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Original Article

Dynamic viscoelastic properties of models composed of posterior denture teeth and denture base resin

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The purpose of this investigation was to compare the dynamic viscoelastic properties of various models composed of denture teeth and heat-cured denture base resin. The specimens were porcelain and resin teeth mounted in denture base resin. Compressive dynamic stiffness and phase differences were measured with a viscoelastic spectrometer. Measurements of the viscoelastic frequency spectrum based on the fast Fourier transform of displacement to applied random forces were analyzed with a spectrum analyzer. The stiffness of the specimens was independent of the frequency. The stiffness of the porcelain specimens was higher than that of the resin ones measured under the same conditions. The phase lag of the specimens was dependent on the frequency. The phase lag of the porcelain specimens was lower than that of the resin ones measured under the same conditions. This study suggested that the acrylic resin teeth had greater toughness and higher shock-absorbing ability than the porcelain teeth, and that the porcelain teeth were more brittle than the acrylic resin ones, whether the teeth were isolated or in dentures.

Key words: Dynamic viscoelastic property, Stiffness, Phase lag, Denture tooth

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Introduction

When selecting teeth for the fabrication of removable prostheses, each patient's anatomic and physiologic requirements and the properties of the artificial teeth themselves should be taken into consideration. The properties demanded of the posterior denture teeth are high fracture toughness, minimal wear, no permanent deformation, ease of grinding, minimal abrasion of opposing dentition, and so on. The wear characteristics of artificial teeth have been reported by many investigators[1,2]. There have been few studies, however, of other mechanical properties.

We previously demonstrated that acrylic resin teeth have a lower elastic modulus, greater toughness, and higher shock-absorbing ability than porcelain teeth based on the results of a static compression test and an impact test[3]. There was some doubt, however, as to whether these characteristics would also be displayed in dentures. In our experimental specimens constructed with teeth and denture base resin, the mechanical properties of the denture base resin may affect the properties of the specimen more strongly than those of the denture teeth. Whereas acrylic resin teeth are chemically bonded to the denture base, there is a mechanical retention between the porcelain denture teeth and denture base. Therefore, the doubt is due to the existence of the denture base resin and the different means for retaining the teeth in the denture base.

Further investigation has been carried out to evaluate the mechanical properties of artificial teeth by

Table 1. Compositions of materials used

Materials	Composition (weight %)		Batch No.
Denture teeth			
Plastic teeth	Poly(methyl methacrylate)	97.0	210921
	Ethylene glycol dimethacrylate	3.0	
	Pigment	added	
Porcelain teeth	Feldspar	80.0	250527
	Quartzite	20.0	
	Pigment	added	
Denture base resin			
Powder	Poly(methyl methacrylate)	100.0	180922
Liquid	Methyl methacrylate	99.7	210922
	Ethylene glycol dimethacrylate	0.3	
	Hydroquinone	added	

placing them in denture base resin under conditions similar to actual clinical situations. The purpose of this investigation was to compare the dynamic viscoelastic properties of models composed of posterior denture teeth and denture base resin by using a viscoelastic spectrometer.

Materials and Methods

The tooth materials were lower right second premolar porcelain and acrylic resin teeth (Livdent FB-20 teeth, G.C. Co., Tokyo, Japan). All were of the same shape (size: 28M/30). The acrylic resin teeth were composed of highly cross-linked poly(methyl methacrylate). The compositions of the materials used are given in Table 1. Livdent teeth are commonly used in Japan, and it is possible to obtain both porcelain and acrylic resin teeth of the same shape.

The test specimens were composed of teeth and the denture base resin (Fig 1). Ten specimens for each tooth type were made in the same shape. The teeth were mounted in a 12.1 mm diameter conventional heat-cured denture base resin (Acron, G.C. Co., Tokyo, Japan). The specimens were 11.0 mm in height. Extreme care was taken to adjust the position of the teeth so that the long axis would be perpendicular to the horizontal plane, and also so that the alignment of both buccal and lingual cusps would correspond with the compensating curve. The clear resin was polymerized according to the manufacture's recommendations. To create a flat surface, the base surface of the specimen was prepared with silicone carbide paper No. 1000. The specimens were stored in a desiccator at room temperature for 60 days, and then in physiological saline solution (Otsuka Pharmaceutical Co. Ltd., Tokyo, Japan) at room temperature for 30 days. Measurements were performed both after storage in the desiccator and after storage in physiological saline solution.

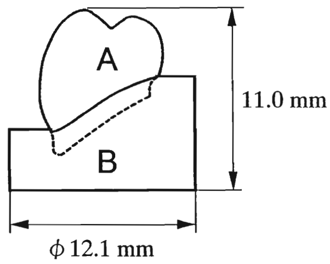

Fig 1. Illustration of a tooth (A) mounted in denture base resin (B).

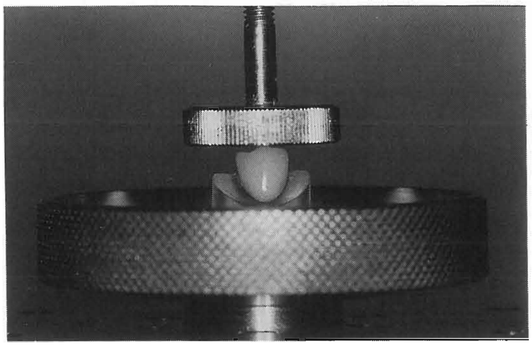
Fig 2. A specimen to which a static force is being applied with the testing apparatus.

Differences in compressive stress, strain, and phase difference between the two types of specimens were measured with a viscoelastic spectrometer (Orientec Co., Ltd., Tokyo, Japan), adopting the forced vibration non-resonance method. Static compression had previously been applied to the buccal cusps of the teeth (Fig 2), and then the vibrating force was added to

Table 2. Test conditions performed with the viscoelastic spectrometer

Static Force (N)	Dynamic Force (N)	Condition of Specimens
10.0	3.0	dry[a]
20.0	5.0	dry[a]
10.0	3.0	wet[b]
20.0	5.0	wet[b]

[a] after a 60-day storage period in the desiccator
[b] after a 30-day storage period in physiological saline solution

this force. Measurements of 10 specimens for each material were performed under two sets of dynamic conditions (Table 2). One set consisted of a static load with magnitude of 10.0 N as a preload and a dynamic load with an amplitude of 3.0 N, and the other comprised a static load with magnitude of 20.0 N and a dynamic load with an amplitude of 5.0 N.

The relationships between load and deformation are as follows:

Load: $F = F_0 + F_1 \sin \omega t$
Deformation: $D = D_0 + D_1 \sin (\omega t - \delta)$
F_0 = static load (preload), F_1 = dynamic load

where

ω : angular frequency
δ : phase-lag or loss angle

This dynamic test indicated a structural stiffness (F_1/D_1) and a loss tangent ($\tan \delta$). The linear relationship between dynamic force and displacement was confirmed with an oscilloscope (V-550B, Hitachi, Ltd., Tokyo, Japan).

Rapid measurements of the viscoelastic frequency spectrum based on the fast Fourier transform of displacement to applied random forces were analyzed with a spectrum analyzer (3582A, Hewlett Packard, Co., Fullerton, CA, USA). The spectrum analyzer provided random mechanical noise consisting of sinusoidally varied components with a frequency of 0–50 Hz (Fig 3). The spectrum analyzer worked as a dual channel fast Fourier transform analyzer. The complex transfer function *H(f)* was defined as the ratio of the cross power spectrum G_{YX} and the autopower spectrum G_{XX}.

$$H(f) = G_{YX} / G_{XX} = Y(f) \cdot X^*(f) / X(f) \cdot X^*(f)$$

where

X(f): input signal function

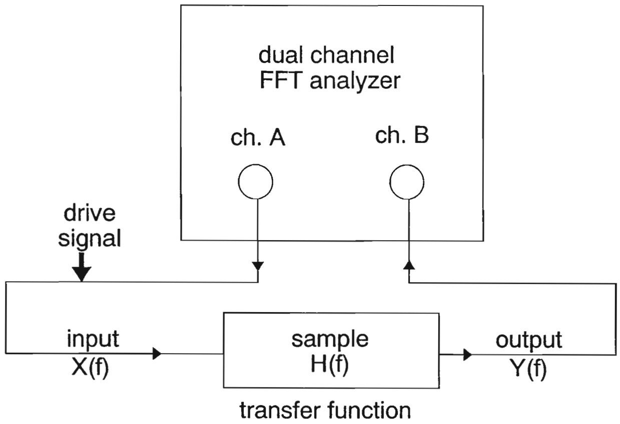

Fig 3. The schema of fast Fourier transform testing.

X(f)*: the conjugate function of *X(f)*
Y(f): output signal function

The amplitude of the transfer function is the ratio of output/input of the stiffness and the phase-lag. In this study we defined amplitude of transfer function as stiffness. The transfer functions were shown on the analyzer display and recorded with an X-Y plotter (D-73BP, Riken Denshi, Co., Tokyo, Japan).

The unpaired Student's t-test was used to compare differences between the two models. The paired Student's t-test was used to compare differences in the same models between the period after storage in the desiccator and that after storage in physiological saline solution.

Results

The fast Fourier transform analysis showed that the stiffness of the specimens was independent of frequency under all conditions tested (10.0 N, 20.0 N static load, dry or wet). The typical spectrum of the test specimens obtained by the analyzer is shown in Fig 4.

The stiffnesses of the specimens measured in this study are shown in Fig 5. The stiffness of the porcelain specimens measured under each condition was significantly ($p<0.001$) higher than that of the acrylic resin specimens measured under the same condition. There were no significant differences in the stiffness of either the acrylic resin or the porcelain specimens between dry and wet conditions.

The phase lags of the specimens measured in this study are shown in Fig 6. The phase lag of the porcelain specimens measured under each condition was significantly ($p<0.001$) lower than that of the

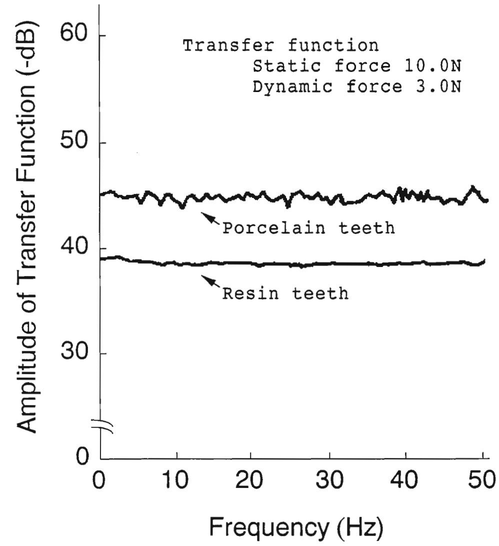

Fig 4. Typical stiffness spectrum of specimens to which a static force of 10.0 N and a dynamic force of 3.0 N are being applied, under dry conditions, on fast Fourier transform analysis.

acrylic resin specimens measured under the same condition. The phase lag of the specimens was frequency-dependent under all conditions. There were no significant differences in the phase lag of either the acrylic resin or the porcelain specimens between dry and wet conditions.

Discussion

We need to know the mechanical properties of biomaterials to achieve success in clinical treatments. The dynamic properties of dental materials are especially important in view of the clinical reality that teeth are stressed during mastication. The viscoelastic spectrometer is useful in evaluating the dynamic viscoelastic properties of materials, because it allows measurement of their dynamic loading and deformation.

This investigation was carried out to evaluate the mechanical properties of specimens under conditions similar to those that occur in clinical situations. Test specimens of the same shape were 11.0 mm in height, considering the mean values of vertical measurements in premolar regions between maxillary and mandibular ridge crests[4]. The measurements were made under two conditions in which dynamic force was superposed on static force: A static load of 10.0 N and a dynamic load of 3.0 N and a static load of 20.0 N and a dynamic load of 5.0 N, respectively (Table 2). We considered these conditions to be the most suitable, based on previous studies of the masticatory min-max forces of complete denture wearers[5,6].

The strength and stiffness of denture base acrylic resin are reduced after the sorption of water[7]. In the present study, there were no significant differences in

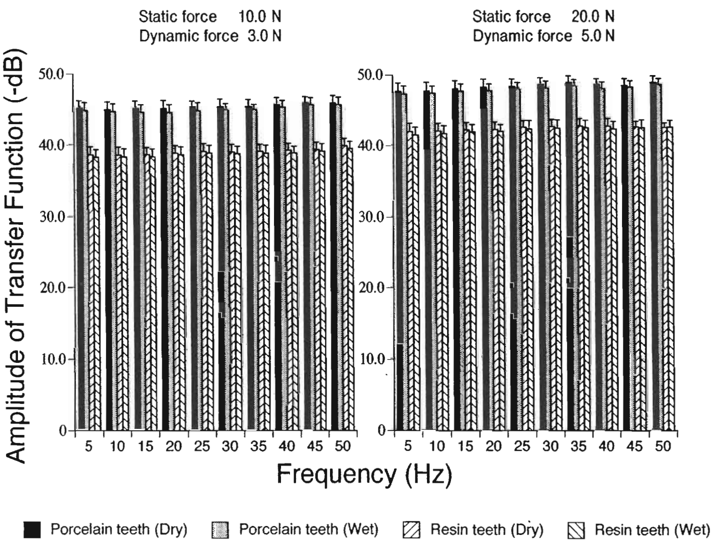

Fig 5. Stiffness of the specimens.
The figure indicates the mean and standard deviation for each 5 Hz, considering statistical manipulations. Significant differences ($p<0.001$) were observed between porcelain and acrylic resin specimens under each dynamic condition.

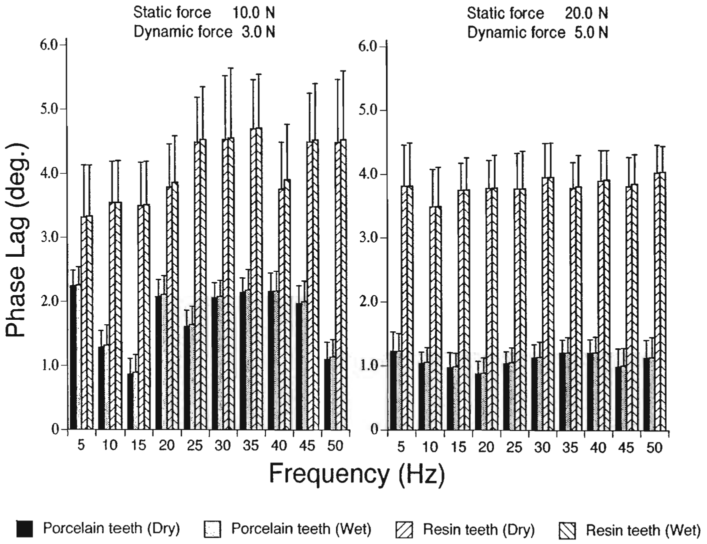

Fig 6. Phase lag of the specimens.
The figure indicates the mean and standard deviation for each 5 Hz, considering statistical manipulations. Significant differences ($p<0.001$) were observed between porcelain and acrylic resin specimens under each dynamic condition.

the stiffness and phase lag of the porcelain and acrylic resin teeth between the period after storage in a desiccator and that after sorption of physiological saline solution. Our results suggest that the sorption of water did not effect the dynamic viscoelastic properties of the specimens.

Stiffness relates to the slope of the force versus the deformation curve. The greater the stiffness value, the less the strain for a given stress. Our previous study on the properties of posterior denture teeth showed that phase lag related to fracture toughness[3]. The greater the phase lag value, the more energy the specimens can absorb for a given stress. Acrylic resin teeth have a lower elastic modulus, greater toughness, and higher shock-absorbing ability than do porcelain teeth[3]. This study demonstrated differences between the porcelain specimens and the acrylic resin specimens. The porcelain teeth and the acrylic resin teeth in removable dentures displayed the properties of each, despite the presence of denture base resins.

This study also demonstrated differences between the porcelain teeth and the resin teeth because the specimens were the same shape. Considering the results of our previous study[3], the results of this study suggested that the resin teeth had greater toughness and higher shock-absorbing ability than the porcelain teeth and that the porcelain teeth were more brittle than the resin teeth. Resin teeth should be selected when the first requisite for the artificial teeth in the dentures to be constructed is high shock-absorbing ability, and porcelain teeth should be selected when the requisite is high masticating efficiency.

References

1. von Fraunhofer JA, Razavi R, Khan Z. Wear characteristics of high-strength denture teeth. J Prosthet Dent 1988 ; 59 : 173–5.
2. Winkler S, Monasky GE, Kwok J. Laboratory wear investigation of resin posterior denture teeth. J Prosthet Dent 1992 ; 67 : 812–4.
3. Shimoyama K, Uchida T, Nagao M, et al. Mechanical properties of artificial teeth. Bull Tokyo Med Dent Univ 1993 ; 40 : 13–6.
4. Watt DM, MacGregor AR. Designing Complete Dentures. 2nd ed. Bristol : Wright, 1986:40–3.
5. Bearn EM. Some masticatory force patterns produced by full denture wearers. Dent Pract Dent Rec 1972 ; 22 : 342–6.
6. Watanabe T. Study of masticatory forces of complete denture wearers. (in Japanese, English abstract). Kokubyo Gakkai Zasshi 1990 ; 57 : 1–16.
7. Phillips RW. Skinner's Science of Dental Materials. 9th ed. Philadelphia : Saunders, 1991:199–203.