The vibratory properties of an obturator prosthesis with a soft lining material

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This study used modal analysis to evaluate the vibratory properties of cast obturator prostheses fitted with soft lining material. Three types of buccal flange bulbs were prepared: a resin (R) type; a 2 mm-thickness relined (RM) type; and a type fully relined with MOLTENO⁶, (M) type. A vibration generator excited the obturator, while a Laser-Doppler Vibrometer detected the vibrations at specified measurement points. Both the excitation and response signals were sent to an FFT analyzer, which calculated the frequency response functions. Then, using DAMPCAL simulation software, the decay rates and the maximum amplitudes of rest and clasp parts were calculated. Statistical analysis was performed by means of one-way ANOVA with Fisher's PLSD test. The results indicated that for impacts simulated on both the defective and non-defective sides, the R type showed a significantly higher decay rate than did the other samples (p<0.0001). When impacts were directed at the defective side, (p<0.0001). Only the M type, however, showed significantly smaller values when impacts were directed at the defective side (p<0.0001).

Key words: Modal analysis, decay rate, obturator prosthesis, soft lining material

Introduction

Most patients with either congenital or acquired maxillary defects require rehabilitation by means of obturator prostheses, which are generally heavier than ordinary prostheses. The force acting on an obturator prosthesis is a complex combination of the vertical dislodging force, the occlusal vertical force, the lateral force, and the anterioposterior force. Because the bulb part of the prosthesis is placed directly into the defective area where the surrounding soft tissue changes its shape during speech or mastication, there is a cantilever effect on the abutment teeth, which leads to greatly increased loads being applied to the abutment. Therefore, in the design and construction of obturator prostheses, greater attention needs to be paid to safeguarding the remaining dentition.

Dentists have often recommended the use of lined obturator prostheses with the aim of engaging more anatomical undercuts and thus gaining more retention. They may also seal off the surgical defect tightly, resulting in less irritation to the soft tissue. Moreover, some studies have reported that these materials may help to distribute the occlusal forces exerted on the
bone and underlying tissues. Modal analysis is one method used to determine the dynamic characteristics of a structure by investigating how each component of the structure vibrates when subjected to dynamic loading. Oki et al. recently used modal analysis to investigate the effects of resin bulb structures in a cast obturator prosthesis on the vibratory characteristics of the rest and clasp parts. The following parameters for vibratory characteristics were used: modal animation, amplitude, maximum displacement, and decay rate. The results showed that the bulk structures of the obturator prosthesis responded differently, with the buccal flange and hollow obturators showing no twisting movements, smaller amplitude and maximum displacement, and higher decay rate than the solid version.

To date, there have been no studies focusing on the effects of soft denture liner material on the vibratory properties of cast obturator prostheses. The purpose of this study was to demonstrate the influence of regular type MOLTENO® (MOLten Medical Co., Osaka, Japan) resilient lining material on the vibratory properties of the rest and clasp parts of obturator prostheses by the use of modal analysis in vitro. Decay rates and maximum amplitudes of the rest and clasp parts of cast obturator prostheses were chosen as the parameters for evaluating the vibratory properties of the following three test pieces: all resin (R) type, 2 mm-relined (RM) type, and fully-relined (M) type bulb buccal flange obturators. The data were compared among the three cases to identify the sample that most effectively limited the detrimental effects to the abutments.

Materials and Methods

1. Construction of test subjects

A model cast was selected from among those of patients treated by our clinic. The defect type was one commonly found in maxillectomy patients, corresponding to Aramany’s Class I, or $V_{1/2}H_{1/2}T_{1/2}O_{1/2}$ according to the VHS classification suggested by Hashimoto et al. On the non-defective side, the teeth from the left central incisor to the left second molar remained. The model cast was duplicated with silicone duplicating material (Wirosil, BEGO, Bremen, Germany) and poured into an extra hard stone (NEW FUJIROCK, GC Co., Tokyo, Japan) to create the master cast (Fig. 1). To standardize the shape of the obturator bulb, the defect was modified as shown in Fig. 2. A duplicated refractory cast was then made from the adjusted master cast. The framework was waxed up and casted in Co-Cr alloy (Biosil-5®, Degussa AG, Hanau, Germany). The framework had two embrasure clasps on the first and second molar, and on the first and second premolar. The anterior part comprised an RPI bar clasp placed on the central incisor (Fig. 3). The buccal flange obturator was then waxed up on the framework, and the artificial teeth (Bioblend, DENTSPLY International Inc., NY, USA, and Orthosit, IVOCLEAR, Liechtenstein) were arranged. The cast was flasked, boiled out, and packed into a box-shaped buccal flange obturator with heat-cured acrylic resin (ACRON, GC Co., Tokyo, Japan). The resin was processed in the curing unit for two hours at 80 °C, then for thirty minutes at 100 °C before being deflasked and polished. The obturator created using

Fig 1. A master cast corresponding to Aramany’s Class I

Fig 2. Scheme of the standardized obturator bulb (25 × 37 × 28 × 29 mm widths, 29 mm depth, and 4 mm thickness)
this process was the R type (Fig. 4). After it was used in the vibration measurement experiments, two bulb cores were made of NEW FUJIROCK from the R type cast to allow modification of the bulb shape and to create the other two samples.

Approximately 2 mm of the outer surface of the R type resin bulb was cut off. The obturator was flashed using one of the cores. The ordinary laboratory procedure for the regular type MOLTOEN® was then carried out. The material was softened using a heating-box and injected into the mold of the obturator bulb. The flask was then pressed sufficiently and placed in boiling water for 5 minutes. After the flask had cooled, the obturator was carefully removed. The sample obtained using this step was the RM type (Fig. 5). After being measured, the whole bulb of the obturator was removed and replaced with MOLTOEN® using the other bulb core. This new sample was the M type (Fig. 6). The sample was measured again under the same conditions. The weights of the R, RM, and M types were 63.4, 61.6, and 58.3 g, respectively.

2. Measurement system

The overall measurement system is shown in Fig. 7. A 512-D Vibration Generator (EMIC Co., Tokyo, Japan) was used to apply excitation signals to the subject, while a 5860A Transducer (Dytran Instruments Inc., CA, USA), connected to the Vibration Generator, was used as a force sensor for measuring the applied excitation force signals. A LV-1300 Laser-Doppler Vibrometer (ONO SOKKI Co. Ltd., Kanagawa, Japan), whose sensor head was held by a 5-Axis Stage (Meritsu Seiki Co., Kanagawa, Japan), was used as the velocity measuring transducer which detected the vibration response signals from the subject. Both excitation and response signals were fed into a CF-6400 FFT analyzer (ONO SOKKI Co., Ltd., Kanagawa, Japan) for calculating the frequency response function at each measurement point. The whole setup was placed on an AYN-1007 K4 Vibration Isolator Table (Meritsu Seiki Co., Kanagawa, Japan). All the frequency response functions data were input into a PC-9821 Xn personal computer (NEC Co., Tokyo,
Japan) and analyzed using Vibrant Win modal analysis software (Marubeni Solutions Co., Tokyo, Japan).

3. Measurement procedure

A non-contact, high-speed 3-D shape measurement system, SURFLACER (UNISIN Inc., Osaka, Japan) was used to measure the contours of the R type obturator, and the obtained data were sent for analysis and display on an Indigo workstation (Silicon Graphics Inc., CA, USA). There, the 3-D data were computed by utilizing SURFACER, 3-D surface data management-convert-analysis software (Imageware Inc., MI, USA). The obtained image was used to define the X, Y, and Z coordinate values of each measurement point. In this study, 61 measurement points were established on each sample, with the measurement points located at equivalent positions on the three obturators. These values were then input to the Vibrant Win modal analysis software to construct the shape file of the obturator.

The experiment was performed in a laboratory at a temperature of 24 °C and 75% relative humidity. The obturator prosthesis was screwed onto a rod connected to the vibration generator. The occlusal plane of the obturator, which was estimated according to the occlusal plane of the artificial teeth and the 3 rests on the framework, was set parallel to the horizontal plane. The reflection tapes were placed on the measurement points to increase the reflectivity of the laser beam (Fig. 8). Miyake reported that accurate measurements could be taken by using reflective adhesive tapes when the angle of laser incidence was from 0 to 75 °. In our study, the angle of incidence of the laser beam at each measurement point was within the mentioned range. Both the He-Ne laser beam direction and the vibration direction were aimed parallel to the vertical axis.

Periodic random excitation was selected as the excitation force signal, and the investigated frequency range was set from 0 to 1600 Hz. Coherence functions were used in the FFT analyzer to check the quality of the measurements. Coherence value becomes unity when no other external factors influence the measurements, but it falls to a low value if affected by external noise. The measurements were performed when the
coherence functions were greater than 0.9 in the frequency range being investigated, as in previous studies. The frequency response function at each point was obtained from the summed averages of eight measurements by the FFT analyzer. Next, all the frequency response functions of each sample were transferred to the Vibrant Win modal analysis software. They were analyzed in the frequency range from 0 to 1200 Hz by using the curve-fitting function. The curve-fitted frequency response functions of each measurement were then finally calculated.

4. Transient response simulation experiments

All of the curve-fitted frequency response functions were used in the transient response simulation part of Vibrant Win. Transient response waves at 30 points established on the rests and clasps of each model were produced after the models were subjected to an impact under two separate simulation conditions (Fig. 9) according to Oki et al.'s study:

1) When 40 N in the direction of the vertical axis impacted simultaneously on each of three rests on the non-defective side (Simulation I).
2) When 10 N in the direction of the vertical axis impacted simultaneously on each of four artificial teeth (premolar to molar) on the defective side (Simulation II).

To evaluate the transient response wave obtained at each measurement point, the wave peaks were carefully selected and plotted on the computer display. Then by employing the method of least squares, the decay rate ($\sigma$) was calculated using DAMPCAL software (Marubeni Solutions Co., Tokyo, Japan) (Fig. 10). The plotting was repeated four times to avoid any measurement error, afterwards the mean decay rate of the point was obtained. A higher value of decay rate implies that the vibration will cease more quickly after an impact. As for the maximum amplitude value, it was calculated automatically by the software after the simulation.

Statistical analysis was performed according to the One-way Analysis of Variance (ANOVA) with Fisher’s PLSD test ($P<0.01$) to compare the decay rate and the maximum amplitude results of rest and clasp parts among the three samples.

Results

There were four resonance peaks in the frequency range from 0 to 1200 Hz in all samples. Error convergence rate of the curve-fitting function was 99.9 for all the samples. Table I presents the results of the natural
frequencies of the three obturators. For each sample, the natural frequencies remained constant over the 61 frequency response functions. The results of the curve-fitted frequency response functions of each obturator at the first premolar buccal clasp tip are shown in Fig. 11.

The results of the transient response simulation experiment revealed that the inclination of the damping curve in the R type was the steepest followed by that in the RM and M types, respectively, under both simulation conditions (Fig. 12). The mean ± SD of decay rate of the R, RM, and M types at the rest and clasp parts in Simulation I were 3.05 ± 0.10, 1.93 ± 0.06, and 1.33 ± 0.03 sec⁻¹, and in Simulation II they were 3.16 ± 0.09, 1.92 ± 0.06, and 1.33 ± 0.05 sec⁻¹, respectively. In both simulations, ANOVA showed a significant difference in decay rate in all pairs among the three models (Fig. 13). ANOVA also identified the decay rate of the R type as being significantly higher than the others (p<0.0001).

Concerning the maximum amplitude, the results for the R, RM, and M types from Simulation I were 0.33 ± 0.10, 0.63 ± 0.18, and 0.32 ± 0.13 mm, respectively, whereas from Simulation II, the results were 0.18 ± 0.08, 0.21 ± 0.10, and 0.10 ± 0.06 mm, respectively. There were significant differences (p<0.0001) in the two pairs of R and RM types, RM and M types in Simulation I, and in the pairs of R and M types, and RM and M types in Simulation II. The maximum amplitude of the RM type in Simulation I was the largest, and the maximum amplitude of the M type in Simulation II was the smallest (Fig. 14).

### Discussion

To date there are no studies concerning the influences of a soft denture liner material on the vibratory properties of cast obturator prostheses. In this study, the modal analysis was used to investigate the influences of resilient lining material on the vibratory properties of the rest and clasp parts of obturator prostheses. The design of the obturator prosthesis varies according to the site and size of the residual defect. The design of the cast obturator prosthesis used in this study followed the basic principles suggested by Aramany16 and Parr et al.17 This design is often used in clinical practice. Most published data and recommended techniques for applying soft liners suggest that a thickness of 2 to 3 mm is most appropriate18-21. Consequently, the thickness of the lining material of the RM type was set at approximately 2 mm for the purpose of our experiments. In addition, there are several papers in the past literature17-19 which suggested the advantages of using silicone bulb obturators in maxil-

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**Table 1. Natural frequencies of three obturators**

<table>
<thead>
<tr>
<th>TYPE</th>
<th>R (Hz)</th>
<th>RM (Hz)</th>
<th>M (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>330</td>
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<tr>
<td>3</td>
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<td>530</td>
</tr>
<tr>
<td>4</td>
<td>1070</td>
<td>1060</td>
<td>1080</td>
</tr>
</tbody>
</table>

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**Fig 11.** Curve-fitted frequency response functions at the measurement point of the tip of the buccal clasp at the first premolar.
pectomy patients. Therefore, for the M type, we chose a whole resilient bulb obturator.

MOLTENO® is a resilient denture liner material, mainly composed of polyolefin, and is normally used for the lining of ordinary prostheses. Ohkawa et al. suggested that MOLTENO® was an appropriate lining material for long-term use, about 2 to 3 years. In addition, this material is also frequently used for constructing mouthguards. This suggested a potential for the MOLTENO® material to be used for making the whole resilient obturator bulb. Therefore, we chose MOLTENO® for use in these experiments.

Because the density of resin and MOLTENO® are 1.18g/cm³ and 0.88g/cm³, respectively, the volume percentage of the resilient material part to the resin part was calculated by using the weight of the three samples mentioned above, together with the density of both materials. We assumed that the total resin volume in the R type obturator was 100%. The volume of the MOLTENO® portion in the RM type was thus approximately 15% of the total resin portion or about 35% of the resin bulb portion. For the M type, the MOLTENO® material volume was approximately 50% of the total resin part or 100% of the bulb part. Ou et al. used
three different resiliencies of mouthguard materials when evaluating the influence of material stiffness on the human dry skull by measuring decay rate. Although in their study, the volume percentage of resilient material (mouthguard) part to the skull part was considered to be very small, the results showed that the stiffness of the material did in fact, significantly influence the decay rate value. This is in agreement with the fact that mass and stiffness have an effect on the vibratory properties of a structure. Since the volume percentage of MOLTENO® material to total resin part in our study was larger than that in Ou et al.’s study, we predicted that a clear and significant difference of decay rate would be obtained from among the three samples.

Hasegawa reported that the position of the resilient material (in this case, a mouthguard) influenced the damping ratio of the dry human mandible. In our study, the positions of the resilient material differed among the three types, and the decay rate values showed significant differences among them. Our results and Hasegawa’s results are similar in this aspect.

Grant et al. used mobility-measuring devices on healthy teeth to indicate that the range of vertical movement of those teeth was up to 0.02 mm. Recently, Miura et al. reported that the displacement of the upper molar in the palatal and apical direction during mastication varied between 0.068 mm and 0.079 mm. If the abutment movement measured in the condition when the prosthesis is actually set in the mouth is over the above physical ranges, the pros thesis can be considered as a harmful one to abutment. From this experimental design, however, we cannot predict the influence of these obturator prostheses on the abutment directly, because the vibratory properties of each prostheses in vivo must be different from those in this experiment.

Clinically, even if the maximum amplitude of the abutment teeth is within those physical ranges, we consider that the prosthesis whose vibratory properties minimize the maximum amplitude, and stops the vibration of the abutment rapidly would be the preferable one. This is because the occlusion impacts during swallowing or mastication, which cause this movement, happen many times in daily life. In comparison with the normal one, the Aramany Class I obturator prosthesis is much heavier and has a complex combined force acting on. Moreover, the bulb part of the prosthesis is placed directly into the defective area where the surrounding soft tissue changes its shape during oral functions and then causes a cantilever effect on the abutment teeth. From our longitudinal clinical observation, we found that the abutment teeth of the Aramany Class I obturator prosthesis fell down earlier. It can be considered that the vibration of the abutment teeth caused by the obturator prosthesis is one of the factors inducing the fall of the abutment.

Our results indicated that the use of MOLTENO® soft lining material had various influences on the vibratory properties of the obturator prosthesis itself. In Simulations I and II, the results showed that the vibratory properties exhibited in the decay rate of the rest and clasp parts in the R type have significantly the high-
est value among the three samples. When the maximum amplitude at the same positions are considered, the RM type has significantly the highest value, which went far beyond the normal physical ranges mentioned above for all the samples. Consequently, it is necessary to perform a further vibratory analysis to evaluate the effects of soft lining material on the abutment of maxillectomy patients, in vivo. The results from our study will be the fundamental data for the next step in dealing with those patients.

By using an impact hammer as a vibration generator and an acceleration sensor (5.84 mm in diameter) for the response signal, Du et al. recently showed the amplitude of each maxillary dentition without any prostheses or appliances, from the curve-fitted transient response function, when impact was focused directly on the central incisors in healthy subjects and in cleft palate patients. On this basis, therefore, it will be possible to evaluate the effect of the soft lining material for the obturator prosthesis on the abutment in vivo after solving the current limitations, such as miniaturization of the acceleration sensor, or elimination of body movement while breathing when the Laser-Doppler measurement method is used.

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References

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