Theoretical Percussion Force of the Periotest Diagnosis

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The Periotest percussion force acting on a dental implant was estimated by assuming a mass-spring-dashpot model of the implant-bone system constructed on the basis of a clinical experiment. A theoretical value of about 10 N, comparable to hitherto reported experimental values, was obtained for an osseointegrated implant of about 1 g. The percussion force would probably be smaller for a heavier implant.
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Key words: dental implant, percussion force

The Periotest (Siemens AG, Bensheim, Germany) diagnosis by percussion is known to detect a subtle difference in the so-called clinical mobility of teeth.[1,2] Periotest mobility is expressed by an integer (–8 to +50) called the Periotest value (PTV). The relation between PTV and clinical mobility index (CMI: 0 to 3) is as follows: CMI = 0 (PTV = –8 to +9); 1 (+10 to +19); 2 (+20 to +29); and 3 (+30 to +50).[1,2]

The Periotest instrument has been used in clinical studies of dental implants made of aluminum, titanium, and so forth, indicating that PTVs are generally smaller than +10.[3–34] However, premature loading of any dental implant may cause formation of unfavorable fibrous tissue at the interfacial region.[35] It is therefore important to know the percussion force F_{max}. Several attempts have been made to estimate F_{max} experimentally or theoretically based on the implications or assumptions of a simple implant-bone model such as that shown in Fig 1 (see also Table 1).[13,27,36–38] However, the results cannot be considered persuasive because such a simple model is not based on any clinical or animal experiment.

Scholz et al[39] clinically measured the return movement of an osseointegrated Tübingen alumina implant after a known static force deflecting it was removed. Topkaya et al[40] constructed a lumped parameter model (Fig 2) for the implant-bone system by analyzing the measured return movement. The purpose of this paper is to estimate a theoretical value of F_{max} on the basis of the implant-bone model constructed by Topkaya et al.

Outline of the Periotest Instrument

In the Periotest diagnosis, a metal rod of M (8.4 g[41]) mass, the acceleration of which is monitored by an accelerometer, impacts an implant at a constant speed V (0.16 m/s[42]). The rod is rebounded by the viscoelasticity of the implant-bone system. These structures can be considered to be in contact with each other until the rebound velocity becomes maximum; this maximum time is called the contact time τ.[2,43] After τ, the rod is to be separated from the implant, according to Newton's law of inertia.

The rod acceleration is zero at the maximum rebound velocity, because acceleration is the time derivative of velocity. Therefore, τ can be estimated from the monitoring of the rod acceleration.

It is empirically known that a tooth with a larger clinical mobility index (CMI) has a larger value of τ.[43,44] However, τ itself is not a convenient indication scale of mobility for clinical use, partly because of nonlinearity between CMI and τ. Instead, Periotest mobility is expressed by the Periotest value (PTV), defined as:[2,43]

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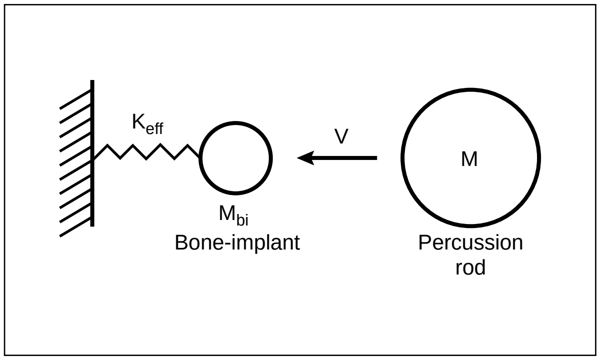

Fig 1 Mass-spring model for the Periotest percussion rod-osseointegrated implant-bone system. V is the impact velocity, M the rod mass, M_{bi} the effective bone-implant mass, and K_{eff} the effective stiffness depending on the percussion point and direction.

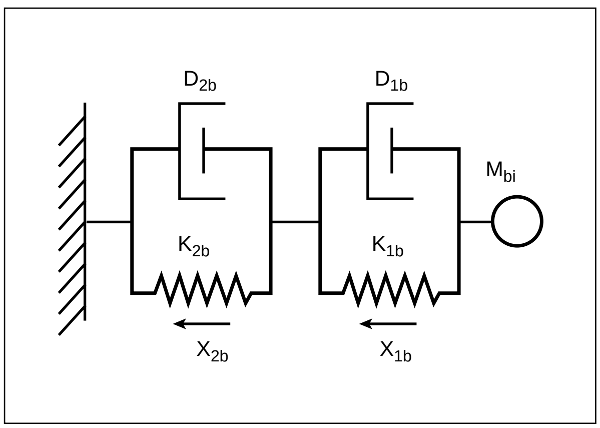

Fig 2 Mass-spring-dashpot model for the Tübingen alumina dental implant-bone system, the osseointegration of the implant assumed to be established.[40] M_{bi} = 4.3 g, a mass of 1.3 g being implied for the implant itself.[40] K_{1b} = 1,122,000 N/m, D_{1b} = 5 Ns/m, K_{2b} = 1,200,000 N/m, and D_{2b} = 290 Ns/m. These values are considered to come from the viscoelasticity of bone.[40] X_{1b} and X_{2b} are displacements.

Table 1 Experimental and Theoretical Values of the Percussion Force F_{max} of Periotest

	PTV	F_{max} (N)
Experimental[36]		about 20
Experimental[13]	–4 to +2	18 to 12
Theoretical[37]	–8 to +13	23 to 7.9
Experimental[27]	–7 (τ = 1.34*)	4.72
Theoretical[38]		π MV/τ

*Measured.
PTV = Periotest value; τ = contact time (ms); M = mass (g) of the percussion rod; and V = impact velocity (m/s) of the rod.

$$PTV = \mathrm{Round}[\tau/0.02 - 21.3] \quad \text{for } 0.266 \leqq \tau \leqq 0.686 \quad (1a)$$

$$PTV = \mathrm{Round}[10(\tau/0.06 - 8.493)^{0.5} - 4.17] \quad \text{for } 0.686 < \tau \leqq 2.270 \quad (1b)$$

where Round[A] denotes the nearest integer to A. The indication scale PTV is designed so as to give a quasilinear correlation with CMI by making PTV ≒ 0, 10, 20, and 30 correspond to CMI = 0, 1, 2, and 3, respectively.

Mathematical Statement of the Periotest Diagnosis and Solutions

It is assumed that the percussion rod is much stiffer than the implant-bone system, so that the former can be considered to be a rigid particle. Then, on the basis of Fig 2, the equations of motion can be written as

$$F = -(M+M_{bi})\ddot{X}_{1b} \quad \text{for } 0 \leqq t \leqq \tau \quad (2a)$$

$$F = -M_{bi}\ddot{X}_{1b} \quad \text{for } t \geqq \tau \quad (2b)$$

$$(M+M_{bi})\ddot{X}_{1b} + K_{1b}(X_{1b}-X_{2b}) + D_{1b}(\dot{X}_{1b}-\dot{X}_{2b}) = 0 \quad \text{for } 0 \leqq t \leqq \tau \quad (3a)$$

$$M_{bi}\ddot{X}_{1b} + K_{1b}(X_{1b}-X_{2b}) + D_{1b}(\dot{X}_{1b}-\dot{X}_{2b}) = 0 \quad \text{for } t \geqq \tau \quad (3b)$$

$$K_{1b}(X_{2b}-X_{1b}) + D_{1b}(\dot{X}_{2b}-\dot{X}_{1b}) + K_{2b}X_{2b} + D_{2b}\dot{X}_{2b} = 0 \quad \text{for } t \geqq 0 \quad (4)$$

Here, F is the compressive force acting on the implant, M, the mass of the rod, and, for instance, $\dot{X}_{1b} \equiv dX_{1b}/dt$, t being the time after the percussion rod-implant contact starts.

The initial conditions at t = 0 are:

$$\dot{X}_{1b} = MV/(M+M_{bi}) \quad \text{:from the momentum conservation law} \quad (5)$$

$$X_{1b} = X_{2b} = 0 \quad (6)$$

At $t = \tau$

$$\ddot{X}_{1b} = 0 \quad (7)$$

The percussion force F_{max} of Periotest can be considered the maximum compressive force acting on the implant. Since it is difficult to obtain any closed-form solution of the above equations, they were solved numerically by using the well-known Runge-Kutta method. The result is: τ = 0.36 ms (PTV = –3 from equation 1a) and F_{max} = 9.8 N. Values calculated of force, velocity, and displacement are plotted against time in Fig 3.

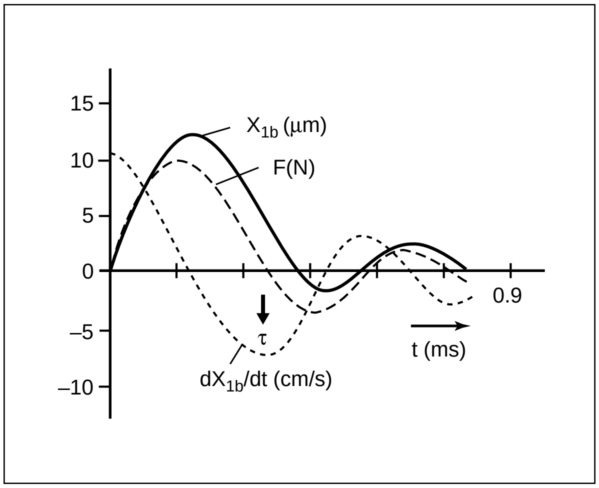

Fig 3 Theoretical variations of Periotest compressive force F, displacement X_{1b}, and velocity dX_{1b}/dt with time t. The lumped parameter model and numerical values shown in Fig 2 were assumed. τ is the contact time.

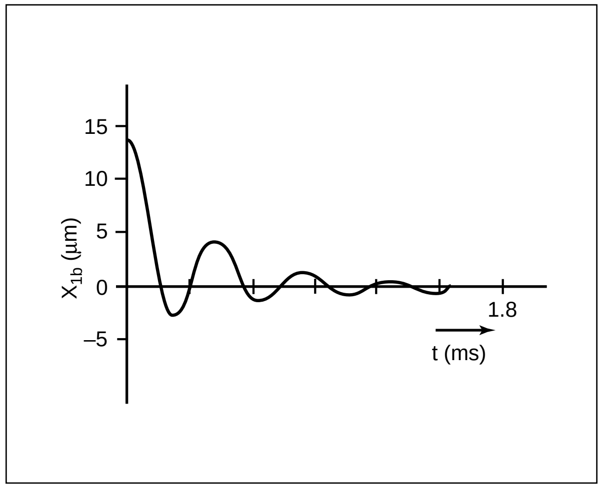

Fig 4 Theoretical return movement of an osseointegrated Tübingen alumina implant after a static deflecting force of 8 N is removed abruptly. The lumped parameter model shown in Fig 2 was assumed. M_{bi} = 4.3 g.[40] (K_{1b}, D_{1b}, K_{2b}, D_{2b}) = (1,122,000 N/m, 5 Ns/m, 1,200,000 N/m, 290 Ns/m)[40] and (1,200,000 N/m, 290 NS/m, 1,122,000 N/m, 5 Ns/m). Notice that both sets of values for viscoelastic parameters generate the same curve.

Discussion

A theoretical value of 9.8 N for the percussion force F_{max} is within the experimental F_{max} range shown in Table 1. This suggests that the above theoretical analysis based on the implant-bone model (Fig 2) of Topkaya et al[40] is reasonable. Furthermore, the obtained theoretical value of PTV = –3 is close to, or within, the PTV range clinically measured for osseointegrated Tübingen alumina implants: –6 to –4[3] and –5 to +5[21]. This agreement between theoretical and experimental values supports the above analysis.

Numerical values for the lumped parameters (M_{bi}, K_{1b}, . . .) in Fig 2 are those that Topkaya et al[40] determined from the computer simulation. However, the interchange in numerical values between (K_{1b}, D_{1b}) and (K_{2b}, D_{2b}) is found to make no difference to the computed profile of the return movement of the implant (Fig 4); that is, the values assigned to viscoelastic parameters such as K_{1b} and D_{1b} are not unique. Similarly, it should be noted that the above interchange makes no difference to the F, X_{1b}, and $\dot{X}_{1b}$ profiles of Periotest and therefore to F_{max} and PTV.

According to the theoretical analysis based on the simplest lumped parameter model of Periotest (Fig 1), F_{max} is written as[38]

$$F_{max} = VM\sqrt{[K_{eff}/(M + M_{bi})]} \quad (8)$$

Here K_{eff} is the effective stiffness, depending on the percussion point and direction; K_{eff} corresponds to a set of K_{1b}, K_{2b}, D_{1b}, and D_{2b} in Fig 2. Therefore, the reproducibility of F_{max} will depend on that of the percussion point and direction. It is expected from equation 8 that F_{max} is small for a heavy implant. Actually, linearity between F_{max} and $M/\sqrt{(M+M_{bi})}$ is also seen for the model of Topkaya et al (Fig 5).

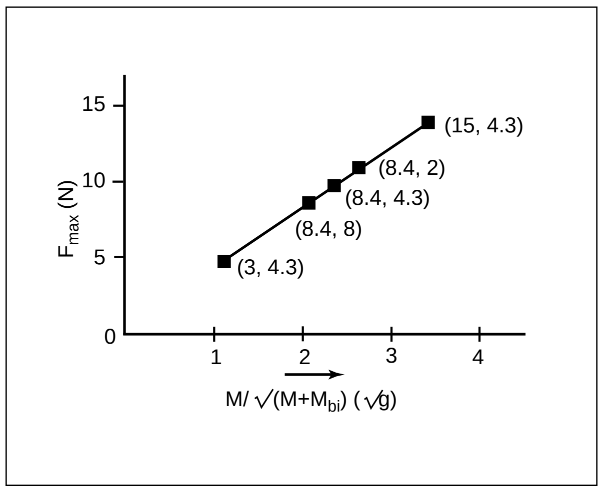

Fig 5 Effect of the masses (M, M_{bi}) on the Periotest percussion force F_{max}. The lumped parameter model shown in Fig 2 was assumed. K_{1b} = 1,122,000 N/m, D_{1b} = 5 Ns/m, K_{2b} = 1,200,000 N/m, and D_{2b} = 290 Ns/m. Numbers in parentheses denote values of M and M_{bi}.

Finally, it should be noted that a theoretical value of about 10 N for F_{max} will be smaller than the typical lateral biting force in the natural human dentition. According to a review paper by Brunski,[45] this value is about 20 N, although reliable data are scarce.

Conclusion

The Periotest percussion force acting on a dental implant has been estimated on the basis of the lumped parameter model (Fig 2) of Topkaya et al[40] for the implant-bone system. A theoretical value of about 10 N, comparable with hitherto reported experimental values (Table 1), has been obtained for an osseointegrated implant of about 1 g. It has been suggested that the percussion force will be smaller for a heavier implant.

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