The purpose of this study was to investigate the effect on the vibratory characteristics of a cast hollow obturator prosthesis retainer when varying its bulb height. Bulb parts with high (H), middle (M), and low (L) lateral walls were prepared. A Vibration Generator was used to excite the three obturators, while a Laser-Doppler Vibrometer was employed to detect the vibrations at specified measurement points. The frequency response functions of each obturator were recorded on an FFT analyzer to enable their modal shapes to be identified. In addition, transient response simulations were carried out and the decay rate (DR) and the maximum amplitude (MA) of the rest and clasp parts of each obturator were obtained. These were statistically analyzed by ANOVA and Fisher's PLSD test (p < 0.01). The modal shapes were almost the same in all obturators. Significant differences were found in DR in all pairs among the three obturator prostheses, with the DR of the L type being the highest. On the other hand, there were no significant differences in MA. We conclude that the L type is preferable from the standpoint of its vibratory characteristics.

**Key words:** modal analysis, obturator prosthesis, decay rate, acquired maxillary defect, hollow bulb.

**Introduction**

Advancements in surgery, radiotherapy, and chemotherapy have led to high survival rates of patients with oral malignant tumors, and this has led in turn to increased demand for prosthetic rehabilitation for patients with acquired maxillary surgical defects. This rehabilitation centers on obturator prostheses, which are provided for such patients to enable, usually successfully, normal mastication, deglutition, speech, and appearance. On the other hand, in partially edentulous cases with large defects, lack of support and retention causes loss of stability of the obturator prosthesis; and the weight of the obturator exerts dislodging and rotational forces on the abutment teeth. In addition, the forces exerted on the artificial teeth on the defect side, especially during mastication, frequently cause a cantilever effect on the abutment teeth. Greater attention must therefore be paid to the preservation of abutment teeth. Brown and Desjardins have suggested that, to maximize support, retention, and stability, the remaining teeth should be aggressively engaged by intracoronal or extracoronal direct retainers and the lateral wall of the bulb should be extended higher geometrically. However, we believe that a low lateral wall height is desirable to
reduce the weight of the obturator.

Arakida\textsuperscript{6} investigated, using strain gauges, the influence of the path of placement on the retentive force when designing an obturator. His results indicated that a path of placement inclined 15 degrees in the palatal direction at the molar part with respect to the perpendicular direction of the occlusal plane was optimal from the standpoint of retention and stability. Myers et al.\textsuperscript{7} demonstrated by photoelastic analysis that the facial cast circumferential retention with palatal cast circumferential clasp reciprocation had shown the most favorable stress distribution of four common partial denture obturator designs. Phankosol et al.\textsuperscript{8} applied modal analysis\textsuperscript{9} and suggested that the vibratory characteristic of an obturator framework without a continuous bar and an indirect retainer might be unfavorable. Oki et al.\textsuperscript{10} evaluated the vibratory characteristics of three cast obturator prostheses classified as Aramany’s Class II\textsuperscript{11} including the solid, buccal flange, and hollow types. The results revealed that the hollow obturator showed rapid damping of vibration with minimal displacement of the retainers. Komin et al.\textsuperscript{12} studied three obturator prostheses with buccal flange bulbs classified into Aramany’s Class I\textsuperscript{11}, in which a model with the bulb made of resin, a partially relined version, and a version that was fully relined with soft material, were compared. The resin type showed the most rapid damping of vibration of the retainers. To date, however, there have been no studies clarifying the relationship between the height of the lateral wall of obturator prostheses and the vibratory characteristics of their retainers.

The purpose of this study was to investigate the effect of changing the bulb height of an Aramany’s Class I cast hollow obturator prosthesis on the vibratory characteristics of its retainer parts. Three samples, in which the bulb part had three different lateral wall designs varying by 1 cm specified as, high (H), middle (M), and low (L), were evaluated from the modal shape, the decay rate (DR), and the maximum amplitude (MA) of the retainers in vitro.

Materials and Methods

1. Test subjects

A model cast corresponding to Aramany’s Class I\textsuperscript{11} or V\textsubscript{1A1P} H\textsubscript{1A1P} T\textsubscript{1A1P} O\textsubscript{1A1P} was selected in this study. On the non-defect side, the teeth from the right central incisor to the right second molar remained. The defect size was 5 cm medial-dis-

![Fig. 1. A master cast.](image-url)
41.50, and 38.97g, respectively. The lateral wall of each bulb covered the lateral scar band.

2. Measurement system

Figure 3 shows a diagram of the overall system. A 512-D Vibration Generator (EMIC Co., Tokyo, Japan) and a 5-Axis Stage (Meiritsu Seiki Co., Yokohama, Japan) were set up an AYN-1007K4 Vibration Isolator Table (Meiritsu Seiki Co., Yokohama, Japan). A 5860A Force Sensor (Dytran Instruments Inc., Chatsworth, CA, USA) connected to the Vibration Generator was applied for measuring the excitation force signals. The response force signals were picked up by a LV-1300 Laser-Doppler Vibrometer (ONO SOKKI Co. Ltd., Yokohama, Japan) whose sensor head was supported by the 5-Axis Stage. The excitation signals and the response signals were led through a charge preamplifier (AMP) into a CF-6400 FFT Analyzer (ONO SOKKI Co. Ltd., Yokohama, Japan) to calculate the frequency response functions at each measurement point. All frequency response functions were input into a Vectra VE PC (Hewlett-Packard Co., Grenoble Cedex, France) and analyzed using Vibrant GEN modal analysis software (Marubeni Solutions Co., Tokyo, Japan).

3. Measurement procedure

The experiment was performed in a laboratory at the temperature and humidity of 24°C and 50%, respectively. In this study, 53 measurement points were placed on each type. Forty-seven measurement points were located at the same points among three obturators except for two points on the lid part and four changeable points on the rim of the bulb part (Fig. 4).

The coordinate value of each measurement point on the H type was measured using SURFLACER, a non-contact, high-speed 3-D Shape Measurement System (UNISN Inc., Osaka, Japan). The 3-D data were computed on an Indigo® workstation (Silicon Graphics Inc., Mountain View, CA, USA) using SURFACER, 3-D surface data management-convert-analysis software (Imageware Inc., Ann Arbor, MI, USA). The coordinate values of each point were input into Vibrant GEN to draw the wire-frame shape of the H type.

The H type was screwed onto a rod connected to the vibration generator through the hole, which was the exciting force point (Fig. 4). The occlusal plane was set parallel to the horizontal plane. The reflection tapes were placed on the measurement points and as perpendicular to the vertical axis as possible to enhance laser beam detection. The He-Ne laser beam was aimed parallel to the vertical axis and the vibration direction.

Periodic random excitation was selected as the exciting force signal in this study. The frequency range in this examination was 0 to 3200 Hz. The fre-
frequency response function of each measurement point was calculated as the summed average of eight measurements made using the FFT Analyzer. Fifty-three frequency H type response functions were transferred to Vibrant GEN and adjusted using the curve-fitting function in the frequency range from 200 to 2600 Hz with the error convergence rate of curve-fitting maintained at greater than 99.90%. The modal shapes of the H type were then observed.

In the same manner, the coordinate values of the measurement points on the M and L type were computed using SURFLACER to input them into Vibrant GEN and were respectively measured using the FFT Analyzer to produce the curve-fitted frequency response functions and modal shapes. In these two obturators, each error convergence rate of curve-fitting was also maintained at above 99.90%.

4. Transient response simulation experiments
Using all the curve-fitted frequency response functions, the transient response waves were produced at 21 points established on two embrasure clasps and the RPI system of each obturator by Vibrant GEN transient response simulation. In this simulation, the models were impacted under two separate simulation conditions (Fig. 5) according to Oki et al.’s study.10

The DR and MA were used to evaluate the waveforms. For the DR, the wave peaks of each measurement point were carefully selected and plotted on the computer display. The DR was then calculated by the method of least squares using the DAMPCAL application (Marubeni Solutions Co., Tokyo, Japan). The plotting was repeated 8 times to avoid measurement error, after which the mean DR of the point was obtained. The MA value of each measurement point was automatically calculated using DAMPCAL software (Fig. 6).

Statistical analysis was performed according to the One-way Analysis of Variance (ANOVA) with Fisher’s PLSD test (p < 0.01) to compare the DR and MA results among the three samples.

Results

The results for curve-fitted frequency response functions at the measurement point of the second molar buccal clasp tip are shown in Fig. 7. There were four resonance peaks in the analyzed frequency range from 200 to 2600 Hz in all the samples. Table I presents the natural frequencies of the three obturator prostheses. In the first natural mode (Mode 1), the natural frequencies of three obturators were different. In the second and third natural modes (Modes 2 and 3), the natural frequencies were almost the same. At the fourth natural mode (Mode 4), the natural frequencies were the same.

Figure 8 shows the modal shapes of the H type. In Mode 1 for the H type, there were two nodal points: the measurement point adjacent to the exciting force point and that at the artificial canine tooth. The resin part fluttered with an imaginary axis of rotation between two nodal points. At the same time, the pos-
terior part behind the axis moved up and down like a see-saw with an imaginary axis of rotation between two measurement points along the finishing line. In Modes 2 and 3, the H type had one nodal point each at the base of the minor connector of the molar and the pre-molar part. Each embrasure clasp vibrated with high amplitude while the other parts remained relatively stationary. In Mode 4, the H type had one nodal point at the rest of the molar part. The embrasure clasp at the

molars moved up and down like a see-saw with a high amplitude, with an imaginary buccal-palatal axis of rotation through the nodal point, while the other parts remained relatively stationary. As for the other two obturators, the modal shapes demonstrated almost the same pattern of movement of the H type at each natural mode.

Figure 9 presents the transient response simulation waves of the three obturators at the second molar buccal clasp tip in simulation I. The mean ± SD of DR of the H, M, and L types at two embrasure clasps and the RPI system in Simulation I were 8.25 ± 0.39, 10.91 ± 0.37, and 13.22 ± 0.48 sec⁻¹, and in Simulation II they were 8.17 ± 0.17, 10.97 ± 0.26, and 13.75 ± 1.04 sec⁻¹, respectively. In both simulations, significant differences were found in all pairs among the three obturator prostheses (Figs. 10 and 11) (p < 0.0001).

Concerning the MA, the results for the H, M, and L types from Simulation I were 5.47 ± 4.84, 9.66 ± 8.58, and 10.24 ± 8.39 x 10⁻³ mm, whereas in Simulation II
they were 1.95 ± 1.16, 2.43 ± 1.91, and 1.59 ± 1.00 x 10^{-1} mm, respectively. In both simulations, there were no significant differences in all pairs among the three obturator prostheses (Figs. 12 and 13).

**Discussion**

The resection in Aramany’s Class I is performed along the midline of the maxilla; the teeth are maintained on one side of the maxillary arch. This class is the most frequent maxillary defect. The design of the cast obturator prosthesis used in this study followed the basic principles. This design is often used in clinical practice. However, the abutment teeth in Aramany’s Class I are more subject to dislodging and rotational forces when the obturator prosthesis is placed in the mouth due to the heaviness of the obturator bulb. In addition, patients in Class I have liner tooth and arch arrangements, as compared to patients in Class II who have square or ovoid arch forms. Because the fulcrum line or axis of rotation of the obturator prosthesis is influenced by the position of the occlusal or cingulum rests, and due to the size and configuration of the defect, Class I obturators tend to be less effective as indirect retainers than Class II obturators. Consequently, Class I obturator prostheses are both heavier and less stable, and usually exhibit more movement when subjected to the forces exerted during mastication. To increase the longevity of the abutment teeth, it might be useful to investigate the dynamic characteristics of the retainer parts of the obturator.

Modal analysis, a method of elucidating the dynamic characteristics of a structure by investigating how components vibrate in resonance, has been applied recently in evaluating not only maxillary and mandibular major connectors but also in cast obturator prostheses.

As for the curve-fitting procedure, Phankosol et al. have stated that in investigating the obturator frameworks, the measured frequency range was 0 to 2000 Hz but the range of curve-fitting was 220 to 2000 Hz, because noise interferes with the response function. Arksornnukit et al. mention that in investigating the mandibular removable partial denture frameworks, the measured frequency range was 0 to 1600 Hz but the range of curve-fitting was 80 to 700 Hz; and consequently the error convergence rate of curve-fitting function was above 99.90%. In the present study, the measured frequency range was 0 to 3200 Hz. Although several curve-fitting trials were carried out using this range, we were able to complete the curve-fitting procedure when the range of curve-fitting was set from 200 to 2600 Hz, in which all distinct resonance peaks were included. The error convergence rate in this case was above 99.90 % for all obturators, similar to that reported by Arksornnukit et al.

The natural frequencies of the three obturators were markedly different in Mode 1. The natural frequency of the heaviest obturator (H type) was the lowest at 240 Hz, and that of the lightest (L type) was the highest at 290 Hz. Natural frequency is a function of mass and stiffness. With increased mass, the natural frequency falls; the results of Mode 1 agreed with this principle. This phenomenon might relate to the fact that the first natural frequency of a structure is called the fundamental frequency, and it decides the basic vibratory characteristics.
Although the modal shapes were closely similar among the three obturators, these observations provide useful data for predicting durability and for detecting flaws or weak points in the structure. When a fluttering movement of the structure is observed at the resonance within elastic deformation, such movement will result in stress concentration points at which structural failure may first occur. In Mode 1, there will be a stress concentration line between two nodal points. This might be a result of the weight and bulk of the bulb. As for the other natural modes, there will be a stress concentration point at the bases of the minor connector (Modes 2 and 3) and at the rest of the molar part (Mode 4). Hashimoto\(^{18}\) surveyed 115 partially edentulous obturator prostheses, including 66 cast obturators, and observed that the clasp parts of the obturator prostheses were the most frequently broken. This report predicted that in clasp fracture cases, the stress may have been focused on the clasp part, since the obturator prosthesis intermittently rotated up into the defect due to occlusal pressure. This prediction was in agreement with the results of our vibration analysis.

Because the abutment is an integral part that influences the prognosis of the obturator prosthesis, it is necessary to increase the longevity of the abutment teeth. The cantilever effect mentioned above may put the abutment under extreme stress as soon as the obturator is placed in the mouth. Moreover, to prevent food and liquids from leaking into the nasal cavity, the bulb of the obturator is placed tightly into the defect area; however, the surrounding soft tissue changes its shape during the very common activities of mastication, swallowing, and speech. We thus conclude that a prosthesis with the properties of reducing the maximum amplitude of the abutment and of damping the vibration of the abutment as quickly as possible is preferable from the standpoint of the vibratory characteristic.

Miura et al.\(^{19}\) recently reported that the displacement of maxillary clinically healthy molars in the palatal and apical direction during mastication varies between 0.068 mm and 0.079 mm. The results of our study indicate there to be no significant differences among the three obturators with respect to mean MA of the retainer parts in the vertical direction, but the mean MA of all the obturators far exceeded the normal physical range mentioned above, possibly jeopardizing the abutments. On the other hand, the H type showed by far the lowest DR of the three obturators. A low DR indicates that the vibration is not rapidly damped. The reason why the H type showed the lowest DR might be that the top of the bulb, which protruded, transferred its greater degree of movement to the retainers. Consequently, the L type, which showed the highest DR, would be the obturator of choice from the standpoint of preservation of the abutments.

For settling the best bulb design from the viewpoint of preserving the abutments, it will be necessary to make direct measurements of the vibratory characteristics of the abutments while the obturator prosthesis is installed in the mouth. Iida et al.\(^{20}\) recently used an impact hammer as a vibration generator and an acceleration sensor (5.84 mm in diameter) to detect the response signal to investigate the vibratory characteristics of the maxillary dentition in four cleft lip and palate patients before and after bone grafting. They succeeded in demonstrating that after bone grafting the modal

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![Fig. 12. The MA of the three obturator prostheses in Simulation I.](image1)

![Fig. 13. The MA of the three obturator prostheses in Simulation II.](image2)
shapes of the maxillary arch showed no phase differences in any of the subjects, and the maximum displacements of the central incisors conspicuously decreased in three subjects. As for our experiments, it was nearly impossible to apply the acceleration sensor, since at the abutment with the clasp arm there are no locations where it could be placed. Use of a laser-doppler vibrometer as a response signal sensor is now regarded as the only potential method for realizing such measurement, since it is a non-contact sensor with a focus point 0.02 to 0.4 mm in diameter. On the other hand, to enable in vivo vibratory studies it is necessary to solve several problems such as elimination of head movement while breathing, regulation of the laser beam power for application to the human body, and accurate anchoring of the laser sensor head. Further developments to enable in vivo vibration analysis are needed.

References


