Bender-type Tooth-Movement Transducer

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Summary

A tooth-movement transducer using bender-type piezoelectric ceramics was developed for the measurement probe of the Tooth Mobility tester. It is small, light and suitable for oral examination and it is possible to evaluate the tooth mobility of a molar in the direction of the tooth axis. The transducer utilizes a set of long and rectangular ceramic beam. It includes two supporting points and it is possible to adjust the resonance frequency by moving two points. This frequency is applied as the measuring frequency. The basic characteristics of the transducer and clinical applicability of the measurement probe are confirmed using an artificial tooth model and human tooth.

Keywords: *bender-type, tooth mobility, mechanical mobility, piezoelectric ceramics, tooth movement*

1. INTRODUCTION

Tooth mobility examination is important in planning dental treatment and in evaluating its results. A manual examination of tooth mobility is regularly carried out in dental clinics with the fingers or dental hand-held instruments. This, however requires skill and experience [1]. The PERIOTEST® has been designed to measure tooth mobility objectively [2]. An electronically controlled rod percusses the tooth and it is decelerated when it impinges on the tooth. After hitting the tooth, the rod recoils. This contact time represents the measuring parameter proper. The force of the impact rod on the tooth, however, is sometimes strong and can cause pain. The authors have previously reported on an automatic diagnosis system for tooth mobility in clinical use, by applying a small random vibration (30-1000 Hz) on the tooth [3]. However it is fairly large because of the requirement for a personal computer for a data sampling and analysis.

In a previous study, the authors have already developed a "Tooth Mobility (T-M) Tester" for evaluating the tooth mobility objectively and quantitatively [4]. The developed tester is composed of a measurement probe and system amplifier. A single-frequency vibration is applied to the tooth surface, an acceleration response is measured, and then the mechanical mobility of the periodontium is calculated. The tooth-movement

transducer of the probe utilizes a set of bimorph piezoelectric ceramic disks. It is therefore small, light, and suitable for oral examination. It is, however, difficult to measure the tooth mobility of the molars in the direction of the tooth axis. Then it has been expected that a smaller probe would be developed. It is, however, difficult to make a modified, smaller probe and to adjust the measuring frequency because of the structure of the previous probe.

In this study, the authors have developed a new measurement probe using a transducer composed of bender-type piezoelectric ceramics. The transducer utilizes a long and rectangular ceramic plate which is smaller than the one used previously [5]. This paper deals with the basic characteristics of the newly-developed transducer and the clinical applicability of the measurement probe.

2. TOOTH MOBILITY TESTER

<2.1> T-M Tester In the developed T-M tester, a single sinusoidal vibrational force is applied to the tooth surface and an acceleration response is detected using the transducer of the measurement probe. A block diagram of the tester is shown in Figure 1 [4]. The acceleration signal, which is amplified by means of a charge amplifier, is converted to a root-mean-square value using a RMS/DC circuit. Unnecessary movements from probe handling are eliminated using a 100 Hz high-pass

<2.2> Mobility Index The biomechanical mobility λ (a reciprocal of mechanical impedance) of the periodontium is defined as $\lambda = V/F = A/2\pi fF$ (F : force, A : acceleration, V : velocity, f : vibrating frequency), when a single sinusoidal vibration is applied to the tooth surface and an acceleration is detected at the driving point. The mechanical mobility of the periodontium expresses the tooth movability, which was proposed by Noyes *et. al.* [6]. The mobility index of tooth movability is defined as $MI = KA = K2\pi fF\lambda$ (K : proportional constant), but it is a dimensionless quantity. When F and f are constant, the MI score is proportional to A and λ . Because the mechanical mobility of the periodontium is typical of tooth movability, it is proper to evaluate the tooth mobility using the MI score.

<3.1> Design of Measurement Probe Figure 2 shows a measurement probe using bender-type piezoelectric ceramics transducer. The measurement probe, which was developed for the T-M tester previously, utilized a set of piezoelectric ceramic disks [7]. The ceramic disks were 25.5 mm in diameter and 100 μm thick, with the fringe fixed with a holding ring. The shim between the two ceramics is made of Be-Cu and is 100 μm thick. When the resonance frequency of the transducer is used as the actuating frequency for the transducer, the acceleration response is larger and more sensitive [4]. The disk-type ceramics of smaller size, however, require a higher resonance frequency. In order to decrease the resonance frequency within a range from 300-500 Hz [7], it is necessary to reduce the thickness of the ceramics and shim of the transducer or to increase the diameter of the transducer. Unfortunately, the former produces a fragile transducer and the latter does not satisfy the plan of miniaturization.

The block diagram illustrates the data acquisition system for the piezoelectric sensor. It includes the following components and signal flow:

- Contact pressure picking-up** and **Piezoelectric actuating** signals are inputs to the **Strain amplifier**.
- The **Strain amplifier** output is multiplied (indicated by a circle with an 'X') and then sent to the **Window comparator**.
- The **Window comparator** has two outputs: one to a speaker (labeled **Initial-set pressure**) and another to the **Measuring trigger**.
- The **Measuring trigger** also receives input from the **Integrating trigger** and sends a signal to the **Digital panel counter**.
- The **Digital panel counter** has two outputs: one to a speaker (labeled **10 countings**) and another to the **Integrating trigger**.
- The **Integrating trigger** sends a signal to the **Sampling gate**.
- The **Sampling gate** outputs to the **V/F converter**.
- The **V/F converter** outputs to the **S/H amplifier**.
- The **S/H amplifier** outputs to the **RMS/DC converter**.
- The **RMS/DC converter** outputs to the **HPF**.
- The **HPF** outputs to the **Charge amplifier**.
- The **Charge amplifier** outputs to the **Acceleration picking-up**.
- An **Oscillator** provides input to the **Piezoelectric actuating** and the **Strain amplifier**.

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63(L) x 5(W) mm and 100 μ m thickness. The two ceramics polarized in reverse directions are deposited onto both sides of the shim. The piezoelectric strain constant of ceramic is -360×10^{-12} m/V in d_{31} . The surface of the ceramic is covered with a moistureproof coat. One of the bimorph ceramics is used for actuating and the other for detecting acceleration. Because the newly-developed transducer is short, narrow and about 500 μ m in total thickness, it is more suitable as a tooth-movement transducer used in mouth. A cotton felt of about 2 mm thickness held at a supporting point suppresses the high metallic Q of the shim and avoids any slipping out caused by a shock.

A photograph of the newly developed measurement probe using bender-type piezoelectric ceramics is shown in Figure 3. The probe has an overall length of 170 mm and is about 100 g in weight. The pointed end of the probe is thin and small-sized at 6.5 mm in thickness and 11.5 mm in width, so as to be easily inserted into the mouth. It then becomes easier to measure the tooth mobility of the periodontium from every angle in mouth. Inside the probe's grip, which is 22 mm in diameter, is a space for an electric driver and preamplifier, making the whole T-M tester portable for clinical use.

<3.2> Adjustment of Resonance Frequency When it is assumed that this rectangular transducer behaves as a cantilever beam (clamped and free end), the resonance frequency is

$$f = \frac{\alpha^2}{4\sqrt{3}\pi} \frac{T}{L^2} \sqrt{\frac{Y}{\rho}} \quad \dots \dots \dots (1)$$

where T is the thickness of beam, L is the length of the beam, Y is the Young's modulus, ρ is the density of the beam and α is the boundary condition constant [8]. When the material and the α of the beam are determined, the resonance frequency depends on the thickness and length of the beam. It is apparent that the resonance frequency decreases by lengthening instead of thinning the beam according to Eq. (1). Moreover, it is possible to make the beam narrower because the resonance frequency is independent of the beam width. In this way, the bender-type transducer achieves mechanical strength and allows for a miniaturization of the measurement probe.

The transducer beam includes two supporting points. By changing the distances among OA, AB and BC, it is possible to adjust the resonance frequency. The acceleration spectrum of the bender-type transducer is shown in Figure 4. The solid line is the spectrum in the case of OA=10, AB=20, and BC=33 mm. The gray line is in the case of OA=14, AB=20, and BC=29 mm. The distance between the A and B supporting points is kept at 20 mm and the applied pressure to the beam at the point is 50 gf. When the supporting points A and B move parallel to one another in the direction of the point C, the spectrum includes two sharp resonances, f_{BC} and f_{OA} . As described later, these resonances are related to the length of OA and BC, respectively. Namely, the shorter OA distance is

related to the high-resonance frequency f_{OA} , and the longer BC distance is related to the low-resonance frequency f_{BC} . The figure shows that as OA becomes longer, the f_{OA} becomes lower, and as BC becomes shorter f_{BC} becomes higher.

<3.3> Characteristics of the transducer Figure 5 shows a mechanical mobility spectrum for the measurement probe with the newly-developed bender-type piezoelectric ceramics where the supporting points are kept at OA=23, AB=14, BC=26 mm. In the case of nocontact with any object, the probe involves four resonances in the spectrum below 5 kHz, shown in the figure (a). When a part of the transducer OA touches some stiff object such as resin, f_{OA} (≈ 300 Hz) and f'_{OA} (≈ 2137 Hz) shrink but f_{BC} (≈ 500 Hz) and f'_{BC} (≈ 3275 Hz) do not change, shown in the figure (b). Conversely, it is also confirmed that f_{BC} and f'_{BC} shrink, and f_{OA} and f'_{OA} do not change, when a part of the transducer BC touches something. From the above discussion it becomes clear that a vibrating condition related to OA determines the resonance frequency f_{OA} and conversely BC determines f_{BC} . It is therefore confirmed that each vibration related to OA and BC is independent. The resonance frequency in Eq. (1) gives a fundamental frequency of the cantilever beam with the end clamped and the other end free. The resonance frequency for the second mode of vibration with an additional node is 6.267 times the fundamental frequency. The resonance frequency for the third mode with two nodes is 17.55 times the

Fig. 3 Bender-type measurement probe.

Fig. 4 Two sharp resonances of the transducer.

fundamental frequency [9]. f'_{OA} is 7.12 times the fundamental frequency f_{OA} and f'_{BC} is 6.55 times the frequency f_{BC} . It is therefore suggested that f'_{OA} and f'_{BC} are the frequencies for the second mode of vibration, respectively.

4. MI SCORES OF TOOTH MODEL AND HUMAN INCISOR

Figure 6 shows a mechanical mobility spectrum for the probe below 500 Hz. In this figure, a solid line represents the spectrum for cases in which the measuring tip does not come into contact with any other object. The spectrum involves two sharp resonances, a low resonance frequency f_{OA} of 300 Hz and a high resonance frequency f_{BC} of 500 Hz (see Fig.5). The frequency f_{OA} is applied as the measuring frequency for the measurement probe. As it is within the frequency range of 300-500 Hz which is suitable for human teeth [7], it is sufficient as an artificial model. The other lines indicate spectra which are measured using an artificial tooth model shown in Figure 7.

The tooth model includes four teeth whose periodontium were diagnosed with clinical tooth mobilities of M0, M1, M2 and M3, respectively. M0 indicates no perceptible movement and a healthy and clinically firm tooth. M3 indicates a degree of mobility indicative of a hopeless prognosis [10]. The artificial periodontal ligaments are made of silicone impression material of thickness 0 (M0), 0.28 (M1), 0.56 (M2), and 0.84 mm (M3). Because it is supposed that the width of the periodontal ligament is one of the causes of pathological tooth mobility [7]. The dotted, gray-dotted, broken and gray-broken lines in Fig.6 represent four spectra (encircled) for cases in which the tip comes into contact with the M0, M1, M2 or M3 tooth at 50 gf, respectively. The M0 tooth is clinically firmer than the M3 tooth and the greater the tooth mobility, the larger the mechanical mobility. It can be seen in the figure that the spectrum magnitudes for M0 to M3 are significantly different at 300 Hz. It is clear that the mechanical mobility spectrum is different depending upon the tooth mobility.

Table 1 shows the average and standard deviation of tooth mobility index *MI* scores for four teeth using the artificial tooth model. These values were obtained using the T-M tester equipped with the newly-developed measurement probe using a measuring frequency of 300 Hz. The coefficient of variation (standard deviation / mean value) in ten measurements is within 1 %. The results can be explained well, and the differences between M0, M1, M2 and M3 are clear from the table. A slight deviation indicates a precise measurement. Next, the tooth mobility of human maxillary left central incisor with a healthy periodontium is measured ten times. The *MI* score is also shown in the table. The data clearly show that the T-M tester and measurement probe are applicable for clinical use.

(a) four resonances of the probe

(b) shrink of f_{OA} and f'_{OA}

Fig. 5 Mechanical mobility spectra of measurement probe in the case of no/contact with any object.

Fig. 6 Mechanical mobility spectra for the probe in the case of contact with teeth.

5. CONCLUSIONS

A tooth-movement transducer using bender-type piezoelectric ceramics was developed for the measurement probe of the T-M tester. The transducer is 63(L) x 5(W) mm and 500 μ m thickness. The transducer plate has two supporting points which can adjust the resonance frequency of transducer by changing the distance between two points. The measurement

Fig. 7 Artificial tooth model.

Table 1 MI scores of tooth model and human incisor.

teeth		M0	M1	M2	M3	incisor
MI score	mean	7531	7746	7828	8156	7480
	SD	25	25	12	19	26

probe using this transducer is small, light and suitable for oral examination. It is possible to evaluate the tooth mobility of a molar in the direction of the tooth axis using this probe. This paper describes the basic characteristics of the transducer and the clinical applicability of this measurement probe is confirmed using an artificial tooth model and human tooth. The coefficient of variation in ten measurements is within 1 %.

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