The digital technologies used in the general industry are being increasingly applied to dental treatment, leading to a remarkable development in dental technology.1–4 To date, digital technologies have been utilized in various aspects of dental implant treatment, including implant placement simulation/planning using dental CBCT and the creation of surgical guides using CAD/CAM, allowing many dentists to save time during implant surgery and perform safe implant treatment with less surgical invasion.5–8 Recently, digital technologies have been introduced for the fabrication of fixed implant superstructures, and their superiority has been increasingly demonstrated.9–13

Intraoral scanners (IOSs) are being increasingly used in dental practice, and optical impressions fabricated using an IOS are expected to solve problems associated with conventional impression techniques using silicone. The conventional silicone impression technique is associated with a risk of infection from medical wastes such as impression materials and plaster, technical complexity, and patient distress during making of the impression. The use of IOSs in clinical dental practice can solve many of these problems, including time- and cost-related problems.14–16 Moreover, IOSs are being continuously improved to achieve better accuracy and increased scanning range. Although their use was conventionally limited to patients requiring a single crown or those with only a few missing teeth,17–20 newly developed IOSs can be used for patients with multiple missing teeth, demonstrating high precision of the technology.21–24 Furthermore, a number of studies have described the fabrication of working models for implant superstructures using an IOS and a 3D printer,
and compared the accuracy of these models to those of models obtained by the conventional method using impression materials and plaster. The results showed no statistically significant differences between the two types of models but demonstrated the superior performance of 3D printers.25–28

With the progressive aging of the population worldwide, implant overdentures have become an important option in terms of the prophylactic concept of dental implants and cost advantages.29–32 Implant overdentures are usually recommended for patients in whom implant-supported fixed dental prostheses are contraindicated and have been associated with low implant survival rates.33 However, properly designed implant overdentures show a survival rate comparable to that of implant-supported fixed dental prostheses, with high patient satisfaction.34–37 Implant overdentures have also been shown to provide a high therapeutic effect with low surgical invasiveness and thus are considered to be a promising implant-supported prosthetic option for the rapidly aging global population. Under such circumstances, Tanaka et al described the use of an IOS designed for complete avoidance of patient stress by extraoral scanning of the existing dentures and the use of a 3D printer resin with a low bacterial/viral adhesion rate for the fabrication of implant overdentures in clinical dental practice and demonstrated a favorable outcome.38 However, few studies have evaluated the accuracy of copy overdentures (copy dentures) fabricated using an IOS and a 3D printer.

The objective of this study was to compare the 3D accuracy of copy dentures fabricated using an IOS and a 3D printer (IOS copy denture) to that of copy dentures fabricated using the conventional method (conventional copy denture). The null hypothesis was that the accuracy of an IOS copy denture is equivalent to that of a conventional copy denture, with no significant difference for either the maxillary or mandibular complete denture.

**MATERIALS AND METHODS**

The flowchart of this study is shown in Fig 1.

**Fabrication of Reference Dentures**

Individual trays for the edentulous maxillary and mandibular models were prepared, and a precise impression was obtained using a silicone impression material (EXADENTURE, GC). Plaster (New Fujirok, GC) was poured into the impression to create a working model. Artificial teeth (Veracia, Syofu) were arranged according to the average intermaxillary distance to complete the maxillary and mandibular reference dentures (Fig 2a).

The maxillary and mandibular reference dentures were scanned using a high-precision dental laboratory scanner (D2000 Dental Lab Scanner, 3Shape A/S; accuracy, 5 μm [ISO 12836]) to obtain data (basic data), which were saved as Standard Triangulated Language (STL) data (Fig 2b, n = 1).

**Fabrication of an IOS Copy Denture**

Optical impressions of the maxillary and mandibular reference dentures were recorded using an IOS (Trios 3, 3Shape) and saved as STL data (IOS reference dentures). In the scanning protocol, the occlusal surface of the denture was scanned first (Fig 3a), followed by continuous scanning of the mucosal surface (Fig 3b). The data obtained from the scans of the maxillary and mandibular reference dentures were sent to a 3D printer (P30, Institut Straumann). The forming angle for 3D printing was set as shown in Fig 4. The denture base and artificial
Fig 2  (a) Maxillary and mandibular reference dentures. (b) Standard triangulated language data of the reference denture obtained using a high-precision dental laboratory scanner.

Fig 3  Scanning protocol of the reference dentures. (a) Occlusal surface and (b) mucosal surface.

Fig 4  Forming angle of 3D printer for the (a) denture base part and (b) artificial teeth part.
teeth were fabricated using a 3D printer, with different printing materials for each (FREEPRINT denture and FREEPRINT temp, respectively; DETAX for both; Fig 5). The lamination pitch (the pitch between the layers of the material to be mounted for the formation of objects) was set at 100 μm, which was the minimum setting value of the 3D printer.

The supporting sprues were removed, and ultrasonic cleaning with 100% isopropyl alcohol was performed for 5 minutes, followed by drying for 30 minutes at 25°C. Subsequently, the denture base and artificial teeth underwent a second curing process using a photopolymerization machine (Flash-light plus, SHERA Workstoff Technologie) with 2,000 flashes. The two parts were adhered together using a denture base resin under 1.5-kg pressure. The product was subjected to a final polishing procedure to complete the fabrication of the IOS copy denture (Fig 6a; n = 5).

Finally, the IOS copy denture was scanned with a high-precision dental laboratory scanner to obtain the IOS copy denture.

**Fabrication of Copy Dentures Using the Conventional Method**

Impressions of the maxillary and mandibular reference dentures were fabricated using impression jigs and an alginate impression material (HI-TECHNICOL, GC). A room-temperature curing resin (AROMA FINE PLUS, GC) was poured into the inner surface of the denture base impression, and then another room-temperature curing resin (ProCAST DSP and UNIFAST III, GC) was poured into the inner surface of the artificial teeth impression. After curing the room-temperature curing resins, the maxillary and mandibular complete dentures were subjected to final polishing to complete the fabrication of the conventional copy denture (Fig 6b; n = 5).
Finally, the completed denture was scanned with a high-precision dental laboratory scanner to obtain conventional copy denture data.

**Analyses of Scanning Data**

The basic data, IOS reference denture, IOS copy denture, and conventional copy denture data were imported into 3D analysis software (GOM Inspect 2020, GOM) for data superimposition. Data superimposition was performed using the best-fit algorithm. The IOS reference denture, IOS copy denture, and conventional copy denture data obtained were compared to the basic data to determine positional differences and calculate the concordance rates for the surface areas of the artificial teeth and denture base, with differences within 200 μm considered to be concordant. The distribution of the surface deviations of the best-fit dentures was visualized and evaluated using color mapping.

**Statistical Analysis**

The concordance rates of the maxillary and mandibular IOS reference denture, IOS copy denture, and conventional copy denture were analyzed using Kruskal-Wallis test, followed by Steel-Dwass multiple comparison test for significant differences, with a significance level of .05.

**RESULTS**

The concordance rates of copy dentures fabricated by each method are shown in Fig 7. The median (interquartile range) rates were 99.8% (5.0), 81.0% (6.5), and 54.2% (13.9) for the maxillary IOS reference denture, IOS copy denture, and conventional copy denture, respectively, and 99.9% (1.1), 86.0% (6.2), and 58.8% (18.0) for the mandibular IOS reference denture, IOS copy denture, and conventional copy denture, respectively.

Statistically significant differences in concordance rates were observed between the IOS reference denture and IOS copy dentures and between IOS copy dentures and conventional copy dentures \( (P < .05) \), but not between maxillary and mandibular complete dentures \( (P > .05) \). The color mapping of the scanned data showing the median rates for each impression method is shown in Fig 8.

**DISCUSSION**

The use of implant overdentures in fully edentulous patients is expected to contribute to the improvement of patient quality of life (QOL) and a high level of patient satisfaction, resulting in an increasing demand for this therapy.\(^{39-42}\) Implant overdentures are also subject to changes due to age-related degradation, such as cracks, attrition, and discoloration of the resin; however, patients often have an emotional attachment to the form and usability of their implant overdentures. Therefore, copy denture technologies are used in dental practice. Currently, copy dentures are fabricated using dedicated jigs, impression materials, and room-temperature curing resins.\(^{43,44}\) However, the procedure for making copy dentures is complicated and associated with problems such as deformation of the impression material and curing contraction of the resin, which may affect the accuracy of copy dentures. Walter et al reported that the application of digital technology in copy denture fabrication can significantly reduce the number of office appointments and labor in dental laboratories, resulting in reduced treatment time and costs.\(^{45}\) Tasopoulos et al and Arai et al provided patients in actual dental practice with copy dentures fabricated using an IOS and a 3D printer with satisfactory clinical outcomes.\(^{46,47}\) However, little is known about the accuracy of copy dentures fabricated using an IOS and a 3D printer.
The present study fabricated copy implant overdentures using an IOS and a 3D printer and compared their 3D accuracy to that of copy dentures fabricated using the conventional method. The data obtained in this study showed that the median concordance rates of the maxillary and mandibular IOS reference dentures were nearly 100%, as shown in a box-and-whisker plot (Fig 7), demonstrating that the IOS used in this study provides accurate impression of maxillary and mandibular complete dentures.

The statistically significant difference observed between the IOS reference denture and IOS copy denture might be attributable to the accuracy of the 3D printer and changes in denture dimensions caused by the curing contraction of the resin. Although Hada et al reported that the most precise 3D printing can be achieved by a forming angle of 45 degrees, the present study used a forming angle of 90 degrees. This is because the use of a 45-degree forming angle results in the attachment of supporting sprues to the mucosal surface of the denture, and subsequent removal of the sprues may affect the accuracy of the denture’s mucosal surface. However, the statistically significant difference in concordance rates between the IOS copy denture and conventional copy denture suggests that fabrication of the IOS copy denture is simpler and more effective compared to fabrication of the conventional copy denture in terms of fabrication of dentures with less adjustment, regardless of the forming angle. The IOS copy denture showed a smaller interquartile range (box size, error) than the conventional copy denture, suggesting that the new method can fabricate copy dentures with fewer errors as many times as possible, which can contribute to the improvement of patient QOL. The color mapping of the maxillary IOS copy denture showed many errors within ± 20 mm, whereas that of the maxillary conventional copy denture showed a large positive error at the maxillary tuberosity and a large negative error at the posterior edge of the denture. The errors at the

![Color mapping of copy dentures fabricated using different methods.](image)
The results of the present study demonstrate that the use of an IOS allows for easier fabrication of copy dentures with greater accuracy compared to the conventional method. The use of an IOS can also help avoid contact with infectious wastes, such as impression materials and plaster, and significantly decrease the risk of infection transmission from patients. Furthermore, denture morphology data can be saved and used to refabricate disposable dentures that can be exchanged, for example, on a monthly basis. In the event of denture breakage, refabrication of the denture can be ordered by telephone or email without any stressful procedures for patients, such as retaking impressions. The fabrication of a new denture with increased thickness in the portion corresponding to the breakage is also possible. The digital denture fabrication method using an IOS also allows for the optimization of the artificial teeth arrangement and occlusal vertical dimension in the software. This is one of the features that enables various applications, including using IOS data from existing dentures to fabricate a new denture without the need to fabricate an occlusion plate. This method can also be used for the fabrication of diagnostic templates and surgical guides for placement of implant overdentures. The use of data from existing dentures already adapted to the patients’ mucosa allows for the easy fabrication of stable dentures. Thus, the present method provides a favorable option for dental treatment.

Many issues remain to be investigated, including improvement of the order of scanning with an IOS and verifying the method for scanning the artificial tooth side and the mucosal side separately and then superimposing them. Furthermore, there was a statistically significant difference between the IOS reference denture and IOS copy denture in the present study. To solve this problem, future studies should examine the effects of changing the forming angle of the 3D printer as well as printer types.

CONCLUSIONS

In this study, copy dentures fabricated using an IOS and a 3D printer showed greater accuracy than those fabricated using the conventional method, with no significant difference for either the maxillary or mandibular complete denture.

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