INTRODUCTION

Three-dimensional (3D) digital technology enables recording of 3D shapes as digital data, which undergoes processing and rendering to construct 3D shapes with computer assistance. Digital technology is also widely used in medicine and dentistry. In addition to being used as a diagnostic imaging tool, this technology is currently developed and used in a wide range of fields, including 3D shape measurements and target design as well as prosthetic fabrications. For maxillofacial prostheses, highly effective 3D digital technology was used to evaluate water absorption in the inner hollow obturator spaces. Solid and hollow obturator specimens were fabricated using a 3D printer with photocurable resin. Then, the hermeticity was examined by leak testing. These specimens were immersed in distilled water at 37°C. Each specimen was weighed every 24 h for 120 days, and weight changes between each group were compared. Water accumulation in the hollow obturator was not visually observed. Although water absorption was significantly higher in solid specimens, the weight increase rate was also significantly higher in hollow specimens. Applying a laminating 3D photo fabrication made the fabrication of a completely unified hollow obturator model possible.

**Keywords:** Digital technology, Hollow obturator, Water absorption, 3D printer

Fluid accumulation in the hollow spaces of obturator is a continuing problem when fabricating hollow obturator prostheses using the conventional method. To address this problem, the three-dimensional (3D) digital technology was used to evaluate water absorption in the inner hollow obturator spaces. Solid and hollow obturator specimens were fabricated using a 3D printer with photocurable resin. Then, the hermeticity was examined by leak testing. These specimens were immersed in distilled water at 37°C. Each specimen was weighed every 24 h for 120 days, and weight changes between each group were compared. Water accumulation in the hollow obturator was not visually observed. Although water absorption was significantly higher in solid specimens, the weight increase rate was also significantly higher in hollow specimens. Applying a laminating 3D photo fabrication made the fabrication of a completely unified hollow obturator model possible.

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Defects of solid-type obturators while minimizing the denture weight.

Until now, conventional methods similar to those used in normal dentures have been used for fabricating closed hollow obturator prostheses. This has resulted in complex fabrication requiring a high proficiency level of technicians. Thus, closed hollow obturators, including the hollow part, cannot be fabricated together. The mainstream method involved fabricating the open-type part of the obturator, creating the palate part or canopy cover, and then joining them together in room temperature curing or adhesive resins. However, poor adhesion at the joined part or air bubbles in the self-curing resin can cause discoloration of the joint. Moreover, saliva, water, bacteria, etc., can easily enter the hollow section through the joined part, making it unsanitary while causing malodor, decreased esthetic properties, and increased weight. This contamination can also become a source for infection and aspiration pneumonia. In contrast, 3D optical shaping equipment offers a significant advantage in molding single-piece hollow prostheses with no joints. Therefore, problems at the joins can be eliminated, making this method very useful for fabricating hollow obturators. A 3D laminating molding device was used to fabricate a hollow obturator model, and its hermeticity was investigated by leak testing. This study aimed to evaluate water absorption in the inner space of hollow obturator models using the 3D digital technology and to attempt the clinical application.
MATERIALS AND METHODS

Specimen fabrication
A hollow obturator model was fabricated, and its hermeticity was investigated by leak testing. Two types of specimens were used for leak testing: (1) a 30-mm-diameter spherical solid obturator model and no hollow space in the center and (2) a hollow obturator model with a 2-mm-thick outer border and 30-mm outer diameter, and a hollow space in the center (Fig. 1). Each specimen was designed using a modeling software. The hollow center was designed to be subtracted from the 30-mm sphere by outputting a 2-mm sphere decreased at the center of the 30-mm sphere. The models were fabricated based on the data design using acrylic photocurable resin (DS2000, DWS, Thiene, Italy; Lot no. 30160427) with a laminate-type 3D photo fabrication apparatus (DIGITAL WAX 020D, DWS). With the hanging-type photo fabrication system used in this study, laser light was applied below the transparent acrylic container filled with photocurable resin and the obturator part was fabricated by laminating the photopolymerization reaction while gradually elevating the platform (Fig. 2). Because the platform was elevated for each photoirradiation and molding operation, the uncured internal resin is discharged every photopolymerization. The laminating pitch for molding was set at 0.01 mm. The photoirradiation mechanism involved the galvanometer scanner method by moving a high-speed optical axis of a superfine laser while precision was maintained with two mirrors. After completing the model, the ultraviolet curing process was accomplished at 20 min irradiation in the UV curing apparatus (UV CURING UNIT MOD. S-2, DWS) to release the residual monomer.

Leak testing
Each fabricated specimen was immersed in a 37°C distilled water using a Smart water bath, and the specimens were covered with a rubber band to prevent from floating up. We fabricated six pieces of specimen for each model. All specimens were removed from the distilled water every 24 h. Water on the surface of each specimen was wiped off using a paper towel, and the specimen was weighed before returning to the previously described environment, immediately after the weight measurement using a digital weighing scale and observed over 120 days (Fig. 3). Fluids accumulated in the hollow obturator specimens was checked using a megascopic observation with photoirradiation from the base of the hollow specimens every day.

Analysis methods
The amount of water absorption and weight increase rate of the two specimens were calculated using the following formulae and then compared:

\[
\Delta W_n (\times 10^{-3} \text{g}) = W_n - W_0
\]

\[
W_p (%) = \frac{\Delta W_n}{W_0} \times 100
\]

where \( W_n \) (g); weight over \( n \) days, \( W_0 \) (g); initial weight

Statistical analyses were used the Mann-Whitney \( U \) test and performed using SPSS version 18.0 (IBM, Armonk, NY, USA). \( p<0.05 \) was deemed statistically significant.

Specimen
(a) 30.0mm in diameter (b) 2.0mm-thick outer border

Solid obturator model
Hollow obturator model

Fig. 1 The test specimens. a) Solid obturator model. b) Closed hollow obturator model.

Fig. 2 Molding process of the hollow obturator using the laminate type 3D photo fabrication apparatus.
RESULTS

Specimen fabrication
The application of the laminating molding device made the fabrication of the hollow obturator model specimen with a completely unified part possible (Figs. 4-a, b). The solid and hollow model specimen initially weighed 16.78±0.05 and 5.81±0.04 (Mean±SD) (g), respectively.

Leak testing
Logarithmic trends for the volume of absorbed water and weight increase rate were observed while the hollow specimen was submerged in water. Rapid increases were observed from the baseline weight until day 30, after which gradual increases were observed. At the mid-point of observation on day 60, the weight had increased by 0.13 g (2.25%). From then on, values were maintained at the almost the same level until the end of the experiment (Fig. 5). Megascopic observation of the center of the specimens using photoirradiation from the base of the hollow specimens on day 120 indicated little fluid accumulation. The solid and hollow specimens exhibited the same values until day 30; subsequent solid specimen values increased proportionally exceeding those of the hollow specimens. The weight had increased.

Fig. 3 Schematic flow chart of the experimental procedure. (a) Design of each specimen using modeling software. (b) Support design. (c) 3D Printing. (d) Post-processing. (e) Specimens immersed in water and covered with a rubber band to prevent floating up. (f) Measuring the weight.

Fig. 4 Printing of the hollow obturator specimen. (a) Design the closed hollow obturator specimen with sprue using modeling software. (b) Closed hollow obturator specimen after printing.

Fig. 5 Mean change in weight (g) of solid and closed hollow specimens immersed in distilled water at 37°C over 120 days.

Fig. 6 Mean percentage change in wt (%) of solid and closed hollow specimens immersed in distilled water at 37°C over 120 days.
by 0.12 g (0.71%) on day 35; the amount of water absorbed significantly increased in the solid specimens from day 35 onward (Fig. 5). Meanwhile, the absorption rate significantly increased in the hollow specimens from the initial day to day 120 during observation (Fig. 6).

DISCUSSION

Leak testing

The accumulation of fluids in the hollow portion of closed hollow obturator prostheses is a common problem in prosthodontic treatment. Although resin materials absorb water, because the water absorption rate is slow, water is unlikely retained in the obturator portion over a short period as long as there were no leaks. Therefore, poor bonding at the joined parts is one of the causes of water entering the inner space of the obturator part.16 Obturator parts are generally joined part in the upper and lower parts using an adhesive resin. Air bubbles or poor adhesion can cause fluid accumulation. In contrast, water accumulation was not visually observed in the completely unified obturator models made using 3D digital molding in this study.

Based on leak testing, the weight increases observed in the two specimen types were caused by the water absorption mechanism of acrylic resin to the surrounding water. The acrylic resin contains a small number of carbonyl groups, which are polar groups that attract water molecules. Water molecules on the acrylic resin surface are pulled toward the polar residues inside the acrylic resin, spread through the intermolecular gaps of the resin, and gradually infiltrate deeper into the acrylic resin. Therefore, the amount of water absorption could depend on the number of hydrophilic (carbonyl) groups in the acrylic resin polymers.17 Tsuboi et al.16 conducted leak testing using the same method for heat curing resin. They found that although water molecules absorbed in the resin of the hollow specimens eventually reached the hollow center and evaporated and the specimens became saturated because of the water vapor pressure, water molecules were easily diffused in the acrylic resin in the solid specimens, thereby inhibiting water absorption. We also found that although the hollow specimens first exhibited higher absorption rates than the solid specimens, these rates quickly plateaued, whereas solid specimen models exhibited proportionate rates of increase, with the absorbed amount finally reaching an amount proportional to the resin volume. Significant difference was also observed between the solid and hollow models on day 35 because of the differing water absorption mechanisms between these two models. During the initial period until day 30, the amount of absorbed water in hollow specimens was higher than those in solid specimens, and the saturated vapor pressure of the hollow portion and the osmotic pressure of the resin portion were balanced. Finally, the obturator becomes saturated and absorption stops. In fact, the mean weight change of the solid specimens stored for 120 days was 1.4-fold higher than that of the closed hollow specimens, and the weight of the solid specimens tend to increase further. The initial weight of the solid specimens was threefold higher compared to that of the closed hollow specimens in this study. The weight changes for solid specimens were threefold higher than that for closed hollow specimens eventually. Lighter hollow obturator including the original weight is better than the heavier solid obturator for clinical application.

Specimen fabrication and clinical application

The application of a hanging laminating molding device type used in this study made fabrication of a completely unified hollow obturator model possible. Although various methods of fabricating closed hollow obturator prostheses have been previously proposed,7,18-20 certain issues remain, such as in the joined part in the hollow portion and the complex nature of the procedure requiring a certain level of expertise. Therefore, a simple method was devised using a laminate-type photo fabrication 3D printer with photocurable resin to fabricate hollow obturators. The design of the hollow obturator could be arbitrarily set and integrated with no joined part completely. Thus, clinical problems, such as contamination, malodor, and decreased esthetic properties resulting from the entry of saliva and fluids into the hollow part, can be solved. The inner space odor is one of the major causes of malodor of the conventional hollow-type obturators. Bacteria together with other nutrients such as saliva can penetrate through joined part of the obturator and proliferate, making the inner space of the obturator a bacterial reservoir that produces metabolic products of the bacteria causing the malodor.

Computer-aided design/manufacturing (CAD/CAM) systems particularly used to fabricate a removable prosthesis have already been reported.24-27 However, CAD/CAM would not be suitable for a wide range of targets, such as the soft tissue or maxillary defects. Unfortunately, it could not fabricate the seamless hollow prostheses. This means that large amounts of data and time are required for fabrication, and completely integrated hollow prosthesis, which are the optimal type of obturator, cannot be manufactured. However, as optical laminate molding has just been applied to removable prosthesis and hollow obturator prostheses fabrication, only a few reports existed on this topic and the clinical application stage has not been reached. Completely integrated hollow obturator prostheses using optical laminate molding are more easily fabricated than conventional methods; however, some rooms for improvement remain. For example, a large and considerable amount of data and time are required to, respectively, create and complete the entire dento-maxillary prosthesis on the 3D printer. Additionally, the photocurable resin (DS2000) has not yet received pharmaceutical approval in Japan; thus, this new method is not suitable for clinical cases. Therefore, we aim for clinical applications after getting the approval from the Ethics Committee of Tohoku University Hospital. We plan to design a very thin hollow obturator, which can be freest set using the 3D digital
molding. In pursuing the clinical application, we want to confirm the biostability of prostheses created using this method while also attempting to further refine the design and establish a method that easily fabricates not only the hollow part but also the entire prosthesis using the 3D digital technology. The shift toward a digital workflow in maxillofacial prosthetics would open doors of opportunities for all practitioners who were once stocked in the technical difficulties and complexity of the previous technologies.

CONCLUSION

Within the limitations of this study, applying a laminating molding device made the fabrication of the hollow obturator model with a completely unified part possible. Water did not visually accumulate in the hollow obturator specimens. Although water absorption was significantly higher in solid specimens, the weight increase rate was also significantly higher in hollow specimens. These results suggested the novel clinical application of hollow obturator fabricated using a 3D printer.

CONFLICTS OF INTEREST

The authors do not have any financial interest in the companies whose materials are mentioned in the article.

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