.346 milliseconds.

MATERIALS AND METHODS

Modeling the Periotest

The mathematical model of the test is shown in Fig 3. Here, the implant/abutment is modeled as a rigid body that is supported by hard tissue. The supporting tissues are modeled as distributed stiffnesses (springs of stiffness per unit length parallel and perpendicular to the axis of the implant/abutment), with corresponding distributed viscous damping (damping per unit length). This stiffness and damping include the effects of the interface between the implant and the bone. The model assumes that the implant/abutment is impacted by the rod at some general position, and the dynamic response is determined for the various geometric parameters shown, so that the effect of changes in them can be evaluated. The mathematical model predicts the deceleration that the rod would experience during the time when it is in contact with the implant/abutment, thereby simulating the signal shown in Fig 2. This allows an expression for the contact time, and thereby the PTV, to be determined. As can be seen from Equation A6 in the Appendix, this expression depends on several parameters, including the position at which the Periotest rod impacts the abutment, the thickness of the supporting tissue, the stiffness of the supporting tissue, and the damping provided by the supporting tissue.

To calculate a specific PTV from the equations given requires specific stiffness and damping values for both the horizontal (lateral) and vertical directions. Since these are not precisely known, the model was used to predict the differences in PTV that should be observable between different sets of parameters. For this reason, representative vertical and horizontal stiffnesses were selected to match a particular situation and then used to predict the other cases evaluated (see Appendix). This procedure allows the results to be "normalized" to the values obtained experimentally. The model can then be used to evaluate the effect of clinical and physiologic variables, including striking height, thickness of bone, and changes in the interface between the implant and bone.

In Vitro Experimental Apparatus

To validate the changes in PTV predicted by the mathematical model, an in vitro simulation of the implant/abutment system integrated into bone was developed for testing with the Periotest. The apparatus is shown in Fig 4.

The implants and abutments were mounted in 30-mm-diameter discs with thicknesses of 1.87, 2.78, 3.83, and 4.78 mm. The discs were made from Photoelastic FRB-10 plastic (Measurements Group, Raleigh, NC) with an elastic modulus of 9.3 GPa, which is of the same order as reported for compact bone and denser cancellous bone (5 to 20 GPa).[12] These discs were mounted in a circular steel base that supported them around their periphery. The base and disc were in turn mounted on a stand, which also had attached to it an adjustable holder

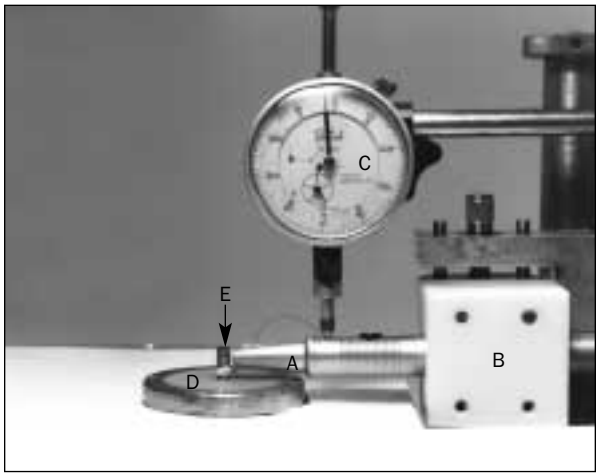


Fig 4 Periotest in vitro setup. A = Periotest handpiece; B = vertical adjustable holder; C = dial gauge; D = photoelastic FRB-19 plastic disc; E = 10-mm abutment.

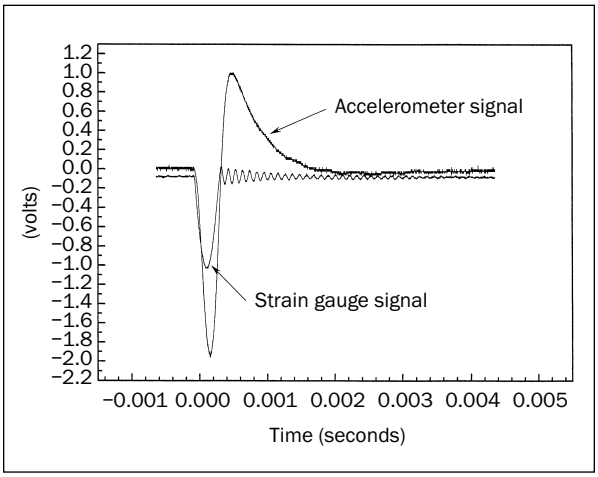


Fig 5 Correlation of signals from strain gauge on the abutment and the Periotest accelerometer. Note both are in phase during contact.

for the Periotest handpiece. The adjustable holder, which was held by a magnetic base, is the same as used by Derhami and coworkers.[8] The handpiece was set at an angle of approximately 5 degrees to the horizontal to ensure that the portion of the rod that impacted the abutment surface was always the uppermost. The height of the impact point from the surface of the modeling material disc was measured using a dial gauge. The distance from the end of the handpiece to the abutment was maintained at 1.5 to 2.0 mm. The implant was a 4-mm flanged implant (SEC 002) of the Brånemark System (Nobel Biocare, North York, Ontario, Canada), while the 10-mm abutment (SDCA 043) was secured to the implant using a 20 N-cm torque.

To obtain greater precision for the PTVs (rather than the integers available from the digital output of the Periotest), the signal from the accelerometer was monitored external to the Periotest and the PTVs calculated directly from these signals. In all cases, the calculated values matched those given by the instrument up to the precision of its output. The PTVs were taken at heights that varied from approximately 5 mm to 10.5 mm (at intervals of 0.25 mm) between the surface of the modeling material and the point of impact of the Periotest rod. At each position, between 8 and 10 values were taken and the average reported. The variation between readings yielded a standard deviation of less than 0.4 PTV for a specific test at a specific location.

To ensure that the accelerometer on the Periotest rod was actually monitoring the motion of the abutment/implant assembly, a strain gauge was mounted on the abutment near the joint with the implant, and the signals from this gauge and the rod's accelerometer were recorded simultaneously. Figure 5 shows the results for the 2 signals and clearly demonstrates that for the first half cycle (while both outputs are negative), the strain gauge and the accelerometer are in phase and giving essentially identical contact times. After the first half cycle, the strain gauge vibrates at a much higher frequency, indicating that the rod is no longer in contact with the abutment. The accelerometer is now measuring the motion of the rod as it moves away from the abutment, while the strain gauge is measuring the motion of the abutment/implant unit alone.

RESULTS

The results of both the numeric modeling and the in vitro testing are shown in Fig 6. It includes the variation in PTVs for various striking heights and for the 4 different thicknesses of the disc material. To normalize the numeric results, the experimental PTVs for the 1.87-mm disc were used to select the damping and stiffnesses (see Appendix for details). With this normalization, the mathematical model effectively reproduces the experimental results. It should be noted that for the thickest disc (4.78 mm), the implant did not extend through the entire disc. As a result, the engagement of the implant and disc was limited to the length of the implant below the flange (4.16 mm). As discussed in the Appendix, this is the dimension that was used in the numeric model.

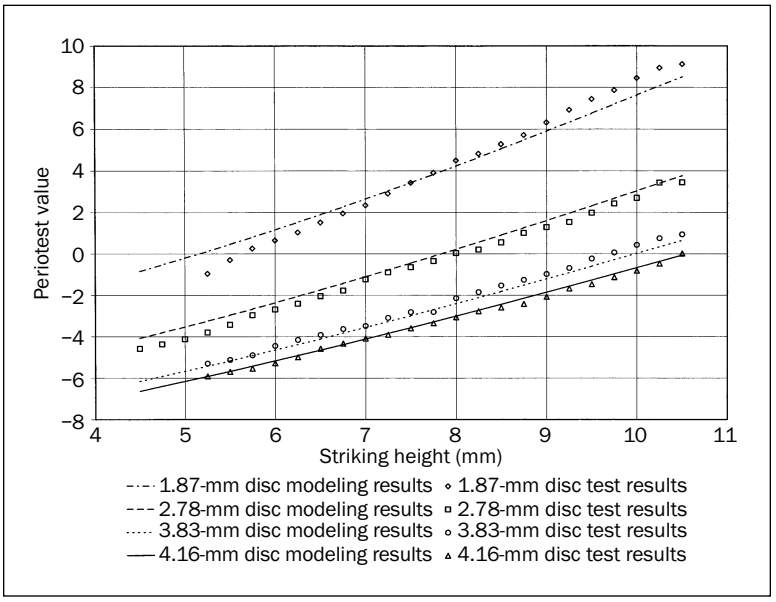


Fig 6 Comparison of numeric model and in vitro experiment for various striking heights and support heights.

The results show consistent trends that increasing the thickness of the supporting disc (ie, bone) increases the natural frequency (ie, decreases the contact time) and thereby decreases the PTV. It also suggests that for the thinner disc (bone) there is a larger marginal increase or decrease in PTV for the same actual decrease or increase in the thickness. As an illustration, note that at a striking height of 8 mm for the 2.78-mm-thick base, the PTV was 0, while for the 1.87-mm disc at the same striking height, the calculated PTV was 4.2. On the other hand, the difference of PTV between the 2.78 and 3.83 mm discs (at an 8-mm striking height) was approximately 2.

The slope of the curves yields the variation of PTV with striking height for a given disc. Again, this variation was strongest for the thinner discs. Considering the 1.87-mm disc, the difference in PTV for striking heights of 8 and 10 mm was approximately 3.8, while for the 3.83-mm disc, the difference was approximately 2.5. Overall, the results indicated a very strong dependence of the PTV on the position of the striking rod and the thickness of the supporting tissue.

DISCUSSION

The variation of the PTV with the variables shown has a number of consequences for the clinical use of the technique. Using the results above and the mathematical model, these effects can be quantified and predicted.

Location of Impact

One of the most often mentioned difficulties with the Periotest is the large variations that occur depending on the exact location of the striking rod on the abutment. With the handheld use of the instrument, it is virtually impossible to strike the abutment at a precise location. As seen above, a variation in striking height of only 1 mm can produce a difference in PTV of between 1 and 2. This suggests that a standardized height should be employed, for example, along the top rim of the abutment.

Angulation of the Handpiece

The dramatic change resulting from alteration of the striking height of the impact may also explain the differences found in attempting to repeat the same test in the same position. The usual practice is to attempt to have the Periotest rod positioned perpendicular to the axis of the abutment during the test. Because the rod itself is 2 mm in diameter, a small change in angulation of the rod relative to the abutment may cause the effective point of contact to change by this diameter (Fig 7). Again the results showed that a variation of 2 mm can cause a change in PTV between 2.5 and 4.0. This suggests that, to eliminate this possibility, a small angle should be maintained between the perpendicular to the abutment and the handpiece.

Changes in Bone Thickness

One of the implant variables that is monitored is the bone thickness at the bone-implant interface. While this can be determined using radiography in

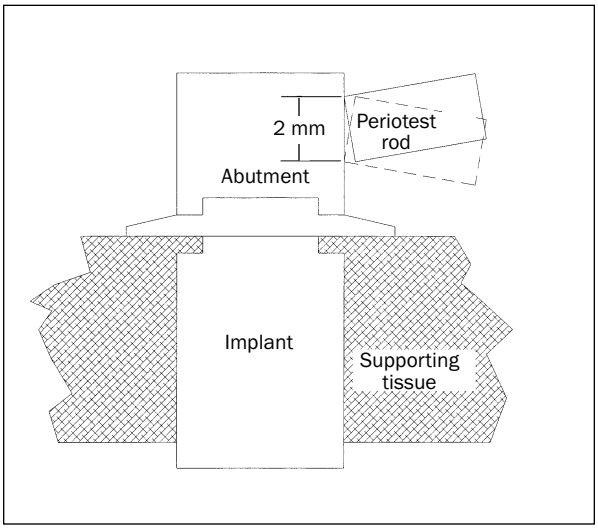


Fig 7 Effect of angulation of the Periotest on striking height.

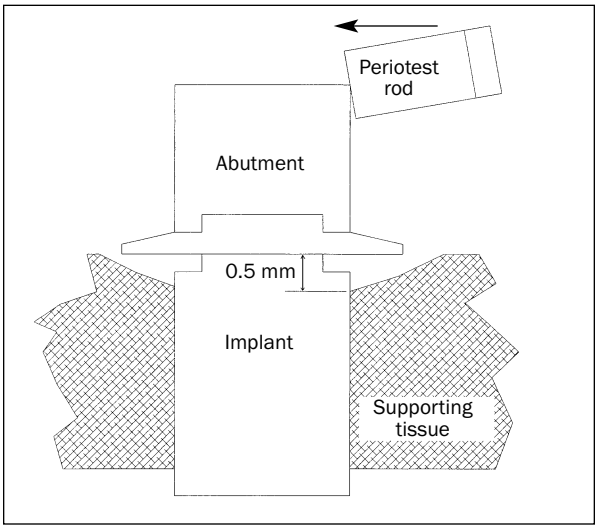


Fig 8 Effect of change in bone height.

the case of dental implants, it cannot be readily assessed in craniofacial osseointegrated implants. It is of interest to predict how a variation in bone thickness would be sensed by the Periotest. Consider the example of an extraoral flanged implant in which the position of the impact on the abutment is constant, and consider the variation that would occur if resorption of the supporting tissue under the flange of the implant occurred so that it thinned by 0.5 mm. The numeric model predicts that if the original thickness were 3 mm and this was reduced to 2.5 mm, the PTV would increase by approximately 2.4 (Figs 6 and 8).

This sensitivity to changes in the supporting tissue also has implications for the direction in which the Periotest is taken. If the thickness varies around the periphery of the implant/abutment, then the direction of impact could change the PTV an appreciable amount. This suggests that more consistent values can be obtained by using a constant direction during PTV recording. It may also be useful to monitor the PTV in different directions to note any preferred orientation of changes in bone thickness.

Change in Stiffness of the Supporting Tissue

Since a change in the structure of the supporting tissue will result in a change in its stiffness, the PTV will also change. If the stiffness of the supporting tissue were to be reduced to 50% of its original value (for example, if the entire bone contact at the bone-implant interface were replaced by soft tissue) the PTV would change by 7 to 8, depending on the original value. This is again a dramatic change and illustrates the extreme sensitivity of this test to changes in stiffness of the supporting tissues.

CONCLUSION

Following implant placement, changes in bone stiffness will occur during remodeling and cellular and acellular mineralization. Presumably, any effect on bone metabolism that influences these processes will influence bone stiffness. Consequently, it is thought that non-destructive mechanical evaluation of bone stiffness surrounding an osseointegrated implant may provide means of indirectly assessing the integrity of the bone-implant interface. In the present study, it would appear that the Periotest, in the modified form used and the mathematical model developed, has the ability to discriminate stiffness of the bone-implant system with appropriate precision.

The Periotest has been shown not to produce interinstrument or intraoperator variability.[8] However, it is vulnerable to variations in the striking height. This issue may be compounded by the rod of the Periotest having a 2-mm diameter. To use the instrument in a repeatable manner, the following is suggested:

1. The upper rim of the abutment should serve as the point for impact by the rod.
2. The handpiece should be maintained at a slight angle (1 to 5 degrees) from the perpendicular to the abutment axis, so that the rod impacts the rim and not the cylindric surface of the abutment.

3. The direction along which the PTV recording is taken is fixed. It may also be useful to record values in 2 perpendicular directions.

It should be also appreciated that the absolute magnitude of the PTV has little importance in the assessment of the bone-implant interface. The value of the Periotest lies in comparing the PTVs for a specific implant over time. Thus, as bone stiffness changes, the relative change in PTV for an implant will provide insight into the condition of the interface for that individual implant.

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APPENDIX: DYNAMIC MODEL OF THE IMPLANT/ABUTMENT AND PERIOTEST

As described above, the implant/abutment of mass m_i is modeled as a rigid body, which is impacted by the point mass m_p of the Periotest rod. During the time that the abutment and impacting rod are in contact, the dynamic response of the system is described using the coordinates θ (rotation of the system) and x (displacement of an arbitrary point O) as shown in Fig A1. In the free-body diagram of Fig A1a, the distributed stiffnesses per unit length of the supporting tissue are given as k for the horizontal and k* for the vertical. It is also assumed that the damping of the supporting tissues (c, c*) is viscous in nature and is proportional to the stiffnesses (α is the proportionality coefficient). The distances shown in Fig A1 include:

- The distance, d, from the point of impact of the rod, O, to the center of gravity of the implant/abutment, G
- The distance l_1 from O to the surface of the supporting tissue (termed the striking height)
- The distance l_2 from O to the base of the supporting tissue or the base of the implant, whichever is smallest (termed the engagement height)
- The radius of the implant, b

As a result, $l_2 - l_1$ is the thickness of engagement of the implant and supporting tissue.

In the mass-acceleration diagram of Figure A1b, J_G is the moment of inertia of the implant/abutment about its center of gravity, G. The superposed dot denotes differentiation with respect to time. The equations of motion can be derived by equating forces and moments from the 2 diagrams in the standard manner. This leads to 2 coupled differential equations, which are conveniently written as (the details of this development can be obtained from the authors):

$$[m]\begin{Bmatrix}\ddot{\theta}\\ \ddot{x}\end{Bmatrix}+[c]\begin{Bmatrix}\dot{\theta}\\ \dot{x}\end{Bmatrix}+[k]\begin{Bmatrix}\theta\\ x\end{Bmatrix}=\begin{Bmatrix}0\\ 0\end{Bmatrix} \qquad \text{(Equation A1)}$$

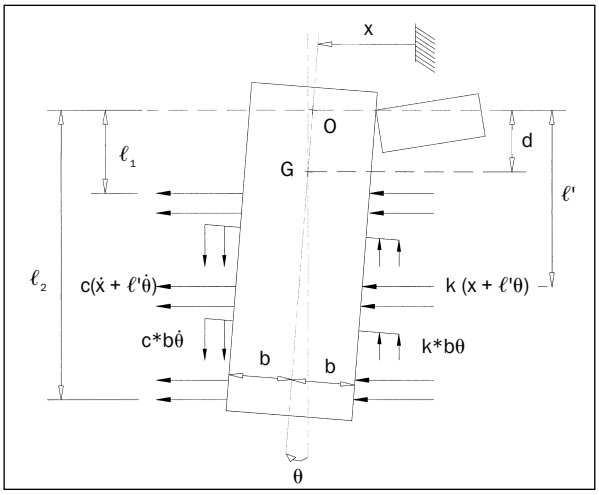

Fig A1a Free-body diagram of implant-bone model.

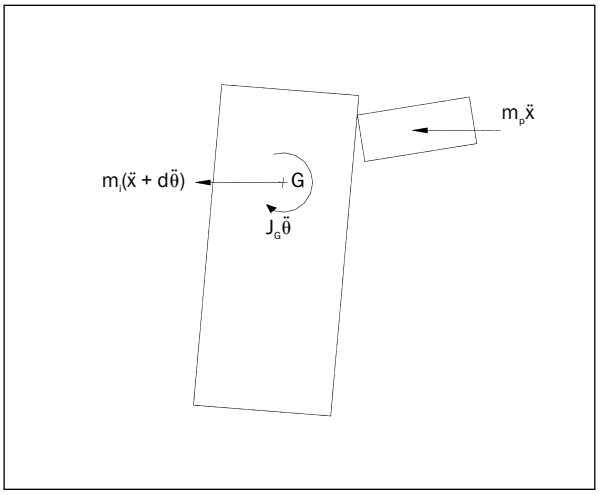

Fig A1b Mass-acceleration diagram.

where the mass, stiffness, and damping matrices are:

$$[m] = \begin{bmatrix} J_G + m_i d^2 & m_i d \\ m_i d & m_i + m_p \end{bmatrix} \qquad \text{(Equation A2)}$$

$$[k] = \begin{bmatrix} \frac{k}{3}(\ell_2^3 - \ell_1^3) + k^* b^2(\ell_2 - \ell_1) & \frac{k}{2}(\ell_2^2 - \ell_1^2) \\ \frac{k}{2}(\ell_2^2 - \ell_1^2) & k(\ell_2 - \ell_1) \end{bmatrix}$$

$$[c] = \alpha[k] \qquad [c^*] = \alpha[k^*]$$

$$\alpha = \frac{c}{k} = \frac{c^*}{k^*}$$

For a typical implant/abutment, the mass m_i is of the order of 0.5 gm, while the mass of the Periotest rod m_p is 8 gm. As a result, the mass of the implant/abutment m_i and the corresponding moment of inertia J_G can be neglected, as they have a small influence. The equations of motion then reduce to

$$\begin{bmatrix} 0 & 0 \\ 0 & m_p \end{bmatrix} \begin{Bmatrix} \ddot{\theta} \\ \ddot{x} \end{Bmatrix} + \alpha \begin{bmatrix} k_{11} & k_{12} \\ k_{21} & k_{22} \end{bmatrix} \begin{Bmatrix} \dot{\theta} \\ \dot{x} \end{Bmatrix} + \begin{bmatrix} k_{11} & k_{12} \\ k_{21} & k_{22} \end{bmatrix} \begin{Bmatrix} \theta \\ x \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix}$$

(Equation A3)

where the stiffness matrix components, k_{ij}, are as previously given.

Equation A3 is equivalent to a single degree of freedom system. For a solution in which the implant/abutment is at rest prior to being impacted by the rod, the coordinates θ and x are related by

$$k_{11}\theta + k_{12}x = 0 \qquad \text{(Equation A4)}$$

so that the equivalent single degree of freedom equation of motion reduces to:

$$m_p\ddot{x} + \frac{(k_{11}k_{22} - k_{12}^2)}{k_{11}}(x + \alpha\dot{x}) = 0 \qquad \text{(Equation A5)}$$

$$m_p\ddot{x} + c_e\dot{x} + k_e x = 0$$

where

$$k_e = \frac{k_{11}k_{22} - k_{12}^2}{k_{11}}, \; c_e = \alpha k_e$$

are the effective stiffness and effective damping in the single degree of freedom system.

The solution to Equation A5 is well known and has been previously given.[12] The contact time was shown to be

$$T = \frac{1}{p\sqrt{1-\zeta^2}}\left[\pi - \tan^{-1}\frac{2\zeta\sqrt{1-\zeta^2}}{1-2\zeta^2}\right]$$

where

$$p = \sqrt{\frac{k_e}{m_p}}$$

$$\zeta = \frac{c_e}{c} = \frac{\alpha k_e}{2m_p p} = \frac{\alpha}{2}p \qquad \text{(Equation A6)}$$

where ζ is the damping ratio and p is the undamped natural frequency.

The corresponding PTV can be calculated from Equation 1, given in the body of the text.

To evaluate the contact time and then the PTV, it is necessary to have the stiffnesses k and k* as well as the damping constant α. This was done by selecting the ratio of k* to k and the absolute value of k, so that the results for the 1.87-mm disc at a striking height of 7.5 mm match the in vitro results, and so that the difference in PTV resulting from the difference in disc thickness from 1.87 to 2.78 mm also matched with that obtained from the experiments. This resulted in a ratio of k*/k of 10. It should be noted that for the 4.78-mm disc, the distance l_2 was taken as the implant length (4.16 mm), since the implant does not extend through the disc as it does for the other thicknesses. The experimental output from the strain gauge shown in Fig 5 shows the system to have very little damping, and as a result the damping constant α was set to 0.