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Trueness of the apical and middle root portion segments of 3D-printed removable die and alveolar cast designs manufactured using stereolithographic 3D printing

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Abstract

Purpose: The present study evaluated the effects of the root portion design, segment (middle vs. apical), and part (die vs. cast) on the trueness of three-dimensional (3D)-printed removable die-cast complex.

Material and Methods: The trueness of apical and middle segments of the root portion of 45 3D-printed removable dies and casts with three different root portion designs ($n = 15$) was assessed using a metrology-grade computer program. The three removable dies and cast designs (root form [RF], conical [CON], and cylindric [CYL]) were created using professional computer-aided manufacturing computer programs (DentalCAD 3.1 Rijeka, and InLab CAD 22.0), and manufactured using stereolithographic 3D printer (Form3; FormLabs, Somerville, MA). Subsequently, the 3D-printed removable dies and casts were scanned by a single operator with an intraoral scanner (PrimeScan; Dentsply Sirona, Charlotte, NC), and their respective standard tessellation language files were aligned and compared to master reference files in a metrology-grade computer program (Geomagic Control X; 3D systems, Rock Hill, NC). The root mean square (RMS) values of the middle and apical segments for each removable die and cast were calculated and analyzed using a mixed model including a repeated measure 3-way analysis of variance (ANOVA) and post-hoc stepdown Bonferroni-corrected pairwise comparisons ($\alpha = 0.05$).

Results: A statistically significant 3-way interaction between factors was detected, suggesting that the part (removable die or alveolar cast) and their design affected the RMS values of their apical and middle root portion segment. ($p = 0.045$). The post-hoc analysis identified significant differences between RMS values of the apical segments of the CON and CYL removable dies ($p = 0.005$). Significant differences were observed between the middle and apical segments of the CON ($p < 0.001$) and RF removable die designs ($p = 0.004$). No statistically significant differences were noticed between the RMS of the different alveolar cast designs ($p > 0.05$). Significant differences were detected between the apical and middle segments of the same alveolar cast design ($p < 0.05$).

Conclusions: For the manufacturing trinomial and 3D printing strategy used in the present study, the interaction of the part, design, and segment affected the trueness of removable dies and alveolar casts. The trueness was higher on the middle segment on removable dies and alveolar casts in all designs used, except for CYL removable dies, where the trueness difference between segments was small. Higher trueness values may be achieved with designs with simple apical segment geometries.

KEYWORDS
3D printing, CAD-CAM, fixed prosthodontics, removable dies, trueness

Contemporary data acquisition technologies and computer-aided design and computer-aided manufacturing (CAD-CAM) systems such as three-dimensional (3D) printing can be used to fabricate accurate prosthodontic appliances.[1–3] Research suggests that contemporary 3D printers present several advantages to other manufacturing methods such as molding, injection, and milling including reduced wastage, high consistency, and the ability to create fine details such as undercuts and complex internal geometries.[2] For these reasons, 3D printing has been accepted as a reliable method for manufacturing dental appliances such as castable patterns, surgical guides, definitive casts,[4] and removable dies.[5,6]

Several factors can affect the accuracy of 3D-printed dental appliances. Design-related factors related to the polygon mesh such as mesh refinement, surface,[7,8] and manufacturing-related factors including material selection,[9] building direction,[10] layer thickness,[5] the need for supporting material,[11] shrinkage between layers, warpage,[12] the effect of gravity on overhangs,[13] and post-processing protocol[14] can affect the accuracy of 3D-printed objects. Furthermore, the manufacturing trinomial[9] comprised of the manufacturing technology, the 3D printer, and the material used influence the quality of the 3D-printed dental appliances, especially, if its accuracy depends on the precise fit of two or more objects as with 3D-printed definitive casts with removable dies.[15]

Contemporary CAD computer programs permit designing definitive casts and removable dies with proprietary root portion designs with geometrical features dedicated to providing retention, stability, and support to the removable die.[5] The location of these features varies from one design to another and is generated automatically by the CAD computer program. Usually, the supports are placed on the apical portion of 3D-printed removable dies to avoid distorting the surface of the tooth preparation portion of the removable die. However, support insertion remnants or distortion of the root portion segments during manufacturing may affect the fit of the removable dies in the casts, potentially compromising their accuracy as a complex.

Three-dimensionally printed removable dies are used for veneering and refining the occlusion CAD-CAM restorations and correcting inaccuracies occurring during manufacturing. However, to function adequately and be a true replica of the intraoral structures, specific segments of the root portion of the removable die and cast must fit intimately. Commonly, the root mean square (RMS) method is used to assess the trueness of additively manufactured objects. Presently, only a few studies have assessed the trueness of 3D-printed removable dies and casts,[5,15–17] and research evaluating the trueness of the root portion segments of 3D-printed removable alveolar dies and casts with different root geometries is lacking. This study evaluated the effect of three different root portion designs on the RMS values of the apical and middle segments of 3D-printed removable dies and casts. The null hypotheses were that the root geometry design of the removable dies and casts would not affect the trueness at their apical and middle segments and that the root segment would not affect the trueness of removable dies and alveolar casts.

MATERIAL AND METHODS

The power analysis and sample size for this study were calculated using an open-source statistical computer program (G*Power; Universität Dusseldorf) programmed with an effect size of 0.4 and an α value of 0.05. The power analysis suggested that 15 specimens per group were required to provide a statistical power of 0.8.

For this study, the specimens of previous nondestructive research were used.[15] The specimens consisted of 3D-printed removable dies and casts of the maxillary left sextant with three different root portion designs (root form [RF], conical [CON], and cylindric [CYL]) (Figure 1). Standard tessellation language reference design files for the RF and CON removable die and cast were generated in the same CAD computer program (InLab CAD 22.0; Dentsply Sirona, Charlotte, NC), and the master reference files for the CYL group were produced in a different CAD computer program (DentalCAD

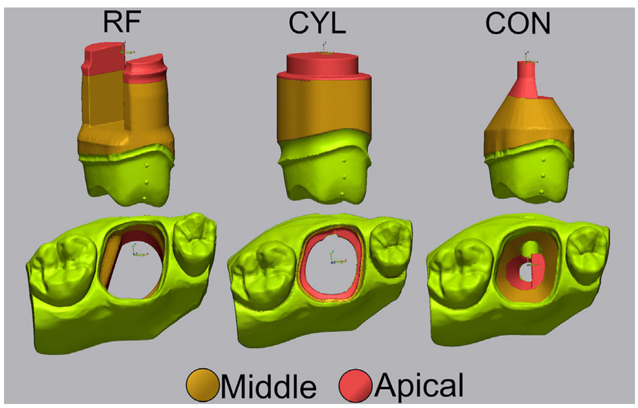

FIGURE 1 Digital designs of the removable dies and alveolar casts with segmented apical and middle segments. RF, root form; CYL, cylindric; CON, conical.

3.1 Rijeka; Exocad; GmbH, Darmstadt, Germany). The RF and CYL designs were generated with a 0.06-mm spacer, a circumferential ditch size of 0.75 mm, and an apical verification window. The CYL design was created using similar design parameters. The length of the root portion of the different designs varied from one computer program to another and ranged from 12 to 14 mm.

The specimens were manufactured using a stereolithographic 3D printer (Form3; FormLabs, Somerville, MA) and photopolymer (Model Resin V2; FormLabs, Somerville, MA). A layer thickness of 25 μm, 0°-build orientation, and the support arrangement proposed by the CAM computer program (PreForm; FormLabs, Somerville, MA) were used. Subsequently, the specimens were immersed in 90% Isopropyl alcohol (FormWash; FormLabs, Somerville, MA) and were post-processed for 30 min at 60°C (FormCure; FormLabs, Somerville, MA) as recommended by the manufacturer. The supports were removed carefully using the clippers provided by the manufacturer, and any protruding support remnants were removed using a sharp laboratory scalpel blade.

The 3D-printed removable dies and alveolar casts were scanned by the same operator (F.A.F.) using a recently calibrated intraoral scanner (PrimeScan; Dentsply Sirona, Charlotte, NC); at this stage, the middle and apical portions of the root portions of the removable dies and alveolar casts were carefully recorded. The intraoral scanner was chosen since its small tip and 20 mm focal length permitted recording hard-to-reach areas such as the apical segment of the root portion of the 3D-printed alveolar casts. Subsequently, the master reference file of each design used to manufacture the specimens was imported into the metrology-grade computer program (Geomagic Control X; 3D Systems, Rock Hill, SC) and their respective apical and middle segments were defined to encompass at least a supporting, retentive, and stabilizing feature of the design (Figure 1). The apical and middle segments were isolated from the rest of the scan using the Split/Region tool in the computer program. Subsequently, the scans of each 3D-printed cast and removable die were imported and aligned with the master reference files using the Initial Alignment and Best Fit Alignments tools. Using the 3D compare tool, the individual RMS values for the apical and middle segments for each removable die and cast were calculated and tabulated for statistical analysis.

The data were analyzed in a professional statistical analysis computer program (JMP Pro 17; SAS Institute, Cary, NC) using a mixed model including a repeated measures 3-way ANOVA to determine the effect of the root portion design, segment, and part (3D-printed removable dies and alveolar casts) on the RMS values measured. The repeated-measures analysis was performed to account for the two measurements performed on each specimen. Stepdown Bonferroni-corrected pairwise comparisons ($\alpha = 0.05$) were conducted post-hoc to elucidate the statistically significant differences between and within groups.

RESULTS

The mean RMS values of the apical and middle root segments of the different removable and alveolar casts can be seen in Table 1 and Figure 2. The RMS color maps for each design are shown in Figures 3 and 4. The mixed procedure detected a statistically significant 3-way interaction suggesting that the part (alveolar cast or removable die) and their root portion design affected the RMS values of their apical and middle segments ($p = 0.045$) (Table 2).

The post-hoc analysis suggested a statistically significant difference between RMS values of the apical segments of CON and CYL removable dies ($p = 0.005$) (Table 3). When the RMS values within removable die designs were assessed (Table 4), statistically significant differences were detected between the apical and middle segments of CON ($p = <0.001$) and RF removable die designs ($p = 0.004$). No statistically significant differences were noticed between the RMS of different alveolar casts ($p > 0.05$) (Table 5). Statistically significant differences were detected between the apical and middle segments of the same alveolar cast design ($p < 0.05$) (Table 6).

DISCUSSION

The null hypothesis of this study was rejected as a significant 3-way interaction was detected between the independent variables ($p < 0.05$), thus suggesting that the part, segment, and root portion designs affected the RMS values of the specimens.

Design and manufacturing factors related to the manufacturing technology, the photopolymer used, and the surface geometry can affect the trueness of 3D-printed removable dies and alveolar casts.[5,6,16] As seen in this study, the design features of the 3D-printed removable dies and alveolar casts affected their trueness at their middle and apical segments ($p = 0.045$). The largest RMS values were observed in the removable die groups, with significant differences detected amongst the apical segments of the CON and CYL designs ($p < 0.05$) and between the middle and apical segments of the CYL and RF designs ($p < 0.05$). These findings can be attributed to the progressively tapering root portion of the CON design and the individual buccal and lingual apical extensions of the RF removable die. Manufacturing these features required multiple supports on the overhung areas located on their central, middle, and apical root portions and resulted in small surface irregularities after removal. Contrarily, the CYL removable dies had a simpler geometry on the apical portion, which required less support than RF and CON designs. Therefore, since this design did not have horizontal overhangs, only its flat apical surface required support insertions. It is worth noting that besides the abovementioned manufacturing considerations, the decision to orient the casts perpendicular to the printing platform was made to standardize the building conditions across designs and to avoid

TABLE 1 Means and standard deviations.

Part	Design	Segment	Mean RMS (mm)	SD (mm)
Removable die	CON	Middle	0.112	0.034
		Apical	0.157	0.037
	CYL	Middle	0.100	0.017
		Apical	0.117	0.013
	RF	Middle	0.108	0.021
		Apical	0.141	0.046
Alveolar cast	CON	Middle	0.039	0.027
		Apical	0.075	0.044
	CYL	Middle	0.042	0.015
		Apical	0.099	0.019
	RF	Middle	0.043	0.029
		Apical	0.091	0.035

Abbreviations: CON, conical; CYL, cylindric; RF, root form; RMS, root mean square; SD, standard deviation.

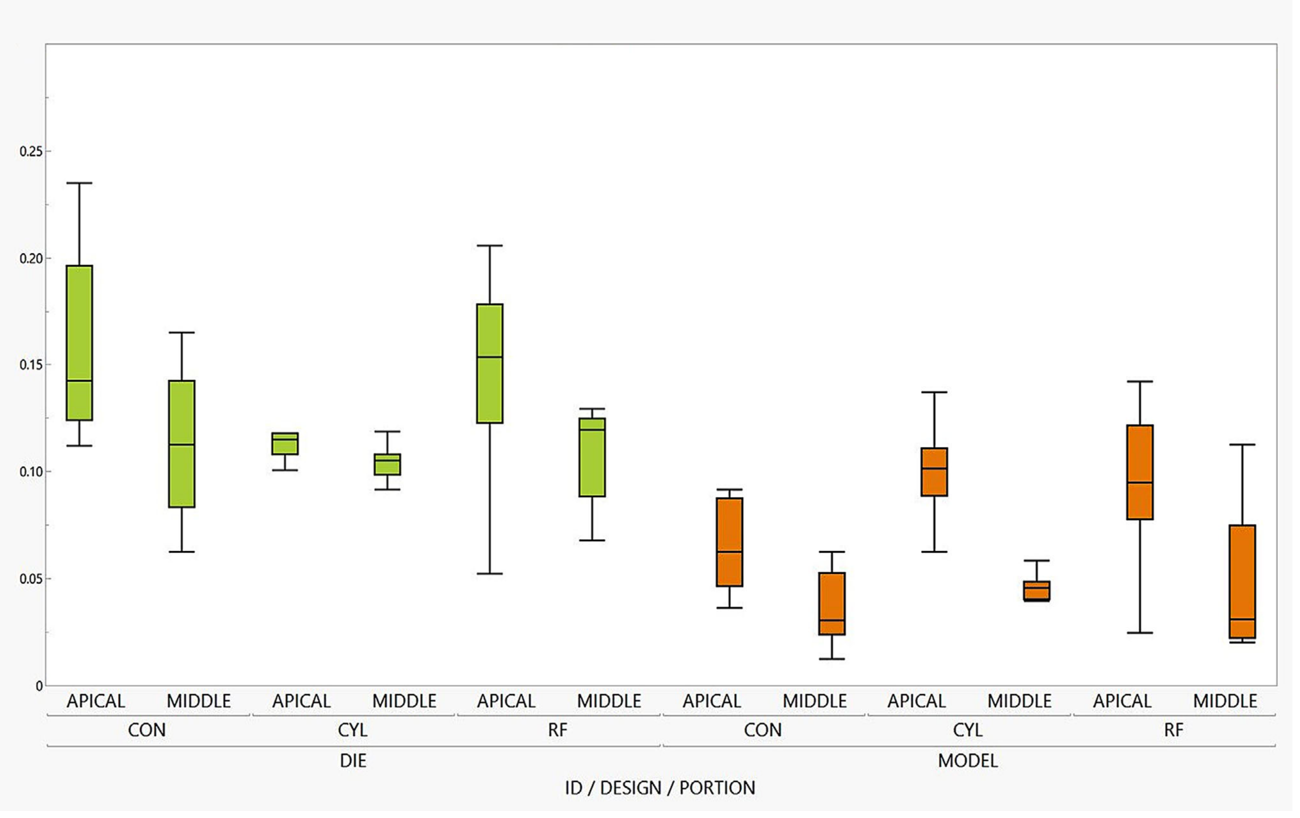

FIGURE 2 Mean root mean square (RMS) of apical and middle segments of removable dies and alveolar casts designs.

supports on the coronal portion of the removable die. This printing arrangement was employed to maintain the surface quality of critical areas such as the finish line, axial walls, and occlusal surface of the coronal portion of removable dies[5,8]; placing supports on these surfaces could compromise their adequacy for manufacturing or adjusting indirect restorations in a clinical or dental laboratory setting.[4]

All 3D-printed alveolar casts exhibited significant differences with greater RMS values on their apical segments regardless of their root portion designs ($p < 0.05$). These findings are like those observed in the removable die groups, where the root portion segments closer to the building platform displayed greater RMS values. Therefore, it is presumed that the surface irregularities created when removing the

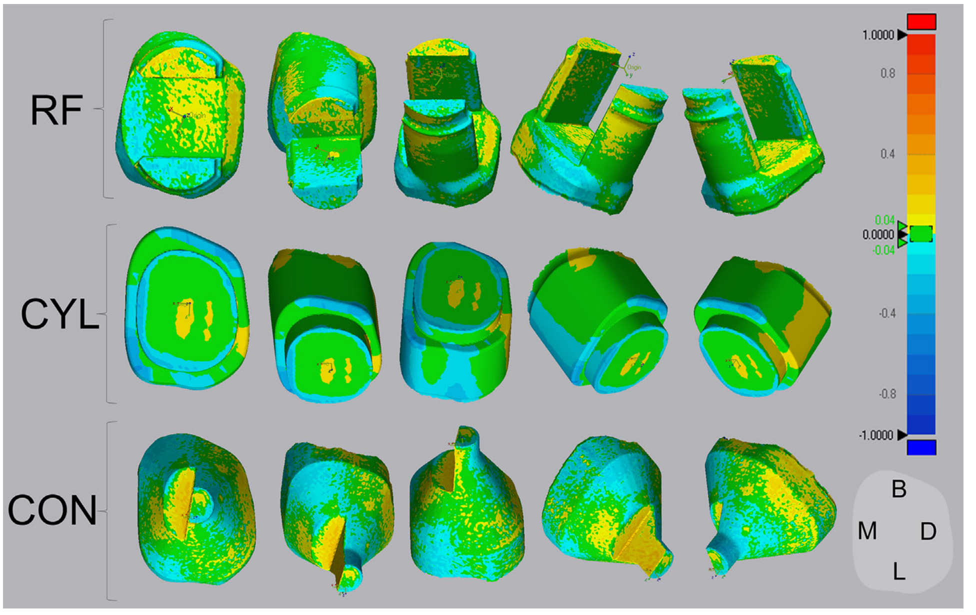

FIGURE 3 Root mean square (RMS) color map of apical and middle segments of the root portion of removable die designs. The image on the lower right side shows the surfaces of the root portion of removable dies when viewed from the occlusal view. RF, root form; CYL, cylindric; CON, conical.

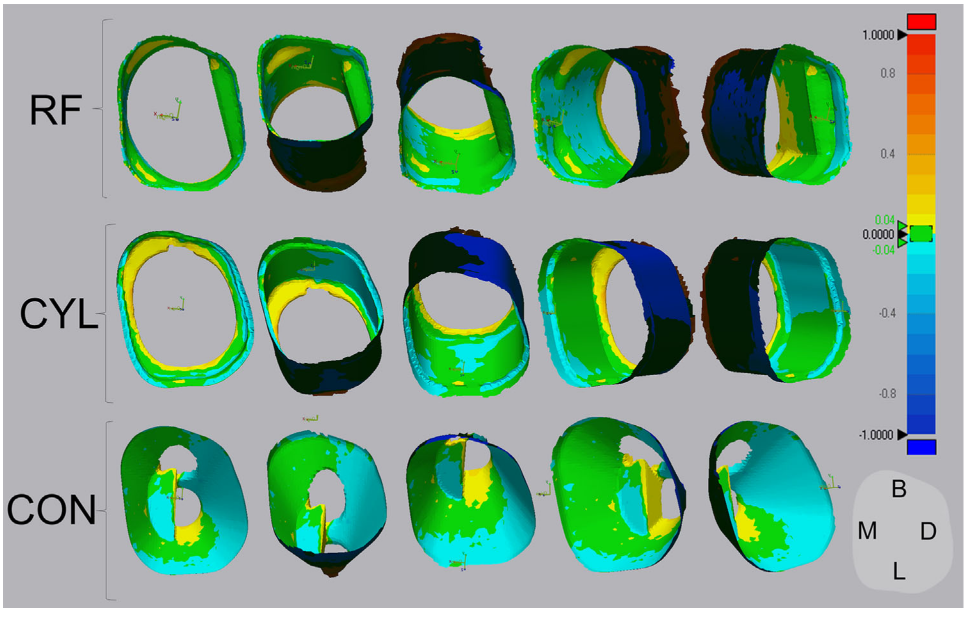

FIGURE 4 Root mean square (RMS) color map of apical and middle segments of the root portion of alveolar cast designs. The image on the lower right side indicates the surfaces of the root portion of the alveolar cast when viewed from the occlusal view. RF, root form; CYL, cylindric; CON, conical.

supports on the apical segment may have led to this localized decrease in trueness. Furthermore, acute geometric features such as sharp edges on the apical and lateral windows located on the apical segments of the CON and CYL designs, or the lateral retentive ledges observed in the RF group may have contributed to the differences.

Research suggests that the accuracy of 3D-printed objects with acute geometrical features can be affected by the quality of the surface mesh,[3] layer thickness,[5] surface features related to manufacturing technology, and pre- and post-processing storage conditions.[6,10,11] Additionally, difficulties in recording specific areas with the intraoral scanner due to their position and depth,[3] and the significant parallelism between the axial walls as seen on the CYL and RF, and on the apical window of the CYL design could have influenced the significant differences noticed between the apical and middle segments of the alveolar casts.

Removable dies and alveolar casts must have specific features to ensure a complex that resembles the intraoral

TABLE 2 Summary of results of ANOVA.

Source of variation	Num DF	Den DF	*f*-value	*p*
Design	2	84.0	0.64	0.530
Segment	1	84.0	113.24	<0.001*
Part	1	84.0	120.28	<0.001*
Design × segment	2	84.0	0.14	0.867
Design × part	2	84.0	4.60	0.012*
Segment × part	1	84.0	4.13	0.045*
Design × segment × part	2	84.0	3.71	0.045*

*Statistically significant at $p < 0.05$.

TABLE 3 Bonferroni-corrected pairwise comparisons of apical and middle segments between removable dies.

Design	Segment	Design	Segment	Estimate	Bonferroni *p*-value
CON	Apical	CYL	Apical	0.040	0.005*
CON	Apical	RF	Apical	0.015	1
CYL	Apical	RF	Apical	−0.024	0.334
CON	Middle	CYL	Middle	0.011	1
CON	Middle	RF	Middle	0.004	1
CYL	Middle	RF	Middle	−0.007	1

Abbreviations: CON, conical; CYL, cylindric; RF, root form.
*Statistically significant at $p < 0.05$.

TABLE 4 Bonferroni-corrected pairwise comparisons of apical and middle segments for the same removable die.

Design	Segment	Design	Segment	Estimate	Bonferroni *p*-value
CON	Apical	CON	Middle	0.045	<0.001*
CYL	Apical	CYL	Middle	0.016	0.730
RF	Apical	RF	Middle	0.03	0.004*

Abbreviations: CON, conical; CYL, cylindric; RF, root form.
*Statistically significant at $p < 0.05$.

condition accurately.[5] In the present study, statistically significant trueness differences ($p < 0.05$) were observed in areas with critical geometrical features meant to provide support, retention, and stability to the complex (Figures 3 and 4). The vertical stop features meant to provide support were in the apical segment of the CYL and CON designs, and the middle segment of the RF design. The CYL and CON designs obtained their retentive features at the expense of the friction from their parallel walls at the middle and apical segments, and both presented significant differences in terms of length and inclination. Contrarily, the RF design obtained its retention from the elastic deformation of its buccal and lingual extensions which were displaced medially by the lateral walls of the root portion of the alveolar cast. All designs achieved resistance at the expense of the antirotating cross-sectional shape of the removable die. Therefore, it would be expected that any significant discrepancies in any of these features, or design flaws could compromise the positional trueness of the removable die-alveolar cast complex.

Recently, research was conducted to evaluate positional trueness of different 3D-printed removable dies and alveolar cast designs.[15,17] In the study mentioned above, CYL removable dies presented significant displacements on the $+Y$ axis ($p < 0.05$) suggesting displacement in the occlusal direction. These findings are contradictory to the results of this study, where the CYL presented a more satisfactory trueness compared to the RF and CON designs. These findings suggest partial seating of the removable die and could be related to difficulties verifying the seating of the removable die since the lateral verification window on the base of the alveolar cast did not permit observing the contacting surfaces between both parts; thus, making it impossible objectively assessing its seating before scanning. Similarly, the CON design displayed significant displacements on the $+Y$ axis ($p < 0.05$). However, these findings concur with the present study since significant trueness variations were noticed between the apical and middle segments of the CYL designs ($p < 0.05$) which could have compromised the overall accuracy of the complex.

TABLE 5 Bonferroni-corrected pairwise comparisons of apical and middle segments between alveolar casts.

Design	Segment	Design	Segment	Estimate	Bonferroni *p*-value
CON	Apical	CYL	Apical	−0.023	0.413
CON	Apical	RF	Apical	−0.015	1
CYL	Apical	RF	Apical	0.008	1
CON	Middle	CYL	Middle	−0.002	1
CON	Middle	RF	Middle	−0.003	1
CYL	Middle	RF	Middle	<0.001	1

Abbreviations: CON, conical; CYL, cylindric; RF, root form.
*Statistically significant at $p < 0.05$.

TABLE 6 Bonferroni-corrected pairwise comparisons of apical and middle segment for the same alveolar cast.

Design	Segment	Design	Segment	Estimate	Bonferroni *p*-value
CON	Apical	CON	Middle	0.036	0.002*
CYL	Apical	CYL	Middle	0.056	<0.001*
RF	Apical	RF	Middle	0.047	<0.001*

Abbreviations: CON, conical; CYL, cylindric; RF, root form.
*Statistically significant at $p < 0.05$.

Interestingly, contrarily to the CYL and CON designs the RF designs presented negative displacements on the *Y* axis ($p < 0.05$) suggesting displacement in the apical direction. Possibly, the sloped configuration of the vertical stop, its position on the middle third of the alveolar cast, and its open apical portion contributed to the apical displacement. In the previous study, significant differences between two locations in the coronal portion of the removable dies were detected, suggesting tilting in the buccolingual direction ($p < 0.05$). These findings can be related to the tapering geometry of the middle segment of the CON design and its short middle portion which made the removable die prone to be displaced horizontally. Additionally, significant trueness variations were noticed between the middle and apical segments of all alveolar casts and the CYL and RF removable dies ($p < 0.05$). Therefore, it can be presumed that the geometry of the root portion and the surface irregularities resulting from the support insertions in the parts of the object closer to the printing platform may have influenced these results.

This study presents limitations related to the single 3D printing photopolymer, manufacturing technology, and 3D printer. Additionally, the model and removable die design tested only represent a small portion of the 3D designs available in modern dental CAD computer programs. The authors acknowledge that different results can be found with different research settings, manufacturing trinomials,[9] 3D designs, or metrology computer programs. Furthermore, the use of an intraoral scanner instead of a bench-top laboratory scanner may have affected the results of the study. However, this compromise was made to record hard-to-reach areas that could only be recorded by closely approximating the tip of the intraoral scanner to the root portion of the alveolar casts while adjusting its angulation as needed to record its apical segment. Despite its limitations, the present study can serve as a reference for the clinicians, CAD computer program developers, and users involved or interested in developing dental appliances digitally and underscores the importance of carefully tailoring the digital design to ensure specific features destined to provide retention, stability, and support are designed and positioned considering manufacturing-related factors and traditional prosthodontic principles.

CONCLUSIONS

Within the limitations of this in vitro study, the findings indicate that the trueness of the root portion of dental models is influenced by the interplay between part design and segment location on both the die and alveolar cast. The middle segment of removable dies and alveolar casts consistently exhibited enhanced trueness across various designs, with CYL dies being the exception. Moreover, the study suggests that simpler apical root portions in removable die designs may contribute to improved trueness. It is crucial to underscore the importance of post-manufacturing inspection and adjustments of removable dies and alveolar models, as these steps are necessary to ensure the accuracy of the areas essential for providing retention, stability, and support.

CONFLICT OF INTEREST STATEMENT

The authors deny any conflicts of interest related to this clinical report.

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REFERENCES

1. Celik HK, Koc S, Kustarci A, Caglayan N, Rennie AEW. The state of additive manufacturing in dental research—a systematic scoping review of 2012–2022. Heliyon. 2023;9:e17462.
2. Van Noort R. The future of dental devices is digital. Dent Mater. 2012;28:3–12.
3. Richert R, Goujat A, Venet L, Viguie G, Viennot S, Robinson P, et al. Intraoral scanner technologies: a review to make a successful impression. J Healthc Eng. 2017;2017:8427595.
4. Al-Imam H, Gram M, Benetti AR, Gotfredsen K. Accuracy of stereolithography additive casts used in a digital workflow. J Prosthet Dent. 2018;119:580–85.
5. Yilmaz B, Donmez MB, Kahveci Ç, Cuellar AR, De Paula MS, Schimmel M, et al. Effect of printing layer thickness on the trueness and fit of additively manufactured removable dies. J Prosthet Dent. 2022;128:1318.e1–9.
6. Revilla-León M, Özcan M. Additive manufacturing technologies used for processing polymers: current status and potential application in prosthetic dentistry. J Prosthodont. 2019;28:146–58.
7. Jadayel M, Khameneifar F. Improving geometric accuracy of 3D printed parts using 3D metrology feedback and mesh morphing. JMMP. 2020;4:112.
8. Eltes PE, Kiss L, Bartos M, Gyorgy ZM, Csakany T, Bereczki F, et al. Geometrical accuracy evaluation of an affordable 3D printing technology for spine physical models. J Clin Neurosci. 2020;72:438–46.
9. Anadioti E, Kane B, Zhang Y, Bergler M, Mante F, Blatz MB. Accuracy of dental and industrial 3D printers. J Prosthodont. 2022;31:30–37.
10. Ide Y, Nayar S, Logan H, Gallagher B, Wolfaardt J. The effect of the angle of acuteness of additive manufactured models and the direction of printing on the dimensional fidelity: clinical implications. Odontology. 2017;105:108–15.
11. Braian M, Jimbo R, Wennerberg A. Production tolerance of additive manufactured polymeric objects for clinical applications. Dent Mater. 2016;32:853–61.
12. Alzyod H, Ficzere P. Material-dependent effect of common printing parameters on residual stress and warpage deformation in 3D printing: a comprehensive finite element analysis study. Polymers. 2023;15:2893.
13. Tiwari K, Kumar S. Analysis of the factors affecting the dimensional accuracy of 3D printed products. Mater Today: Proc. 2018;5:18674–80.
14. Katheng A, Kanazawa M, Iwaki M, Minakuchi S. Evaluation of dimensional accuracy and degree of polymerization of stereolithography photopolymer resin under different postpolymerization conditions: an in vitro study. J Prosthet Dent. 2021;125:695–702.
15. Azpiazu-Flores FX, Johnston WM, Mata-Mata SJ, Yilmaz B. Positional trueness of three removable die designs with different root geometries manufactured using stereolithographic 3D printing. J Prosthet Dent. 2023:S0022-3913(23)00606-6. 10.1016/j.prosdent.2023.08.036
16. Lai Y-C, Yang C-C, Levon JA, Chu T-MG, Morton D, Lin W-S. The effects of additive manufacturing technologies and finish line designs on the trueness and dimensional stability of 3D-printed dies. J Prosthodont. 2023;32:519–26.
17. Azpiazu-Flores FX, Borga Donmez M, Lin W-S, Morton D, Yilmaz B. Verifying the seating of a 3D-printed removable die using elastomeric matrices: a dental technique. J Prosthodont. 2024:1–5. https://doi.org/10.1111/jopr.13839 Epub ahead of print.

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