Comparative Evaluation of the Reproductive Trueness of Zirconia Crowns Fabricated Using Additive Manufacturing and Conventional Milling

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Abstract

Purpose: To evaluate the occlusal reproductive trueness of zirconia crowns fabricated using additive manufacturing (AM) and to compare the surface roughness of crowns fabricated using AM and conventional milling (CM). Materials and Methods: Crowns were manufactured using AM and CM on abutments with total occlusal convergence angles of 16 and 20 degrees. Results: The surface roughness of the AM crowns was less than that of the CM crowns. The differences in reproduction of the occlusal morphology of the abutment crown were greater at 16 degrees than at 20 degrees. Conclusion: AM could be an effective method for manufacturing zirconia crowns. Int J Prosthodont 2021. doi: 10.11607/ijp.7092

Introduction

Zirconia is one of the most commonly used esthetic material for the fabrication of fixed dental prostheses owing to its excellent mechanical properties and record of long-term clinical success\(^1\). Recent advancements in digital technology have favored the fabrication of dental prostheses using three-dimensional (3D) printing (additive manufacturing: AM). Unlike prostheses milled from blocks, AM has several advantages. It allows the fabrication of a near-net-shape dental prosthesis with intricate details (for example, grooves, holes, and cavities). It reduces material wastage and energy consumption and eliminates the need for the various conventional milling (CM) tools (for example, drills and burs)\(^3\). AM has been used
successfully in the fabrication of dental prosthesis using resins and metals, but with limited success in the fabrication using dental ceramics. The accuracy of 3D printing zirconia crowns\(^3\), fracture resistance of implant-supported zirconia crowns\(^4\), and adhesion between ceramics and zirconia\(^5\) have been reported for zirconia crowns fabricated using AM. However, the surface roughness and precision in reproduction of surface morphology of the original crown by zirconia prostheses fabricated using AM have not been investigated adequately; thus, several difficulties exist in expanding the clinical applications of such prostheses. The purpose of this study was to evaluate the occlusal reproductive trueness of zirconia crowns fabricated using AM with two different occlusal convergence angles, and to compare the surface roughness of zirconia crowns fabricated using AM and CM.

**Materials and methods**

Two models of the right maxillary first premolar (A55A–141, NISSIN) were prepared to receive all-ceramic crowns, such that the total occlusal convergence angle was 16 and 20 degrees for each model. Using a design software (exoCAD, KaVo Dental Systems), crowns were designed to replicate the original crown morphology of the right maxillary first premolar, and Standard Tessellation Language (STL) data were cleated. The STL data was exported into the AM and CM systems. The AM crowns were fabricated using a 3D printer based on the principles of stereolithography (SLA) employing a zirconia ceramic paste (3DMix ZrO2 paste, 3DCeram). SLA uses a laser beam to cure the thin layer of slurry. The
green crown is printed layer-by-layer, followed by thermal removal of the binder and sintering of the crown (Fig 1a). In contrast, CM crowns were fabricated using a five-axis milling-manufacturing system (Ceramill Motion2, Amann Girrbach), which combines wet and dry processing, and a highly translucent zirconia ceramic (Ceramill Zolid H+ White, Amann Girrbach). After milling, the CM crowns were sintered in a sintering furnace (Ceramill Therm3, Amann Girrbach), according to the manufacturer's instructions.

The buccal surfaces of the AM and CM crowns for the 16-degree abutment tooth were analyzed for surface roughness before polishing (n=3). The average height (Sa) and maximum height (Sz) of the surface irregularities of the crowns were measured using a contact-free laser microscope (LEXT OLS4100, Olympus) (Fig 1b).

The ability for reproduction of occlusal morphology was compared among AM crowns for the 16- and 20-degree abutment teeth (n=3). The STL data of the reference model and those of the fabricated crowns were superimposed, and a software (GOM Inspect, GOM) was used for measuring the corresponding distances. The measurement points were set at 100-µm intervals in seven cross-sections (A to G) (Fig 2). Statistical analysis was performed for each crown using the Kruskal–Wallis test, followed by a multiple-comparison test using the Steel–Dwass test (JMP Pro 14.2.0, SAS).

Results/Discussion

The findings for surface roughness are shown in Table 1. The surface roughness of
the AM crown was less than that of the CM crown (Fig 3). Regarding the reproduction of occlusal morphology, the differences between the reference model and AM crown were more at 16 degrees than those at 20 degrees at all measurement points (Fig 4). The mean differences were 367.6±49.3 µm for the 16-degree and 202.1±65.0 µm for the 20-degree convergence angles. Significant differences were evident in all combinations at the D-points of the 16-degree convergence-angle crowns (p<0.05).

The results of this study indicate that the smoother surfaces of AM crowns would lead to shorter polishing times and reduce the risk of abrasion of the opposing teeth. However, this is a pilot study and not without limitations. The processing equipment and required corrections, such as those for creating the cement space, at the time of data conversion should be further examined. Furthermore, regarding AM, the thickness of a layer, sintering shrinkage, and direction of addition may affect the precision of the crown 3-5. Additionally, the ability for reproduction of surface morphology should be investigated.

Crowns fabricated using SLA exhibit excellent surface finish; however, the equipment is considered to be expensive. AM systems are priced at approximately 5 times the cost of CM systems. So, the significantly high cost of the equipment would also affect the unit price of AM crowns at the moment. Moreover, it presents a rather longer post-processing time. After AM-crown printed, half a day are required for cleaning, 7 days for degreasing, and 2 days for sintering. In addition, only one shade (white) is currently available. In the
future, reduction in material and equipment costs, improvements in precision, and development of the shade range will expand the applications of the AM technology in clinical practice.

Conclusion

Within the limitations of this study, AM could be an effective method for the fabrication of zirconia crowns in the near future.

Acknowledgments

The authors report no conflicts of interest.

References


Figure legends

**Fig 1** (a) Crown with the binder fabricated using additive manufacturing employing stereolithography. (b) Area of measuring surface roughness on the crown after sintering.

**Fig 2** Measurement points on the occlusal surface of the superimposed Standard Tessellation Language data.
Fig 3 Laser-microscope images showing the surface roughness of zirconia crowns fabricated using (a) Additive manufacturing and (b) Conventional milling.

Fig 4 Reproductive trueness of zirconia crowns.

Same letters indicate the absence of a significant difference.
Table 1 Surface roughness of zirconia crown surface

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<th>Sa (Sq)</th>
<th>Sz</th>
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<tr>
<td>AM</td>
<td>0.89 (1.01)</td>
<td>13.47</td>
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<tr>
<td>CM</td>
<td>1.67 (2.08)</td>
<td>18.07</td>
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Sa: Arithmetic mean height, Sq: Root mean square height, Sz: Maximum height