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Dimensional Stability of Additively Manufactured Maxillary Dental Casts for a Three-unit Fixed Partial Denture Fabricated with Different Build Orientations

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Abstract

Aim This study evaluated the dimensional stability of maxillary dental casts used for a 3-unit fixed partial denture across four build orientations (0°, 30°, 45°, and 90°).

Material and method An upper jaw typodont with tooth preparations for a posterior 3-unit fixed partial denture was scanned by using an industrial scanner. The resulting scan file was nested with different orientations (0°, 30°, 45°, and 90°) and the casts were additively manufactured by using a digital light processing 3-dimensional (3D) printer (n = 7). Subsequently, all additively manufactured casts were scanned with the same scanner at 3 different time points (after fabrication, 1 month after fabrication, and 3 months after fabrication) and the deviations at the fixed partial denture region were assessed with the root mean square (RMS) method. Statistical analysis was performed using a generalized linear model at a significance level of $\alpha = 0.05$.

Results The build orientation and the time point significantly affected the RMS values ($P<.001$). However, the interaction between the main factors did not affect the RMS values ($P=.808$). Among tested build orientations, 0° led to the lowest and 90° led to the highest RMS ($P\leq.001$). In addition, casts with 30° build orientation had lower RMS than those with 45° ($P<.001$). Tested casts had their lowest RMS after fabrication ($P\leq.006$).

Conclusion Dimensional stability of tested casts decreased with increased build orientation. The dimensional stability of tested casts decreased 1 month after fabrication and did not change 3 months after fabrication.

Keywords Additively manufactured cast, Build orientation, Digital light processing, Preparation, Stereolithography

Introduction

Computer-aided design and computer-aided manufacturing (CAD-CAM) technologies have facilitated the digitization of intraoral conditions with intraoral scanners (IOSs) or extraoral scanners (1). These advancements have turned direct digital workflow into a viable alternative as using an IOS to digitize a patient's intraoral condition minimizes the drawbacks associated with conventional impressions (2), which are inconvenient for patients. In addition, generating virtual intraoral data eliminated the time-consuming fabrication of stone casts along with the space needed to store these casts (3-6). However, for those cases that require physical casts, additive or subtractive manufacturing can be used. CAD-CAM technologies have transformed dental practices by enabling digital workflows, minimizing the limitations of conventional impressions, and reducing material waste through additive manufacturing (AM) (7-9). Vat polymerization is a commonly used additive manufacturing method to fabricate dental casts where a photosensitive resin is polymerized layer by layer inside a vat using a light source (10,11). Among the vat polymerization technologies, digital light processing (DLP) has gained prominence in dentistry due to its capacity to reduce manufacturing time and produce intricate objects with smooth surfaces (12-15) .

The trueness of AM dental appliances has been reported to be influenced by several factors, one of which is the resin used (16). Another factor is the build orientation, which is the position of the AM object with respect to the build platform and is an adjustable parameter. The build orientation also affects the duration of the process and resin used due to the modification of the geometry, which results in a different number of layers. While previous studies investigated the impact of build orientation on the trueness of dentate casts (6-7, 17-20), the effect of this factor on the trueness of definitive casts for dental protheses remains unknown.

A dental cast should not only closely approximate the intraoral situation for accurate diagnosis but also should possess sufficient dimensional stability for long-term evaluation. However, the accuracy of AM molds can be compromised due to uneven layer deposition (20). Previous studies have investigated the fabrication accuracy of AM dental casts (5,6,15); while previous studies have examined the fabrication accuracy of these molds, their dimensional stability has not been extensively studied (21). Additionally, studies on the dimensional stability of AM casts have not included 3-unit fixed partial denture constructions (21-22).

A study examining the impact of build orientation on the accuracy of final casts with a 3-unit fixed partial denture prepa-

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ration could enhance the knowledge base of clinicians and dental technicians, potentially streamlining the daily cast fabrication process. Accordingly, the objective of the present study was to assess the impact of build orientation on the dimensional stability of AM definitive casts for a 3-unit fixed partial denture over the course of three months. The null hypothesis was that the build orientation and the time point would not affect the dimensional stability of AM casts for a 3-unit fixed partial denture.

Material and Methods

A priori power analysis (α=.05, 1-β=95%, f=0.68) was performed with the results of a previous study on the effect of print orientation on the fabrication trueness of maxillary casts, and 7 samples per group were considered sufficient (20). A master maxillary typowdont (Dentsply Sirona, Bensheim, Germany) with a prepared right first premolar and right first molar for a 3-unit fixed partial denture was scanned with an industrial scanner (Artec Micro; Artec 3D, Luxembourg City, Luxembourg) to an accuracy of 10 µm (21). The manufacturer's proprietary software (Artec Studio v17; Artec 3D, Luxembourg City, Luxembourg) was used to generate a reference standard tessellation language (STL) file (R-STL). This R-STL was used as the basis for the production of final casts using a DLP-based 3D printer (MAX UV; Asiga, Sydney, Australia).

To produce the casts, the R-STL was imported into the nesting software of a DLP 3D printer (Composer v1.3; Asiga, Sydney, Australia) and positioned on the build platform in 4 different orientations (0°, DLP-0 ; 30°, DLP-30; 45°, DLP-45; 90°, DLP-90) (n=7) (Figure 1). The manufacturer-specific dental model resin (DentaMODEL; Asiga, Sydney, Australia for the DLP 3D printer) with a layer thickness of 100 µm was used to fabricate the specimens (4,8) after the nesting software automatically generated the supports for each orientation. After fabrication, the casts were ultrasonically cleaned (Wash & Cure 2.0; Anycubic, Shenzhen, China) in isopropyl alcohol for 10 minutes (5 minutes pre-wash and 5 minutes post-wash) and post-polymerized by using a xenon polymerization device (OtoFlash G171; NK Optik GmHb, Baierbrunn, Germany) under a nitrogen oxide gas atmosphere for 4000 flashes (2000×2). Within 48 hours of fabrication, all casts were scanned using the same industrial scanner to generate cast STLs (C0-STLs). The same industrial scanner was used to re-scan all the casts to generate cast STLs 1 month (C1-STLs) and 3 months (C2 STLs) after fabrication and all casts were stored in light-proof boxes at room temperature until the second and the third scans (22).
After all scans were completed, the R-STL and C-STLs (C0-STLs, C1-STLs, C2-STLs) were imported into a metrology-grade analysis software (Geomagic Control X v.2022.1.1; 3D Systems) for deviation evaluation. The R-STL served as the reference file and was automatically segmented using the software's auto-segment feature within the region tool. Segmented regions were merged to individually define the fixed partial denture preparations and the remaining surfaces on the dental arch. Alignment of the C-STLs (C0-STLs, C1-STLs, C2-STLs) over the R-STL was achieved by using the software's automated quick initial alignment and iterative closest point-based best-fit alignment tools. After alignment, the software's "3D Compare" tool generated color maps indicating deviations, with red indicating over-contoured surfaces, blue indicating under-contoured surfaces, and green indicating acceptable deviations. Deviations at the fixed partial denture region were automatically calculated using the root mean square (RMS) method (Figure 2). Throughout the process, all scanning and analysis was performed by a single experienced prosthodontist (M.D.).

Normality of data distribution was confirmed using the Shapiro-Wilk test. Subsequently, a generalized linear model analysis test was used to evaluate the data. The analysis included build orientation and time point as main factors and also involved their interaction. Statistical analyses were performed by using SPSS v25 (IBM Corp) with a significance level of α = 0.05.

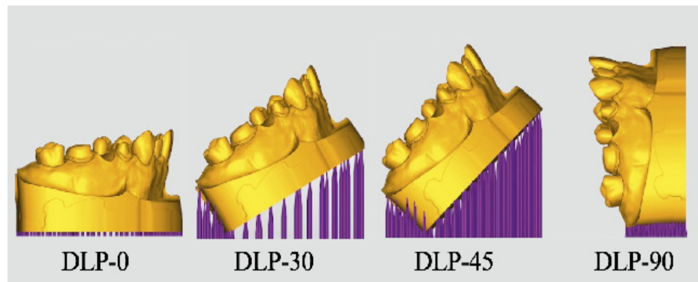

Figure 1: Print orientations with supports of different designs and numbers

Results

Table 1 shows the descriptive statistics of measured deviations. The generalized linear model analysis revealed that the build orientation and time point affected RMS values (P<.001). However, the interaction between these factors did not affect the RMS values (P=.808). DLP-0 casts had the lowest and DLP-90 casts had the highest RMS values (P≤.001), while DLP-45 casts had higher RMS than DLP-30 casts (P<.001). All casts had their lowest RMS values after fabrication (P≤.006) and the difference between the remaining time points did not affect the RMS values (P=.654).

Table 1: Mean±standard deviation RMS values (µm) within each material-time point pair

Build orientation	Time point			
	After fabrication	1 month after fabrication	3 months after fabrication	Total
0°	43.4 ± 3.8	47.9 ± 4.4	54.7 ± 13.4	48.7 ± 5.3^{A}
30°	54.8 ± 9.1	60.0 ± 10.7	61.0 ± 10.8	58.6 ± 10.1^{B}
45°	69.0 ± 14.2	76.3 ± 12.3	77.3 ± 11.7	74.2 ± 13.4^{C}
90°	120.5 ± 10.7	132.8 ± 9.9	134.3 ± 9.1	129.2 ± 11.3^{D}
Total	71.9 ± 31.5a	79.3 ± 34.4b	81.8 ± 33.7b	

Different superscript lowercase letters indicate significant differences among building orientations, while different superscript uppercase letters indicate significant differences among time points. Total values are derive from the pooled data of each build orientation and time point (P<.05).

Discussion

The null hypothesis of the present study was rejected as tested build orientations and time points affected the fabrication trueness of tested maxillary definitive casts for 3-unit fixed partial dentures. DLP-0 casts exhibited the highest dimensional stability, while DLP-90 casts showed the lowest. DLP-30 casts were more stable than DLP-45 casts. The highest dimensional stability of tested casts was observed after fabrication.

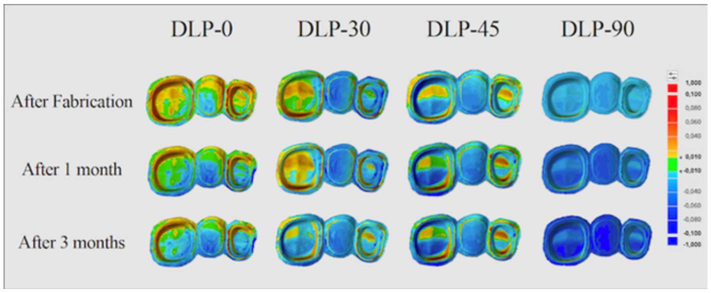

Figure 2: Representative color map of each build orientation-time point pair

A possible explanation for the significantly lower dimensional stability of DLP-90 casts may be the positioning on the build platform, which might can exacerbate the staircase effect, which refers to the loss of geometric accuracy in vertical direction (18). In addition, DLP-90 casts required the highest number of layers and thereby the longest duration for the fabrication, which might have amplified the distortions caused by printing errors and gravity, particularly considering that those casts were printed with the least number of automatically generated supports (Figure 1). Changing the build orientation may have also affected the number of overhangs in the area of interest and 0° build orientation may have improved the overlapping of successive layers and minimized the staircase effect. The gradual decrease of dimensional stability with increased build angle also supports this hypothesis. Nevertheless, the greatest mean deviation of tested casts was 134.3 µm (DLP-90, 3 months after fabrication), which is lower than the previously reported 200-µm threshold value for an additively manufactured cast to be used for prosthetic applications (23). Therefore, it can be stated that tested casts are suitable for prosthetic applications, even 3 months after fabrication.

A qualitative evaluation of the color maps would enhance the interpretation of the differences among test groups, providing insight into the measured deviations and potential clinical implications. Yellow and green were evident on DLP-0 casts, which indicate slight overcontours and acceptable deviations. However, overcontours might lead to fit issues of the restorations to be adjusted on DLP-0 casts and intaglio surface adjustments may be required. These potential adjustments might result in increased cement gap that could lead to retention-related issues. The color distribution of the remaining groups was predominantly blue, indicating undercontours that may be related to the abovementioned causes of deviation, with limited overcontours in the first molar tooth preparation of DLP-30 and DLP-45 casts. After seating fixed partial dentures on DLP-30, DLP-45, and DLP-90 casts, the pontic area may require additional veneering, given the dominant blue on all these casts at this region. However, this additional veneering might impair cleanability and result in excessive soft tissue contact if not adjusted intraorally. Regardless of the build orientation, the magnitude of blue increased with consecutive time points that may indicate dissolution. The fact that all casts were stored in light-proof boxes corroborate this interpretation as additional shrinkage caused by direct exposure to light was eliminated. However, future studies that primarily focus on this aspect are needed to substantiate this hypothesis. Nevertheless, increased undercontours would potentially require more veneering at the pontic region. In addition, the undercontoured abutment teeth might lead to perception of lower retention and cause remakes (Figure 2).

Previous studies have investigated the effect of 3D printing technologies, but few have examined print orientation as a contributing factor to the accuracy of AM casts (7,17,20,24). Maneiro Lojo et al. (16) evaluated partially edentulous maxillary casts and found that a 90-degree print orientation using a liquid crystal display (LCD)-based 3D printer resulted in the lowest accuracy. Another study using an LCD-based 3D printer showed that maxillary implant casts with a single implant in the central incisor region achieved higher accuracy with a 45-degree print orientation compared to 0-degree and 90-degree orientations (7). In addition, research on dentate casts has shown that the effect of print orientation (0 degree, 45 degree and 90 degree) varies depending on the tooth type (24). Ko et al. (17) investigated print orientation (0-degree, 30-degree, 60-degree and 90-degree) and layer thickness (20 µm, 50 µm and 100 µm) using a DLP-based 3D printer not included in the current study. They reported that casts with 0-degree print orientation and 20 µm layer thickness had lower fidelity, which they attributed to potential over-polymerization due to light bleeding through thin layers (17). Another study focused solely on removable dies when evaluating fabrication fidelity with different 3D printers (2).

Although the present study tested a well-established and widely used 3D printer, the limited number of printers was a limitation. Tested build orientations were deliberately chosen to avoid creating support structures on prepared teeth, the area of primary interest; however, different orientations could influence the results. Future research should extend the findings of this study by including other 3D printers using different technologies and model resins. In addition, future studies should evaluate the fit, occlusal contacts, interproximal contacts, and efficiency of adjustments for restorations fabricated or adjusted using these casts.

Conclusion

Within the study's limitations, the following conclusions were drawn:

1. Increased build orientation gradually decreased the dimensional stability of tested additively manufactured casts as the dimensional stability of tested casts in terms of build orientation was 0°, 30°, 45°, and 90° in decreasing order.

2. Regardless of the build orientation, the dimensional stability of tested casts decreased 1 month after fabrication and did not change 3 months after fabrication. However, the measured deviations were within previously reported thresholds regardless of the build orientation and time point.

Declarations

Author Contributions: *Conception/Design of Study- M.D., M.B.D.; Data Acquisition- M.D., A.A.D.T.; Data Analysis/Interpretation- A.A.D.T.; Drafting Manuscript- M.B.D.; Critical Revision of Manuscript- A.A.D.T., M.B.D.; Final Approval and Accountability- M.D.,* *A.A.D.T., M.B.D.; Material and Technical Support- M.D., A.A.D.T.; Supervision- M.B.D.*

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