Measuring Abutment/Implant Joint Integrity with the Periotest Instrument

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Maintenance of the integrity of the abutment/implant interface is essential and is dependent on the abutment screw retaining a preload. Evaluation of this joint is usually done by manual assessment. The purpose of the current study was to determine whether the Periotest instrument could be used to evaluate abutment screw loosening. A custom-designed apparatus was constructed to measure abutment screw loosening. Abutment screws were torqued to 10, 20, 32, and 45 Ncm and then loosened. Objective assessment of screw loosening was carried out with the Periotest device. Subjective evaluation was done by 3 experienced clinicians. The Periotest was found to be more sensitive than manual detection of abutment screw loosening. With a change of 2 in the Periotest value, it was found that the tensile preload in the joint was lost. While the Periotest was more sensitive than manual evaluation, the instrument was not sensitive enough to indicate deterioration of abutment screw loosening prior to loss of tensile preload.
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Key words: abutment/implant interface, abutment screw, abutment screw loosening, Periotest, Periotest value, tensile preload

Maintenance of the integrity of the craniofacial abutment/implant joint is a continual concern, as loosening of the joint may lead to mechanical failure of the prosthesis. The usual evaluation of these joints involves a manual "wobble" test to detect any perceptible relative motion. This may be difficult to perform, and as a result a loose joint may go undetected. It would be advantageous to have a simple, objective means to detect any loosening before it is easily seen via the manual technique. During the past several years, the Periotest instrument (Siemens, Bensheim, Germany) has been used at the Craniofacial Osseointegration and Maxillofacial Prosthetic Rehabilitation Unit (COMPRU), Misericordia Hospital, Caritas Health Group, Edmonton, Alberta, Canada, as a diagnostic tool to evaluate the tightness of the abutment/implant joint.

While the Periotest was developed to dynamically measure the reaction of the periodontium to a defined impact load,[1] it continues to be used for other applications related to implants.[2,3] The device uses an electronically controlled rod that impacts the tooth or implant at a constant velocity. The time taken to decelerate the rod is some measure of the stiffness and damping of the supporting tissue. This time is measured and converted to a numerical value between –8 and +30. This numerical value is termed a Periotest value (PTV). The advantage of the Periotest is that it provides a fast, noninvasive, yet quite reproducible technique to measure mobility without need for a fixed reference point. The Periotest has been examined to provide a measure of oral and craniofacial implant

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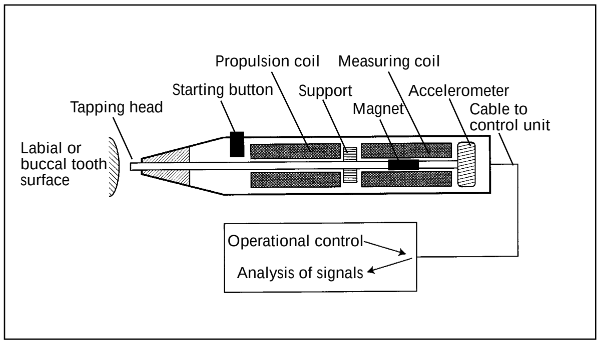

Fig 1 Periotest schematic (derived from Lukas and Schulte[1]).

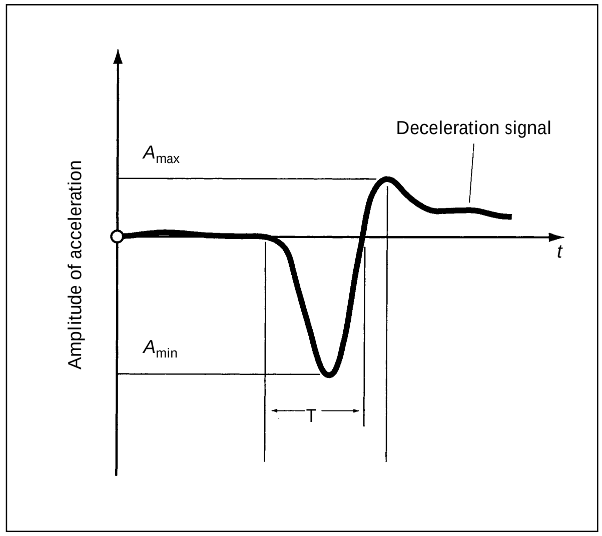

Fig 2 *(Right)* Periotest accelerometer signal (derived from Lukas and Schulte[1]).

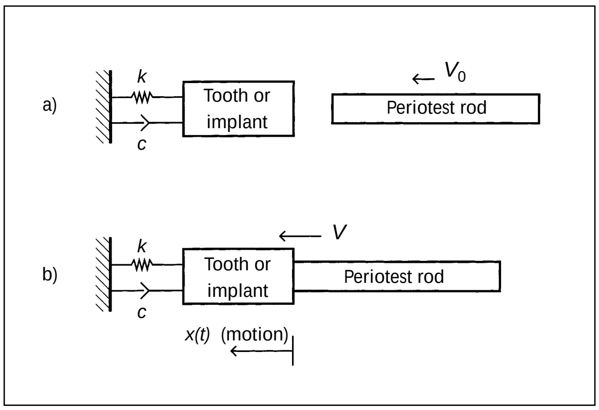

Fig 3 Model of tooth or implant for Periotest evaluation.

stability.[2,4] The PTV has been investigated as a predictor of the degree of osseointegration that has developed at the bone/implant interface. However, there are several factors that can influence the PTV for this application. The quality of the hard tissue in the region of the implant has been shown to be a factor in the PTV,[4] so that no specific values can be deemed appropriate for higher or lower degrees of integration. While the Periotest is applied to the abutment of a craniofacial implant system, it has been shown that the PTV is a function of the distance from the implant flange to the point at which the rod impacts the abutment.[3] All these variations suggest that for implants there is no absolute PTV that can be regarded as acceptable; rather, variations that occur over time may be more meaningful. These and other issues have led researchers to investigate other technologies to evaluate the bone/implant interface.[5,6]

To appreciate the results from the Periotest instrument, it is helpful to understand the nature of the measurements that it makes. The essence of the instrument is shown in Fig 1 and includes a tapping rod that impacts the tooth or abutment/implant assembly. The rod is drawn by a propulsion coil toward the impacting surface and essentially moves at a constant velocity from the moment it leaves the handpiece until it impacts the surface. This means that over a certain distance (approximately 4 mm), the tapping rod is moving at the same velocity and is designed to impact the surface at any time during this constant-velocity travel. The end of the rod inside the handpiece is rigidly connected to an accelerometer, which produces an output proportional to its acceleration. A typical measured acceleration signal for impact with the labial surface of a tooth is shown in Fig 2. This figure shows that the rod first slows rapidly, as the lower portion of the curve indicates. The rod then has its acceleration increase, until after a certain time (T) the acceleration is actually in the opposite direction (upper portion of the curve). The PTV is directly related to T, denoted as *contact time,* when the acceleration changes from negative to positive, and is an average of 16 repeated impacts (independent tests) taken in 4 seconds. This parameter was shown to be the best correlate to the subjective mobility measurements.[2] The question is, "what is T and what factors actually control variations in T?"

To attempt an explanation of the dynamic phenomena, a 1-dimensional model of the system similar to that used by Kaneko[7] was developed (Fig 3). It is important to realize that in normal use of the Periotest, as well as in static mobility measurements, the tooth or implant undergoes both translation and rotation, so that the motion description would require at least 2 coordinates. In what follows, it will be assumed that the mass, stiffness, and damping of the system are the effective values for the dominant motion (this is most likely the rotation of the tooth or implant). The intention is to provide a simple model that gives results within the expected order of magnitude and allows an appreciation of which parameters are the most important.

If the tooth or implant assembly (Fig 3) is modeled as a simple mass and the supporting tissue as having 2 properties—an effective stiffness (k) and effective viscous damping (c)—then the response of the tooth or implant and rod after impact of the Periotest rod can analytically be shown to result in the displacement, velocity, and acceleration developed and given in the Appendix. (An analogy would be the suspension system on an automobile, in which the mass of the car would be supported by the springs, which provide the stiffness, and the shock absorbers, which provide the damping.) If it is assumed that the Periotest rod and tooth or implant remain in contact during T, the contact time can then be theoretically determined from the expression A6 in the Appendix, where ζ is the damping ratio, which is given by c/2Mp, and p is the natural frequency determined from $(k/M)^{1/2}$. The mass (M) includes the mass of the tooth or implant and that of the Periotest rod. The damping ratio is a measure of the damping in the system, while the natural frequency is essentially a measure of the stiffness for a given mass. This simplified model can be used to evaluate the sensitivity of T to changes in tooth parameters. For a typical tooth, the damping ratio (ζ) is estimated to be approximately 0.25. Increasing the damping to 0.50 (factor of 2) causes the contact time to decrease by approximately 3%. Decreasing the stiffness by a factor of 2 causes T to increase by approximately 40%. This suggests that changes in the stiffness, not changes in the damping, would have the most significant effect on the contact time. For PTV of less than 13 (mobilities for healthy teeth) the relationship between T and the PTV is linear: PTV = 50,000 T – 21.3. At a PTV of 0 (subjectively, a stable anchored tooth) T is 0.426 milliseconds, and T must increase by 0.02 milliseconds (approximately 5%) to cause an increase to a PTV of 1. Using the simple model above, this change of 1 in the PTV would be the result of decreasing the damping to 50% of its original value or of decreasing the stiffness by only 7%. Again, the PTV would be much more sensitive to changes in stiffness than in damping.

As suggested above, the purpose of the present study was to evaluate the Periotest instrument as a potential means for clinical assessment of abutment screw loosening and in so doing also compare it against subjective measurements taken by experienced clinicians. If the Periotest is to be used for measuring loosening, then the stiffness changes that are to be measured are not changes in the supporting structure, but changes in the stiffness of the abutment/implant assembly itself. In this case, the stiffness used in the model above is the combined stiffness of the supporting structure and the mechanical assembly. The study below is then to evaluate the effectiveness of the Periotest in detecting changes in the stiffness of the assembly.

Materials and Methods

Experimental Apparatus. The experimental technique to measure the degree of screw loosening compared to the PTV was done in vitro using the apparatus shown schematically in Fig 4 and photographically in Fig 5. All the craniofacial implant components and instruments were of the Brånemark System (Nobel Biocare Canada, North York, Ontario, Canada) and included a 4-mm flange implant (SEC 002) secured into a 5-mm thick, 30-mm-diameter base of aluminum with Loctite 272 compound (Loctite, Hartford, CT). This rigid mounting of the implant was to ensure that the loosening occurred only in the abutment screw. The implant and base were then secured into the test stand directly below the angular motion assembly, and the 4.0-mm abutment and screw (SEC 008) were mounted on the implant using the Torque Controller set (Nobel Biocare Canada). Angular movement of the abutment screw was monitored by means of the assembly shown above the abutment. This includes a collar that held the manual screwdriver (DIB 038), which was in turn held onto the abutment screw by a spring-loaded rod. This rod was held by 2 arms to the vertical portion of the stand as shown. A rotary variable inductance transformer (RVIT-15-60, Schaevitz Engineering, Pennsauken, NJ) was mounted on the top of the rod to measure the angular position. The output of the RVIT was monitored by a digital voltmeter (Fluke 8062A, John Fluke Manufacturing, Seattle, WA), which gave a voltage reading proportional to the angle rotated by the abutment screw.

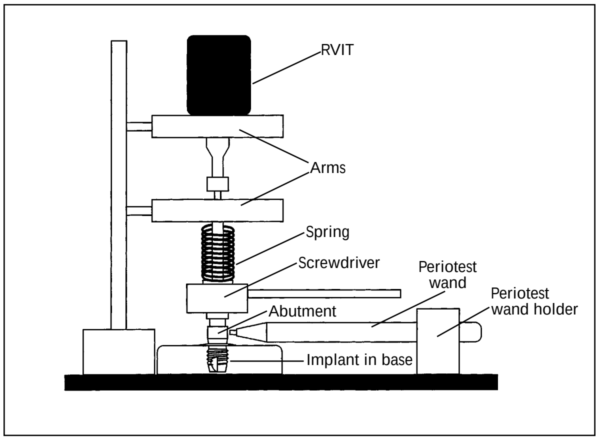

Fig 4 Design of apparatus to determine screw mobility using the Periotest instrument. RVIT = rotary variable inductance transformer.

Fig 5 Apparatus to determine screw mobility using the Periotest instrument.

The stand itself was mounted on close-fitting pins, allowing it to move vertically when released. This allowed the angular measurement assembly to be released from the abutment screw before a PTV was measured by the Periotest handpiece, which was mounted on the base. In addition, the attachment of the arms to the stand could be released so that they could be rotated away from the abutment. This was done to allow the Torque Controller to set the abutment screw with different torques.

Four implants mounted in 4 circular bases, each with their corresponding abutment and abutment screw, were evaluated to provide evidence that the results were not specific to one set of hardware.

Experimental Procedure. *Objective Measurements.* For each of the 4 base/implant combinations, the following procedure was performed:

1. The base with implant was firmly attached to the test stand.
2. The abutment was attached to the implant using the Torque Controller set to a 10 Ncm torque.
3. A PTV was obtained after the Periotest was calibrated.
4. The spring-loaded rod and angular measuring transducer system was engaged with the abutment to give an initial position of the abutment screw.
5. With the screwdriver, the abutment screw was manually loosened from 1 to 3 degrees. The specific angular change in this loosening was measured using the RVIT.
6. The screwdriver, rod, and measuring assembly were lifted from the screw into a noncontact position with the abutment and abutment screw.
7. A PTV was recorded.
8. The previous 3 steps were repeated until the screw was loosened to a total of approximately 50 degrees. At this point the screw was noticeably loose.
9. After completing this series with a starting torque of 10 Ncm, the same series was done at 20, 32, and 45 Ncm.
10. Each implant/abutment/screw and base assembly was tested twice at each torque setting.

To determine the correlation between angular displacement and the torque applied to the abutment screw, a further test was done on each of the four test abutment assemblies. This involved measuring the angular change when the screw was tightened from 10 Ncm first to 20 Ncm, then to 32 Ncm, and finally to 45 Ncm. This procedure was repeated 4 times for each of the 4 assemblies. These torques are the torques available on the Torque Controller. Prior to testing, this instrument was calibrated at Nobel Biocare to be within 2% of the indicated value.

Subjective Evaluation. The subjective tests involved measuring the angular change between the situation in which the screw was torqued to the prescribed value and then loosened by the clinician until it "felt loose" by means of trying to "wobble" the abutment. The procedure outlined below was applied to one of the abutment/implant assemblies in the same apparatus as described

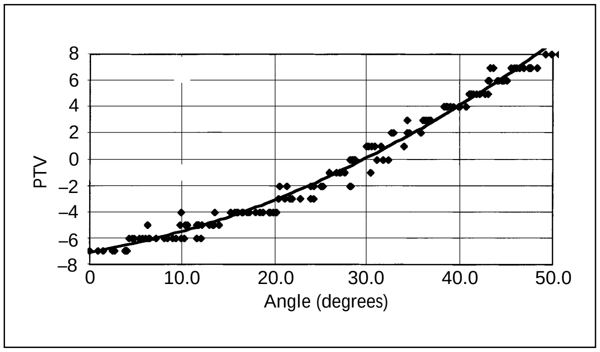

Fig 6 Periotest values (PTV) for abutment screw loosening when the abutment screw was torqued to 10 Ncm.

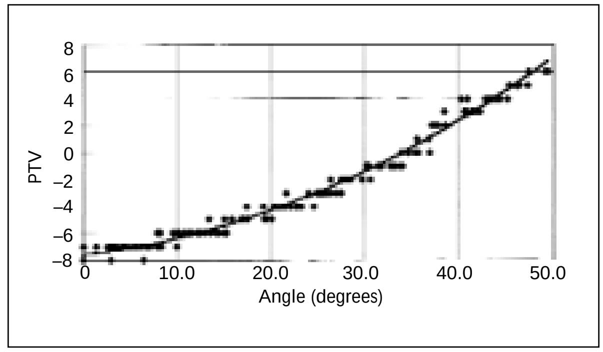

Fig 7 Periotest values (PTV) for abutment screw loosening when the abutment screw was torqued to 20 Ncm.

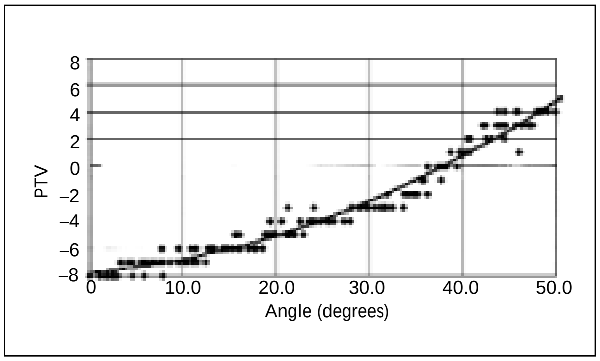

Fig 8 Periotest values (PTV) for abutment screw loosening when the abutment screw was torqued to 32 Ncm.

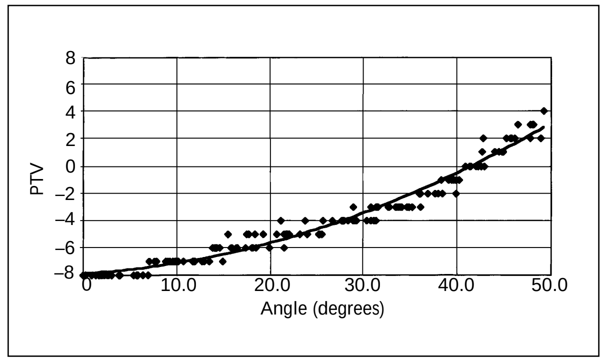

Fig 9 Periotest values (PTV) for abutment screw loosening when the abutment screw was torqued to 45 Ncm.

above for the objective measurements. This series of subjective tests were performed by 3 clinicians.

1. The abutment screw was tightened to 10 Ncm using the torque driver.
2. The angular position of the abutment screw was noted using the RVIT.
3. The clinician slowly loosened the screw using the screwdriver and periodically checked manually for looseness.
4. After detecting when the screw/abutment felt loose (through wobbling the abutment), the clinician noted the angular position of the screw and calculated its difference from the start position.
5. The test was repeated 3 times at the same initial torque value.
6. The screw was successively tightened to 20, 32, and 45 Ncm, and the entire procedure was repeated.

Results

The results of tests on all 4 of the abutment/implant assemblies are shown for each of the 4 initial torque settings (10, 20, 32, and 45 Ncm) in Figs 6 to 9. The PTV ranged from –8 to +8 over an angular range of approximately 50 degrees. As seen from the data, the initial PTV (before any loosening was done) were all either –7 or –8, suggesting that some may have actually had a stiffness equivalent to even lower PTV but were limited by the lower limit of the Periotest (–8). This is likely the reason that the data at the higher initial torques appear to asymptote to –8. At the higher values of angular rotation (> 40 degrees), the data are also more inconsistent than at the lower angular rotations, as the abutment was noticeably loose at this point of the testing. In the central portion of the angular rotation range the data appeared similar.

Table 1 Angular Change Needed to Loosen Abutment Screw (Degrees)

	Amount of torque			
Clinician	10 Ncm	20 Ncm	32 Ncm	45 Ncm
1	28.4	41.4	62.7	67.0
	25.9	38.4	65.7	70.1
	30.6	47.8	55.0	66.3
2	26.8	16.3	26.9	37.3
	21.7	25.0	28.4	27.2
	26.2	24.6	21.8	23.4
3	37.8	32.6	57.9	44.3
	21.8	31.6	28.58	24.4
	27.5	27.7	33.1	26.8
Mean	27.4	31.7	42.2	43.0

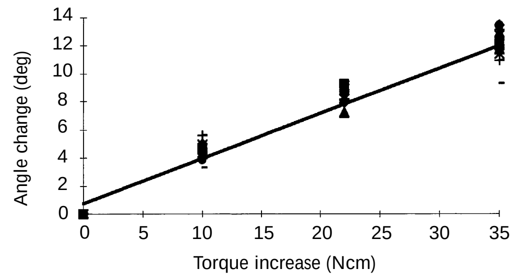

Fig 10 Plot of torque increase versus angle changes. This plot shows the variation in angular measurement that occurred in abutment screws torqued to 10, 20, 32, and 45 Ncm.

To reduce the influence of the initial and final portions of the fitted curve, a second-order polynomial was fitted to the data and is also shown in Figs 6 to 9 with respective correlation coefficients of 0.9874, 0.9873, 0.9744, and 0.9739. (Increasing the degree of polynomial fit results in only marginal changes to the correlation coefficients.) The slopes of each of these curves in the central portion are similar. Selecting a specific stiffness to compare them, eg, at a PTV of –2, gives slopes that result in changes in PTV per degree change of angular loosening. The polynomial fitted curves suggest that it requires respectively 3.2 degrees, 3.1 degrees, 3.2 degrees, and 3.4 degrees of angular loosening to cause a change of 1 in the PTV.

Table 1 summarizes the results from the subjective tests, in which the screw was loosened from the initial torque and tested manually for perceivable motion. The results show that the angular change necessary for subjective perception of looseness is considerably varied, from a mean of 27 degrees for an initial torque of 10 Ncm, to 43 degrees for an initial torque of 45 Ncm. By use of a change in PTV of 2 to indicate that the screw had lost a significant amount of stiffness, the best-fit straight lines from the 4 initial torque tests predicted that this would occur from angular changes of 6.4 degrees for the 10 Ncm torque to 6.8 degrees for the 45 Ncm torque. These values are well below those of the subjective tests.

Discussion

At COMPRU, clinical experience has taught that a consistent change of 2 in PTV usually suggests that there has been a change in the status of the abutment/implant assembly; this would normally trigger a further investigation of the integrity of the joint. For this reason, it is of interest to find what degree of loosening has occurred (ie, what has happened to the torque in the screw) for this change in PTV to occur. Figure 10 shows the variation in angular measurement that occurred with the 4 different initial torque settings. These results were obtained by increasing the amount of torque from 10 to 20 Ncm, then 32 and 45 Ncm, and measuring the angular change that occurred between each torque value. The results are for 4 repeated tests on each of the 4 different abutment/implant assemblies and are shown along with a best-fit straight line for the results. The slope of this line indicates that an increase in torque of 10 Ncm produces an angular change of 2.8 degrees, so that 20 Ncm torque is applied in a change of 5.6 degrees. Assuming that loosening occurs at the same rate, and comparing this value with that required to give a difference of PTV of 2 (2 × 3.1 degrees = 6.2 degrees from above), suggests that for a 20 Ncm torque in the screw, torque would have essentially dropped to zero before a clinically relevant change in the PTV occurred. This does not mean that the screw would be loose, but that the tensile preload in it caused by the tightening vanished.

While the PTV is suggested to be a crude and somewhat insensitive method of measuring screw loosening, the subjective approach is an even poorer method. First, the angular change that was noticeable to the clinicians was at least twice as large as that shown with a change of 2 in PTV. Second, the range over which the loosening was perceived was large for a given subjective evaluator and was even larger between evaluators. Given that this was done in more ideal in vitro conditions, the Periotest was the better means to monitor the looseness of the joint.

Conclusion

In the present format, the Periotest is relatively insensitive to the changes contemplated in the stiffness of the abutment/implant assembly. This is because the resolution of the instrument is reduced to a single PTV, which corresponds to a change of 0.02 milliseconds of contact time. For a PTV of –7, the total contact time is approximately 0.29 milliseconds, so that a change of 0.02 approaches a 7% change in T for the change of 1 in the PTV. If the contact time were used directly, it might be a far better correlate of the change in stiffness that occurs with the screw loosening. An alternative method to measure the stiffness change would be to use the impedance head and power spectral density technique suggested by Elias et al.[5]

Appendix

The impact of the Periotest rod with a tooth or implant (mass m_t) can be modeled as shown in Fig 3, in which the rod (mass m_p) is moving with constant velocity (v_o) prior to impact (a). Immediately after impact (b), the rod and tooth/implant have velocity

$$v = \frac{m_p v_o}{m_t + m_p} = \frac{m_p v_o}{M}$$

Assuming that the rod and tooth remain in contact, this velocity is the initial condition for the vibration of the combined mass ($m_p + m_t = M$) supported by the stiffness k and viscous damping c. The differential equation of motion

$$M\ddot{x} + c\dot{x} + kx = 0,$$

in which the dot indicates differentiation with respect to time, has the solution for the initial velocity (taken at time t = 0) given by (A1) of the displacement as

$$x(t) = \frac{v}{p\sqrt{1-\zeta^2}}\, e^{-\zeta pt} \sin\left(\sqrt{1-\zeta^2}\right)pt$$

where ζ is the damping ratio $\zeta = c/2Mp$ and $p = (k/M)^{1/2}$. The acceleration (as measured by the accelerometer on the rod) is then given by

$$a(t) = \frac{-vp}{\sqrt{1-\zeta^2}}\, e^{-\zeta pt} \sin\left(\sqrt{1-\zeta^2}\,pt + \phi\right)$$

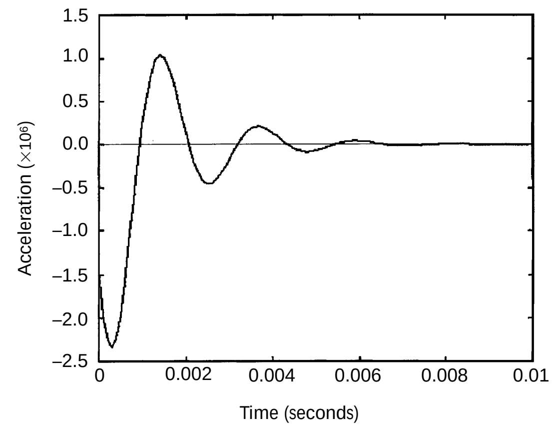

Fig A1 Acceleration response of model.

$$\tan\phi = \frac{2\zeta\sqrt{1-\zeta^2}}{1-2\zeta^2}$$

The contact time is the time after initial impact that the acceleration is zero. The expression for T is then

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

To validate the model, typical values of the parameters M, k, and ζ for a healthy tooth are used to calculate a representative contact time and to compare it to those reported by Lukas and Schulte.[1] For a typical tooth, the mass is approximately 4 g, so that with a Periotest rod of 8 g the total is M = 12 g. The horizontal mobility reported by Kayacan et al[8] is between 100 and 200 $\times 10^3$ N/m and use of the relative amplitudes of the typical acceleration trace suggests a damping ratio of $\zeta = 0.25$. These values give an acceleration response, as shown in Fig A1, and a contact time from 0.60 to 0.94 milliseconds. This is of the same order as reported for teeth with a PTV between 0 and 2.

Note that the stiffness, mass, and damping using the above derivation are the effective k, m, and c for the tooth or implant situation. In general, these values will be dependent on the geometry, mass, stiffness, and damping distributions in the structures being analyzed. However, the relative changes shown will be appropriate for any given situation.

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