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Comparison between acoustic and mechanical tapping methods for assessing the interfacial states of bone implants

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Acoustic and mechanical tapping methods for *in vivo* assessment of the interfaces of bone implants are experimentally compared using implant models made of metal and glass. The former (AcT method) is based on the measurement of the frequency and amplitude of the vibration of a sample induced by a tapping needle. The latter (MeT method) is based on the measurement of the time during which a tapping rod is contacted with a sample. The following results were found. The vibration of a sample induced in the MeT test is very different from that induced in the AcT test; the former is much larger in the maximum amplitude and much lower in the main frequency than the latter, although both are of damped type. Nevertheless, a discrimination between hard and soft interfaces by each test is almost equally clear. It depends on load directions to some extent, reflecting a mechanical difference of the interface and/or the surrounding bone. The MeT test appears to be more sensitive than the AcT test for implant models surrounded by a thin compact bone. For implant models surrounded by a thick compact bone, however, the former is a little less sensitive than the latter.

1. Introduction

Recently, a handy clinical instrument for assessing tooth mobility from a mechanical tapping method (MeT method) has been developed by a group from Tübingen University and Fraunhofer Institute [1–3]. The method is based on measuring the time (0.27 to 2.3 msec) during which a tapping rod kept horizontal is contacted with a tested tooth. The instrument, which is produced commercially under the name of Periotest (Siemens, Bensheim), has been proved excellent [4, 5]. The tooth mobility is expressed by a number called the Periotest value, or PT value, which increases with the contact time, ranging from −8 to 50. The instrument has also been applied to dental implants [5, 6]; for instance, Ogiso *et al.* [6] have reported that apatite-coated metal implants, which are thought to adhere to bone tissue, have PT values of −5 to −7.

In previous papers [7, 8] an acoustic tapping method (AcT method) was described for assessing the interfacial rigidity of various bone implants. The method is based on estimating the frequency (10 to 150 kHz) and amplitude of the vibration of an implant induced by an acoustic tapping force.

The above methods are very different in the measuring principle. The purpose of this paper is to make an experimental comparison between the two methods using several models of implant, bone and interface.

2. Measuring systems

The measuring system of the MeT method, i.e. that of Periotest, can be divided into driving and receiving parts. The former consists of an electronic controller, an electromagnet and a tapping rod and the latter consists of an accelerometer, a data processor and a PT value displayer. A more complete description of the system is available elsewhere [3, 4].

The measuring system of the AcT method used consists of three units: (1) a pulser-receiver, which consists of a pulse generator and a signal amplifier, (2) an oscilloscope, and (3) an acoustoelectric driver (AED) and an acoustoelectric receiver (AER). The system is described in detail elsewhere [7, 8].

PT values were measured six times for each sample.

AcT signals were obtained under the following conditions, unless otherwise specified; AED and AER

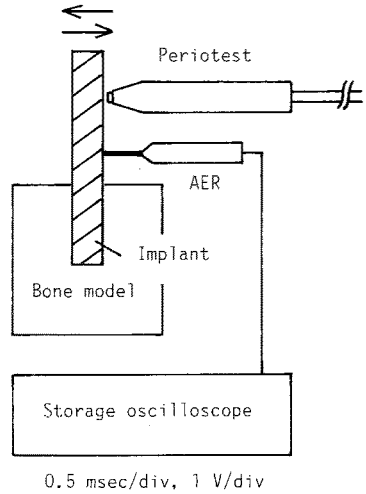

Figure 1 Experimental arrangement for observing the vibrational signal (MeT signal) of an implant induced by a tapping rod of Periotest (Siemens, Bensheim). AER: acoustoelectric receiver.

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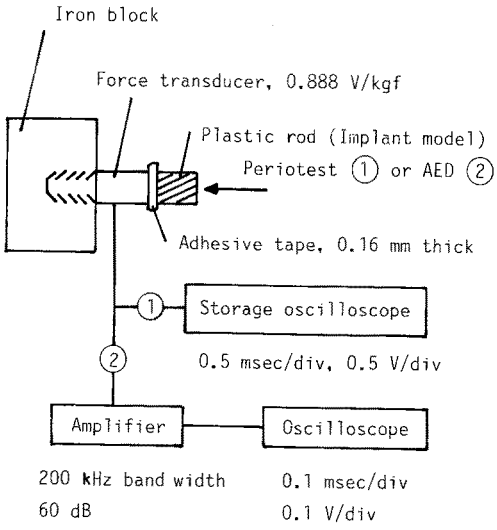


Figure 2 Experimental arrangement for estimating tapping forces acting on an implant. AED: acoustoelectric driver.

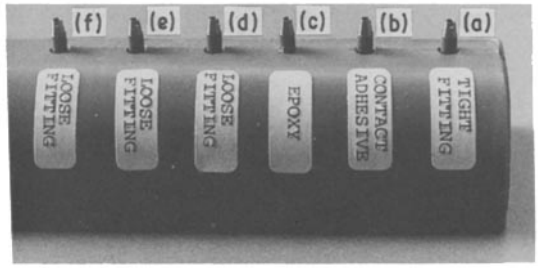
were of needle-type and the amplification and band width of the signal amplifier were 60 dB and 20 kHz, respectively. The scales of time, output voltage and input voltage on the oscillograms shown later are 50 μsec, 0.1 and 5 V per division, respectively.

MeT signals were observed using the above AER and a storage oscilloscope in order to compare them with AcT signals (Fig. 1).

Tapping forces acting on an implant model were estimated using a force transducer (Fuji Ceramics Model FT-50NS, Shizuoka), as shown in Fig. 2.

3. Results

AcT signals and PT values of six dental implants (a to f) embedded in a hard plastic block were measured in four directions (A to D) as shown in Fig. 3. The implants were made of a metal tube of 20 mm long, 4 mm maximum outer diameter and 0.4 g mass, part of its tip being cut. The plastic block was a model of a human alveolar bone; the cortical bone and the cancellous bone were modelled in compact plastic 2 mm thick, and porous plastic, respectively. The implants were fixed to the holes drilled in the block, as follows: (a) mechanical tight fitting, (b) with a hard adhesive, (c) with an epoxy adhesive, and (d to f) mechanical



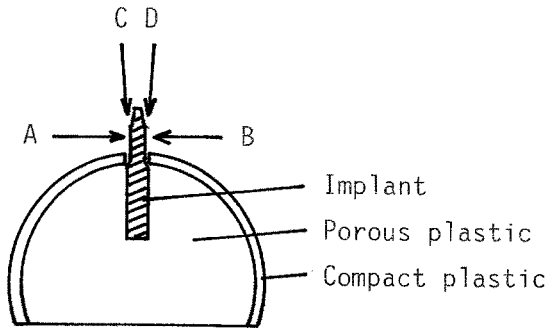


Figure 3 Metallic dental implants (a to f) in a plastic block. Interface conditions: (a) mechanical tight fitting, (b) fixed with a hard adhesive, (c) fixed with an epoxy adhesive, and (d to f) mechanical loose fitting. A to D represent measuring directions.

loose fitting. It was difficult discernibly to move them by a finger, except for sample d. The results are shown in Figs 4 to 7; six PT values for each AcT signal are shown in order of measurement. We see that interfacial state differences between samples can be estimated fairly well by amplitude or main-frequency differences of AcT signals and by PT value differences. Both depend on load directions, reflecting mechanical differences of the surroundings. The period of AcT signals for samples b and c measured in directions C and D is likely to be that for the plastic base itself (see [8]). PT values are reproducible except for sample d, i.e. except for a sample which is very loosely fixed to the base. The MeT test appears to be more sensitive for interfacial differences than the AcT test.

Figs 8 and 9 are MeT signals for the above samples which were measured in directions A and C or D of Fig. 3 using the system of Fig. 1. A comparison with Figs 4 to 7 shows that they are much larger in

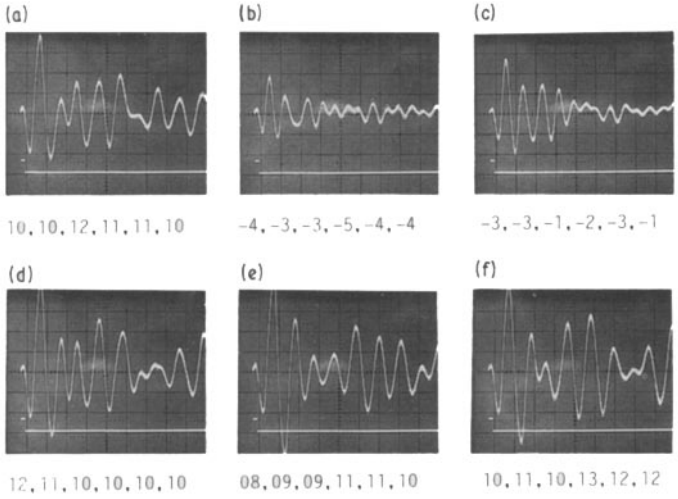


Figure 4 AcT signals and PT values measured in direction A of Fig. 3. AcT signals: vibrational signals obtained from the acoustic tapping test (0.05 msec/div, 0.1 V/div). PT values: Periotest values. Six PT values for each AcT signal are shown in order of measurement. See Fig. 3 for key to (a) to (f).

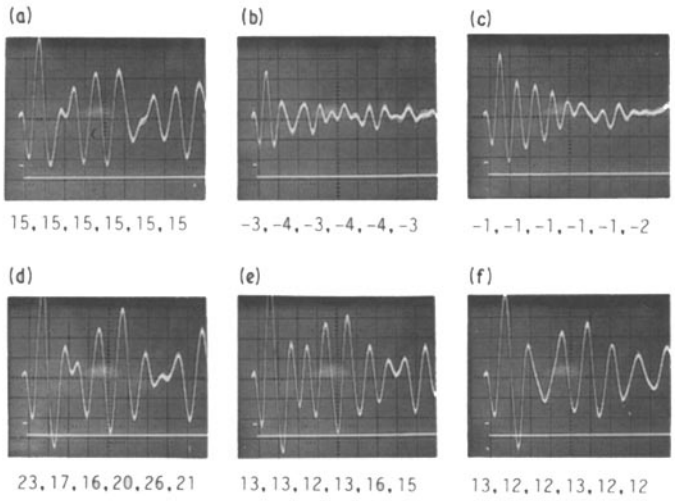


Figure 5 AcT signals and PT values measured in direction B of Fig. 3. See Fig. 3 for key to (a) to (f).

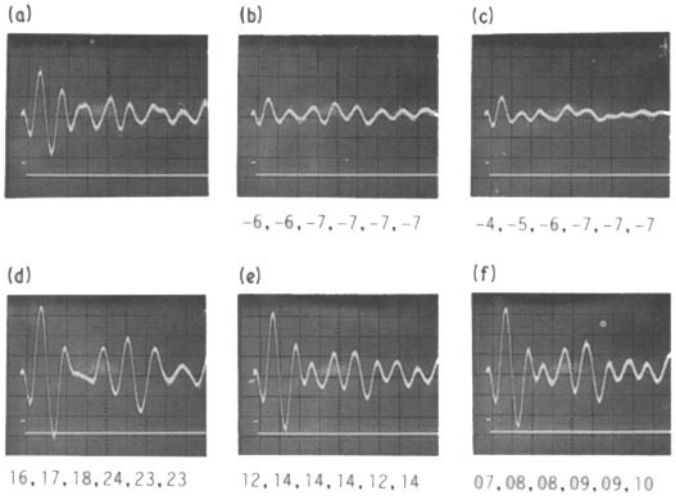


Figure 6 AcT signals and PT values measured in direction C of Fig. 3. See Fig. 3 for key to (a) to (f). It was impossible to obtain reasonable PT values for sample a, because part of the tip was cut.

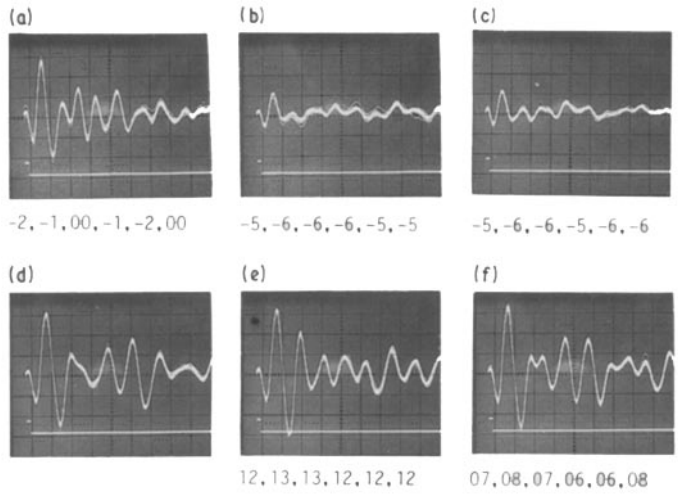


Figure 7 AcT signals and PT values measured in direction D of Fig. 3. See Fig. 3 for key to (a) to (f). It was impossible to obtain reasonable PT values for sample d, because part of the tip was cut.

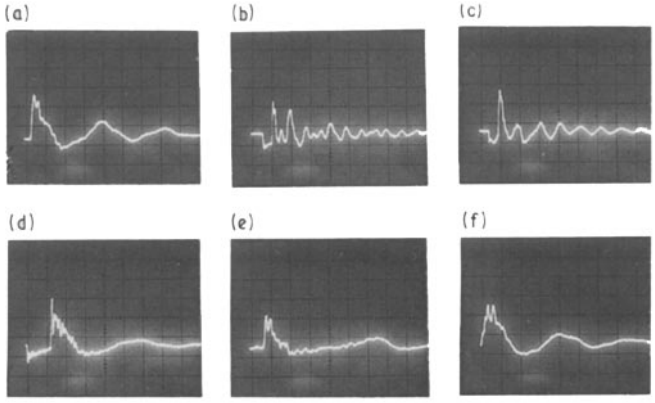


Figure 8 MeT signals measured using the system of Fig. 1 (0.5 msec/div, 1 V/div). Taken in direction A of Fig. 3. See Fig. 3 for key to (a) to (f).

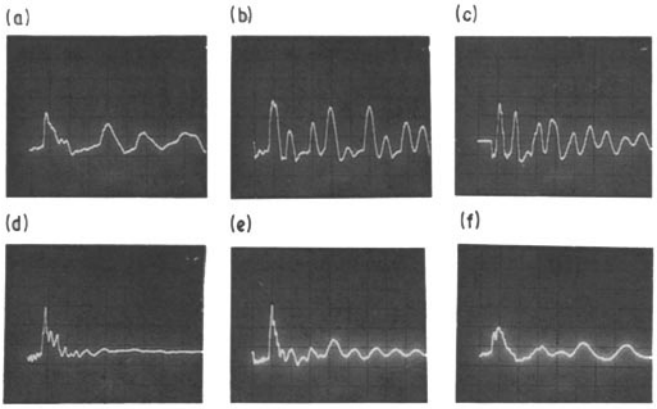


Figure 9 MeT signals measured using the system of Fig. 1 (0.5 msec/div, 1 V/div). Taken in direction C or D of Fig. 3. See Fig. 3 for key to (a) to (f).

maximum amplitude and much lower in main frequency than AcT signals.

Fig. 10 shows the tapping signals of MeT and AcT tests obtained using the system of Fig. 2; two plastic rods made of a phenolic resin were used as implant models, 8 mm diameter and 26 and 18 mm long. The figure shows that the force from the Periotest is about 2 kgf, while the force from the AED loaded by the input voltage of 3 V is about 0.2 gf. We also see that both of the vibrations induced are of damped type, but the vibration period (0.2 to 0.3 msec) of MeT signals is much longer than that of AcT signals.

Fig. 11 shows AcT signals (60 dB, 100 kHz band width) and PT values taken in two directions (A, B) from a glass rod of about 5 mm thick. The rod was partly fixed to a dried thick compact bone of cattle with an epoxy adhesive. We can draw a distinction between bonded and unbonded parts of the rod from AcT signals, but make no distinction from PT values.

Fig. 12 shows AcT signals and PT values taken from three dental implants (a to c) embedded in a dried thick compact bone (d) of cattle. The implants were made of a conical shell-like metal with coated glass, 10.5 mm long and 4 mm maximum outer diameter. The implants were fixed to the holes drilled in the bone, as follows; (a) with a silicone adhesive, (b) with a cyanoacrylate adhesive, and (c) mechanical close fitting. The measurements were done in directions A and B for the implants and in direction C for the bone. We can see a difference in PT value between samples a and b, but not between samples b and c. On the other hand, we can draw a clear distinction between samples a to c from AcT signals.

4. Conclusions

The AcT test based on the frequency and amplitude measurement and the MeT test based on the contact time measurement have shown the following points. Vibrations of a sample induced in both tests are of damped type, but the vibration in the MeT test is very different from that in the AcT test; the MeT test has a much larger maximum amplitude and much lower main frequency than the AcT test. Nevertheless, the results from the MeT test correspond well with those from the AcT test. They depend on load directions to some extent, reflecting a mechanical difference of the interface and/or the surrounding bone. The MeT test

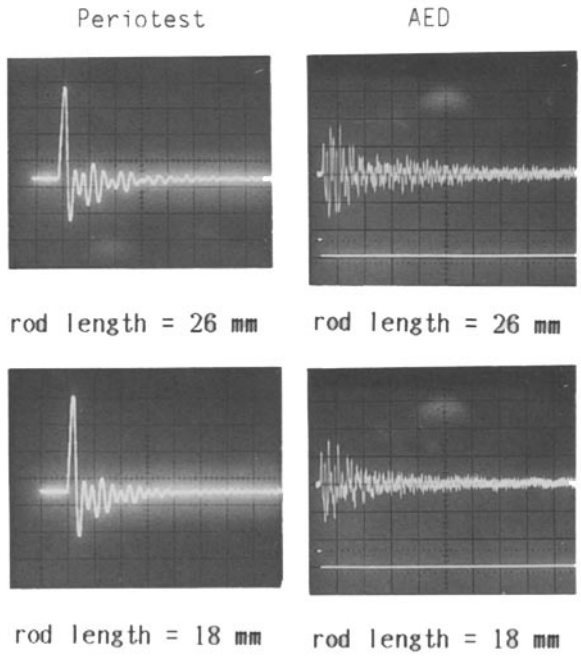


Figure 10 MeT and AcT signals measured using the system of Fig. 2. MeT signals: 0.5 msec/div, 0.5 V/div, AcT signals: 0.1 msec/div, 0.1 V/div.

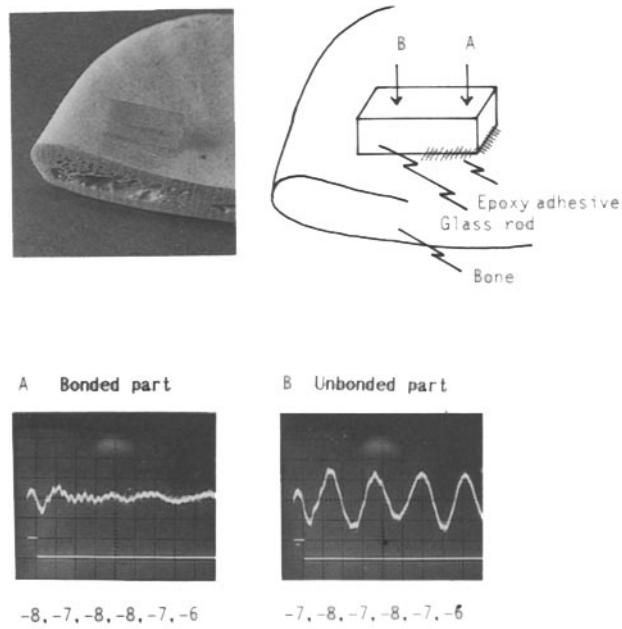


Figure 11 AcT signals and PT values taken from a glass rod partly fixed to a dried thick compact bone of cattle with an epoxy adhesive. A and B represent measuring directions. AcT signals: 20 μsec/div, 0.1 V/div. Six PT values for each AcT signal are shown in order of measurement.

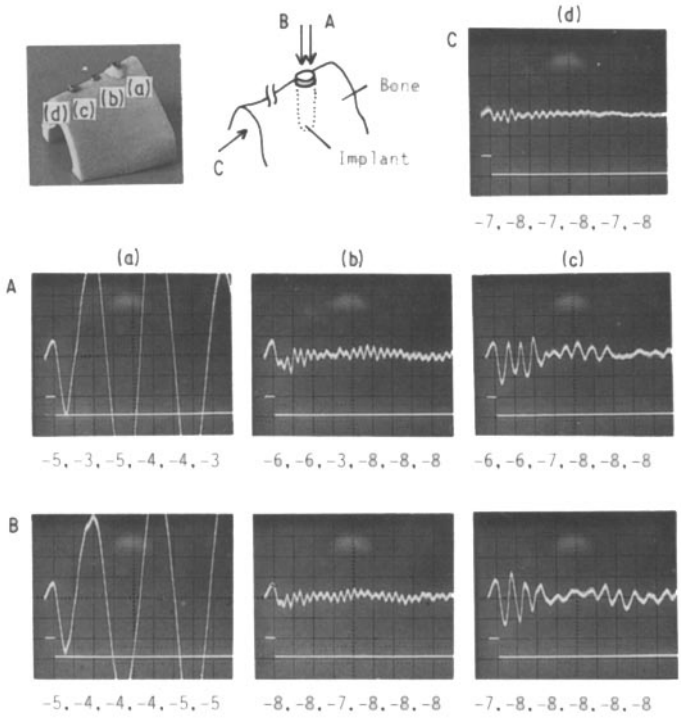


Figure 12 AcT signals and PT values taken from glass-coated metal root implants (a to c) in a dried thick compact bone (d) of cattle. Interface conditions: (a) fixed with a silicone adhesive, (b) fixed with a cyanoacrylate adhesive, and (c) mechanical close fitting. A to C represent measuring directions. AcT signals: 20 μsec/div, 0.1 V/div. Six PT values for each AcT signal are shown in order of measurement.

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