https://doi.org/10.4047/jap.2023.15.3.145

Effect of internal structures on the accuracy of 3D printed full-arch dentition preparation models in different printing systems

Teng Ma[1,2], Tiwu Peng[2], Yang Lin[3], Mindi Zhang[2], Guanghui Ren[1,2]*
[1]Yantai Stomatological Hospital of Binzhou Medical University, Yantai, Shandong, China
[2]School of Stomatology, Binzhou Medical University, Yantai, Shandong, China
[3]School of Public Health and Management, Binzhou Medical University, Yantai, Shandong, China

ORCID
Teng Ma
https://orcid.org/0000-0002-1729-1524
Tiwu Peng
https://orcid.org/0000-0003-1420-8964
Yang Lin
https://orcid.org/0000-0002-5183-5046
Mindi Zhang
https://orcid.org/0000-0002-4315-9973
Guanghui Ren
https://orcid.org/0000-0002-9028-6510

PURPOSE. The objective of this study was to investigate how internal structures influence the overall and marginal accuracy of full arch preparations fabricated through additive manufacturing in different printing systems. **MATERIALS AND METHODS.** A full-arch preparation digital model was set up with three internal designs, including solid, hollow, and grid. These were printed using three different resin printers with nine models in each group. After scanning, each data was imported into the 3D data processing software together with the master cast, aligned and trimmed, and then put into the 3D data analysis software again to compare the overall and marginal deviation whose results are expressed using root mean square values and color maps. To evaluate the trueness of the resin model, the test data and reference data were compared, and the precision was evaluated by comparing the test data sets. Color maps were observed for qualitative analysis. Data were statistically analyzed by one-way analysis of variance and Bonferroni method was used for post hoc comparison ($\alpha = .05$). **RESULTS.** The influence of different internal structures on the accuracy of 3D printed resin models varied significantly ($P < .05$). Solid and grid models showed better accuracy, while the hollow model exhibited poor accuracy. The color maps show that the resin models have a tendency to shrink inwards. **CONCLUSION.** The internal structure design influences the accuracy of the 3D printing model, and the effect varies in different printing systems. Irrespective of the kind of printing system, the printing accuracy of hollow model was observed to be worse than those of solid and grid models. [J Adv Prosthodont 2023;15:145-54]

KEYWORDS
Additive manufacturing; Trueness; Precision; 3D-deviation; Color map

INTRODUCTION

The promotion and advancement of 3-dimensional (3D) printing technology are increasingly enhancing the sophistication of the dental digitally applica-

Corresponding author
Guanghui Ren
Center for Dental Aesthetics, Yantai Stomatological Hospital of Binzhou Medical University & School of Stomatology, Binzhou Medical University, Yantai, Shandong, 142 North Great Street, Zhifu District, Yantai, Shandong 264000, China
Tel +86 0535 6222193
E-mail rgh@bzmc.edu.cn

Received March 29, 2023 / **Last Revision** June 1, 2023 / **Accepted** June 20, 2023

https://doi.org/10.4047/jap.2023.15.3.145

tions, particularly in orthodontics, maxillofacial surgery, implantology, and prosthetics.[1-3] Although the accuracy of 3D printed models shows different levels, most academics believe that resin casts can fulfill the requirements of oral treatment and restoration fabrication and initiate the trend of additively manufactured models replacing plaster casts.[4,5]

The traditional method of obtaining a model of a full arch preparation is extremely technically sensitive, which affects the restoration's accuracy, whereas the fully digital process streamlines the workflow and reduces the potential errors.[6] After obtaining the digital preparation data, working model can be made by additive manufacturing or milling to complete the fine processing of the restoration.[7-10] The current mainstream method of model manufacturing utilizes 3D printing technology. The curing of photosensitive resin aids in transforming the virtual model data into a physical model, which is used to adjust the margin, adjacency, and occlusion of the prosthetics. Sometimes the decorative porcelain is added to achieve the aesthetic effect of rich layers and realistic colors. The diagnostic model can also be formed to promote the communication with patients.[11-13] However, in 3D printed models, many factors may cause distortion, such as the printing principle, printer resolution, resin material, environmental elements, printing direction, support design, base set, polymerization process, surface characteristics, post-processing procedure, aging and so on, which lead to the expansion or shrinkage, thus influencing the dimensional accuracy of the model.[14-17] Digital light processing (DLP) is one of the main technologies of light-curing 3D printing, commonly used in the processing and fabrication of dental resin models.[18,19] Subpixel microscanning (SMS) is a unique 3D printing technology created by Prismlab; the technology eliminates the need for splicing, completely avoids stitching errors, increases the efficiency of printing, and improves the speed of printing, ensuring printing accuracy, and is an industrial-grade printing system.

Considering internal structures, researchers point out that the accuracy of the models obtained using different internal structures designs does not have any statistical difference.[18] However, other studies suggest that solid models have higher accuracy, while hollows deform more easily.[20] Models are always involved in the manufacturing of ceramic and metal prostheses and in the process of studying the accuracy of the finishing line of the prostheses. High-accuracy and high-stability casts guarantee the accuracy of prostheses and the credibility of experimental results.[21,22] Therefore, the research on model accuracy has always been a topic interest, even though the research object has been changing. Studies on the printing accuracy of full arch,[4] partial arch,[23] and implant restoration models,[24] and short unit preparations[25,26] have been relatively comprehensive, but there is a lack of research on the accuracy of 3D printed full-arch preparation models using different internal structures of models in different printing systems.

This study aimed to evaluate the overall 3D deviation and marginal accuracy of printed resin models of full-arch preparations, having different internal sturctures, with two manufacturers of DLP printers and SMS printing systems. According to the null hypothesis: (i) internal structures do not affect the printing accuracy of the full arch preparation model and (ii) in different printing systems, the influence of the internal structure on the printing accuracy of the resin model of the full arch preparation is consistent.

MATERIALS AND METHODS

A maxillary standard model (Dental model; Xingxing Medical, Jining, China) with 14 teeth was prepared under an oral microscope (OMS2380; Zumax, Suzhou, China) following the standard for restorations of the ceramic crown. To fully expose the margin of the abutment, the gingival portion of the model was trimmed 1 mm below the shoulders. Dental antiglare powder (Snow Scan powder; Snow Rock, Kyoto, Japan) was sprayed uniformly on the model to reduce the effect of light reflection on the accuracy of the scan and the model scan was digitized using a desktop scanner (Kavo LS3; Nobel Biocare, Zurich, Sweden) with a scan resolution of less than 4 µm and saved in Standard Tessellation Language (STL) format.

The data were imported into a dental design software (DentalCAD 3.0 Galway; Align, CA, USA) and the redundant parts were removed. Then, the solid and hollow digital models were created, where the wall thickness of the hollow model was 2 mm, the default parameters of the system. The solid model data were generated after unchecking the hollow model option. Solid data were imported into an STL file editing software (magics 24.0; Materialise, Leuven, Belgium), and used the "Honeycomb Structure" function to process the internal structure to a grid state, with the wall thickness of 2.0 mm, the detail size of 0.4 mm, the hole diameter of 6.0 mm, and infill thickness of 1.0 mm (Fig. 1). The model files were saved in STL, respectively.

Using a statistical power analysis program (G*Power3.1.9.7; HHU, Dusseldorf, Germany) with trueness as the main outcome, the effect size was calculated to be 0.65, based on the results of pre-experiment, using an α-level of 0.05 and a 1-β(power) level of 0.80, which resulted in an estimated minimum sample size of nine per group. The samples are divided into three printing systems, DLP1 (AccuFab-D1s; SHINING 3D, Hangzhou, China), SMS (RP-400D; Prismlab, Shanghai, China), and DLP2 (D086-5; Sanwei Additive Technology, Yantai, China), depending on the print strategy. Three printers were used to print each of the internal structures for each of the nine designs (n = 9) with the support of 0 degrees. The models were post-processed following the manufacturers' instruction, which was to enable the resin models to achieve the optimum accuracy. The parameters set for the printers are mentioned in Table 1. After coating with masking powder, the models were scanned using a desktop scanner and calibrated before scanning. Scanning was performed in a near-constant environment (20 - 22°C, air humidity: 40%) by a dedicated, factory-trained staff from a dental laboratory.

The initial data and the scanned data were entered into a 3D data processing software (Geomagic Wrap 2017; 3D systems, Rock Hill, SC, USA), and the Trim-Trim with Curve function was used in the Poly-

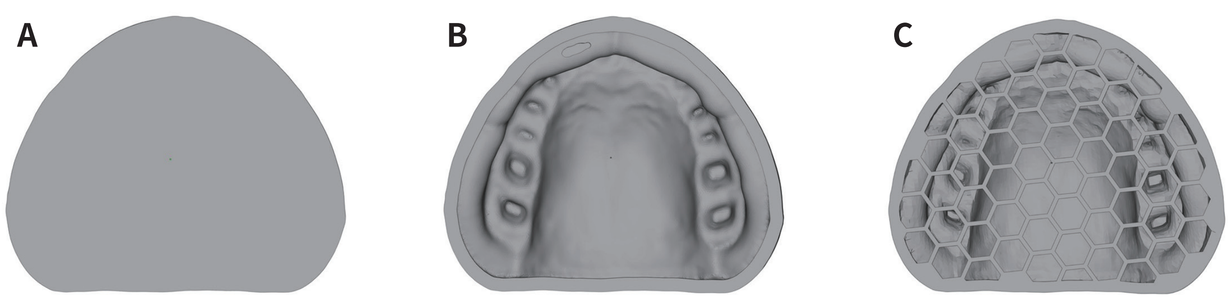

Fig. 1. Internal structures of the printed models. (A) Solid, (B) Hollow, (C) Grid.

Table 1. The parameters set for the printers

Printing systems	Printer name	Printing scheme	Printer manufacturer	Materials & manufacturer	Parameters for printing	Post-processing process
DLP1	AccuFab-D1s	DLP	SHINING 3D	DM12, SHINING 3D	layer thickness: 0.05 mm accuracy: 35 µm wavelength: 405 nm	95% ethanol cleaning for 6 min, light curing for 10 min
SMS	RP-400D	SMS	Prismlab	RP-405-TZ08Y, Prismlab	layer thickness: 0.07 mm accuracy: 34 µm resolution: 17 µm wavelength: 500 nm	95% methanol wash for 1 min, dry and light cure for 5 min
DLP2	D086-5	DLP	Sanwei Additive Technology	XC-DO1, Xianchuang 3D	layer thickness: 0.05 mm XY resolution: 100 µm Z resolution: $\leq \pm 10$ µm wavelength: 405 nm	Use 95% ethanol washing until clean, light curing 5 - 10 min

DLP, digital light processing; SMS, Sub pixel micro scanning.

 https://doi.org/10.4047/jap.2023.15.3.145

gons module to eliminate the initial data according to the position of the margin to use it as a reference. After an "N-point Alignment", the "Global Registration" function was used to match the test model to the reference. Then, in the "Curves", the "Create from Boundary" function was used to extract the reference finishing lines and applied to the scanned data to eliminate the part of preparation (Fig. 2). Next, the reference data and measured data were imported into 3D data analysis software (Geomagic Control X 2016; 3D systems, Rock Hill, SC, USA) without any alignment operation, and the master data were moved to the "Reference". Then, "Mesh from Scanning" was selected, the "3D Compare" and "Boundary Deviation" were used to calculate the overall and margin deviation of the preparation, and the root mean square (RMS) value was obtained for the quantitative analysis. The accuracy was defined as trueness and precision following the International Organization for Standardization. The evaluation of trueness was derived by comparing the differences between the reference and test models (n = 9), while inter-groups difference of models was used to analyze the precision (n = 36). These were used for qualitative analysis as the overall range of the color difference maps was set to ± 0.12 mm and the specific tolerance range was ± 0.04 mm.

Statistical analysis was performed using a statistical software (IBM SPSS Statistics, v24.0; IBM Corp., New York, NY, USA), and measures were expressed as "mean ± SD". Data normality was tested using the Shapiro-Wilk test and the homogeneity of variance was tested using the Levene test. One-way analysis of variance was performed and the Bonferroni method was used for post hoc comparison (α = .05).

RESULTS

Trueness analysis revealed that the overall and marginal deviation were statistically different among internal structures in the three printing systems (P < .001). The trueness comparison of the overall deviation of the solid model showed better accuracy than that of the grid under DLP1 and SMS, while the accuracy of the hollow was the worst. The accuracy of grid structure was the highest, while the accuracy of the solid was better than the hollow in DLP1 printing system. In the trueness comparison of marginal deviation, the accuracy of the solid was not different from that of the grid under DLP1 and SMS printing systems, and was better than that of the hollow. In DLP2 print-

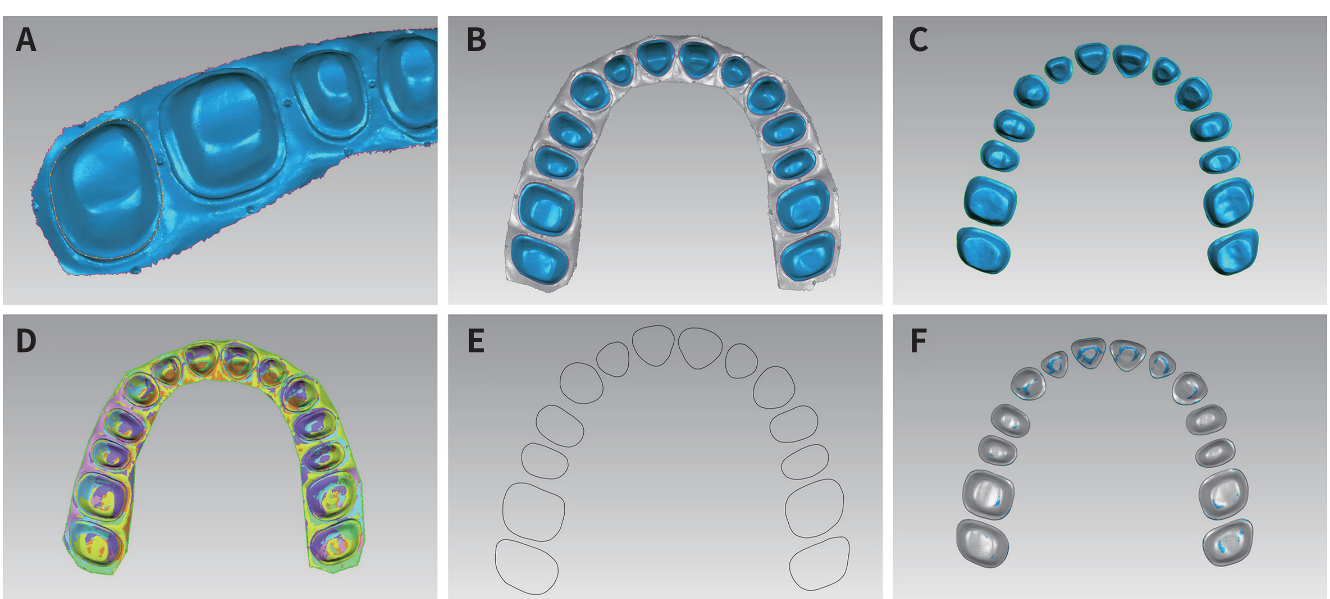

Fig. 2. Data processing. (A) Remove the preparation along the finishing line, (B) Application tailoring, (C) Preparation reference data, (D) Global registration, (E) Extract the marginal line, (F) Apply line clipping.

ing system, the accuracy of the grid was better than that of the solid structure, and the hollow was the worst (Fig. 3).

In precision test, no statistical difference was observed in the overall deviation of different internal structures under DLP1 and SMS printing systems (P > .05). In DLP2, the overall deviation of different internal structures was statistically different (P < .05). The grid structure had a better precision than that of hollow structure, while the other two did not show much difference. Statistical differences were found in the marginal deviations of different internal structures in DLP1 printing system (P < .05); among these, no statistical difference was noted between solid and grid structures, and the hollow structures was worse. In DLP2 and SMS printing systems, the marginal deviation of different internal structures did not show significant differences (P > .05) (Fig. 4).

The color difference maps obtained by superimposing the test model and the reference data showed

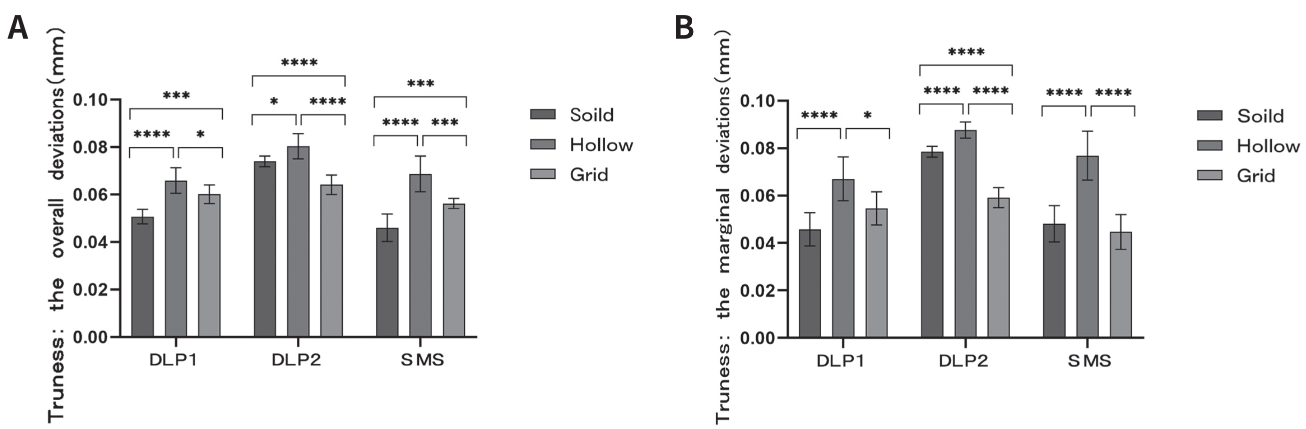

Fig. 3. Trueness: results of overall and marginal deviations between different structures in the three printing systems (P < .001). (A) Analysis of the overall deviation of trueness of different structures. (B) Marginal deviation analysis of trueness of different structures.
DLP, digital light processing; SMS, Subpixel microscanning. *: P < .05, ***: P < .001, ****: P < .0001.

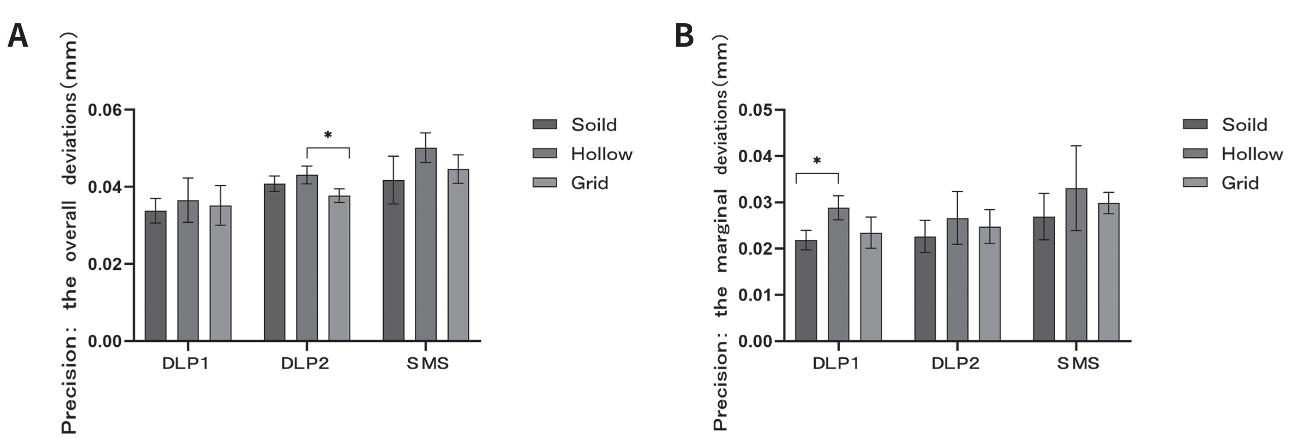

Fig. 4. Precision: results of overall and marginal deviations between different structures in the three printing systems (P < .001). (A) Analysis of the overall deviation of precision of different structures. (B) Marginal deviation analysis of precision of different structures.
DLP, digital light processing; SMS, Subpixel microscanning. *: P < .05.

https://doi.org/10.4047/jap.2023.15.3.145

overall and marginal deviations of trueness. In the overall color maps, the model distortion trend showed contraction on the labial-buccal side and expansion on the lingual side. In addition, the solid and hollow in DLP2 revealed more contraction than expansion, as indicated by the threshold portion of the color bar (gray), whereas the others were more uniform. In the deviation display of the margins, all groups demonstrated significant contraction. The precision of each group as a whole and at the edges was evaluated by overlaying the scanned models between the test groups, which revealed a general difference of 0.04 mm and an insignificant trend of discrepancy (Fig. 5).

DISCUSSION

The overall and marginal RMS values, and color-coded deviation maps used in this experiment were obtained after the comparison of the reference cast with the test data by 3D measurement software, to assess the accuracy of resin models with internal structures in different printing systems, respectively. The quantitative evaluation of the accuracy often employs the RMS value to investigate the accuracy of the model, while the color mapping is utilized to visualize the areas of color representing different degrees of deviation. By setting an appropriate threshold, the trends in shrinkage and expansion can be observed and de-

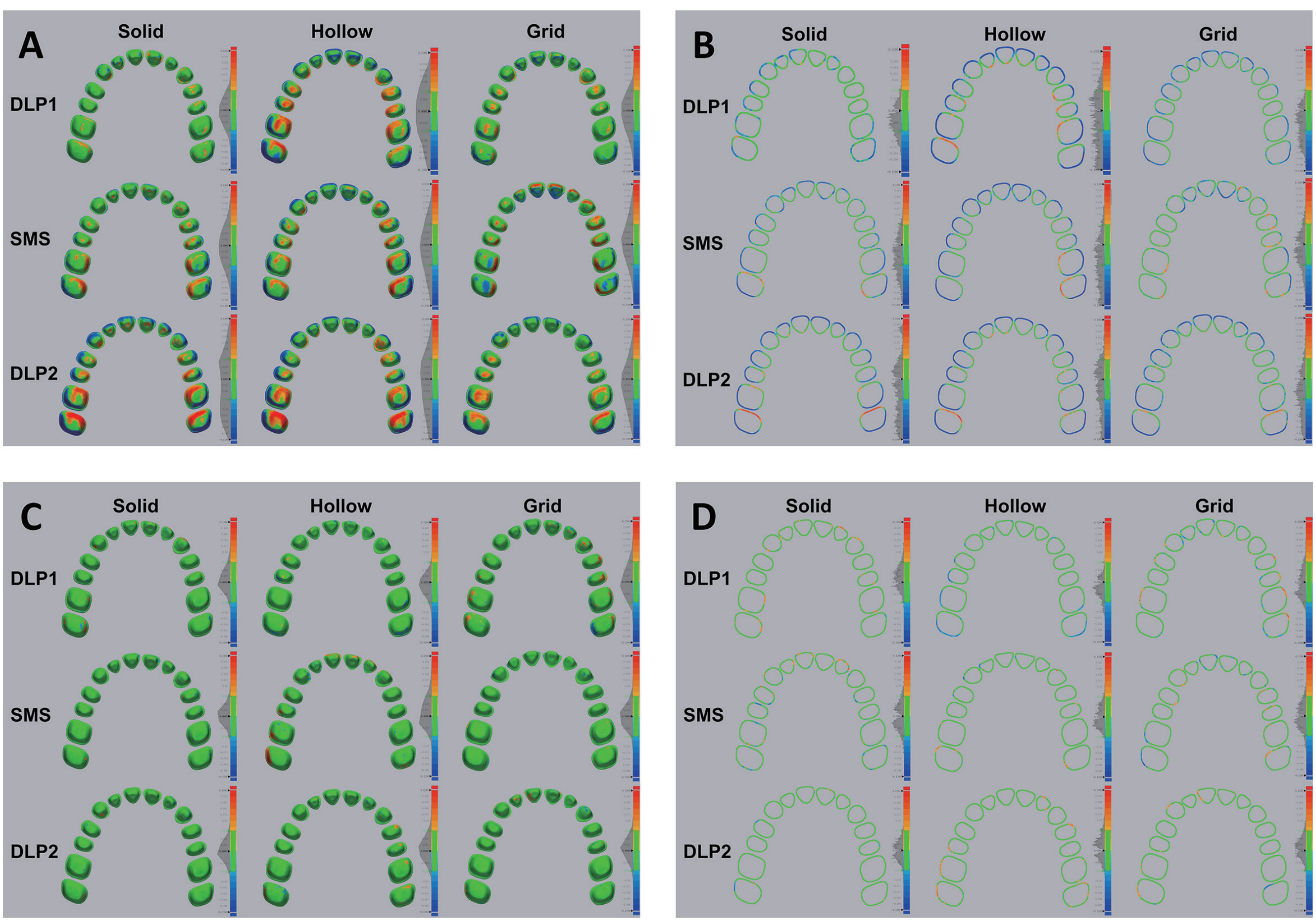

Fig. 5. Color maps of trueness and precision of different internal structures in printing systems. (A) Different printing systems and internal structure of the overall deviation of the trueness, (B) Different printing systems and internal structure of the marginal deviation of the trueness, (C) Different printing systems and internal structure of the overall deviation of the precision, (D) Different printing systems and internal structure of the marginal deviation of the precision.
DLP, digital light processing; SMS, Subpixel microscanning.

scriptive analysis can be performed. In summary, the experimental results illustrate that internal structures affect the accuracy of 3D printed full-arch preparation models; moreover, the influence of internal structure on model accuracy is different in different printing systems. As a result, the null hypotheses are rejected.

Scientists have been investigating the accuracy of the model since the application of 3D printing technology in dental models, including the difference in accuracy among plaster models, milling casts, and 3D printed models, and the influence of different printing technologies, brands, model size, shape, internal design, printing parameters, and post-processing.[4,27] The acceptable accuracy for 3D printed models varies across different disciplines. In orthodontic plaster printing, relatively low accuracy is generally required in the clinical setting, whereas higher accuracy is required for fixed or implant-based restorations. Currently, the highest standard identified for accuracy is < 0.1 mm.[18] Although the accuracy of the model in all groups in this study was within the clinically acceptable range, the restoration needed the margin adjustment on the model. The accuracy of the model determined the accuracy of the restoration. Therefore, if the accuracy of the adjustment of the prosthesis on the hollow structure model is poor, it may affect the accuracy of the prosthesis, thus increasing the workload of doctors in the clinical installation of the prosthesis and affecting the comfort level of patients.

Rungrojwittayakul *et al*.[18] investigated the effect of printing principles and base settings on the printing accuracy of maxillary dental models and found no difference between hollow and solid models in terms of printing accuracy, a conclusion that differs from the results of this study. However, the results of Shin *et al*.[20] showed that the accuracy of the solid model was better than those of the hexagon-filled, internally roughly filled, and hollow models. Moreover, the accuracy of the model with a 4 mm wall thickness was higher than that of the 1.5 mm thickness of the hollow, which was similar to the results of the experiment; it is conjectured that the former study may have led to different results due to the variation in statistical methods. Park *et al*.[28] used cylinders to replace the original tooth morphology to construct a new shape in the X, Y, and Z directions and overall 3D deviation for accuracy evaluation, and observed that the clinical needs were satisfied by all 3D printing technologies involved in the study. In their study, two groups of DLP technologies (DLP 1,104.4 μm; DLP 2,103.3 μm) were lower than that of a polyjet (99.3 μm). Although the accuracy of the DLP models of different brands did not differ much from the median 3D deviation, the intra-group variation of DLP1 was larger than that of DLP2 from the box plot, while the results of DLP2 were more concentrated. This study explored the impact of internal structure design on the accuracy of resin model in different printing systems. The findings revealed heterogeneity in the influence of internal structure on the accuracy of resin model with different printing systems. The precision study also highlighted variability among the models of each test group. Specifically, the hollow models exhibited lower accuracy in any type of printing system.

Different scholars established different tolerances levels within software settings. Resende *et al*.[23] defined the overall range to ± 0.50 mm, with the specified tolerance range of ± 0.025 mm. Likewise, Park and Shin[29] set the maximum error range at ± 1.00 mm, with an allowable error of ± 0.5 mm. In this study, the range set by Gao *et al*.[7] was adopted because they studied the impression accuracy of the whole dental arch preparation. Setting appropriate tolerances makes it convenient to observe the color maps to study the shrinkage and expansion trend of the model. According to the color maps, the deformation trend of the model was visualized as: the red area indicates expansion, the blue area indicates contraction, and the green area indicates 3D deviation within the range of ± 0.04 mm. The models exhibited contraction on the labial-buccal side and expansion on the lingual side and a trend of contraction toward the center in the whole. It is possible that the model contracted and thus was deformed inward, while the marginal part was dominated by contraction. This subjective evaluation was similar to that presented in other studies.[18,28] In some of the models, however, some interesting observations were made, including labial expansion and palatal contraction in the anterior region, which is conjectured to be a possible uneven deformation of the casts and needs further investigation. The gray thresholds, which were not commonly used in other studies, effectively represent the extreme and contraction-expansion states of the model deformation. For example, the contraction-expansion of DLP1 and SMS show fundamentally normal distributions, while DLP2 exhibited more contraction than expansion, with somewhat larger maximum or minimum deviation.

To rule out differences in scanner sensitivity to different resin materials and surface states, the model surface was uniformly coated with antiglare powder, which generally does not affect the final measurement results according to the researchers.[29-31] Accurate 3D deviation results, using 3D data analysis software, rely on the proper alignment.[31] In this study, the alignment chosen was N-point alignment followed by global registration. This approach was selected because the scanned data and reference data were strictly similar and not identical; in such case, global registration is more reliable in similar model alignment.

The detection of marginal deviations is also important in preparation for accuracy study in either models or impressions. Chiu *et al*.[32] used the point deviation function in the software to select 100 points uniformly distributed at the edges of the preparation and analyzed the difference in the accuracy of the edge lines in orally scanned preparations at different resolutions. In one study, Cho *et al*.[26] cropped some of the preparation edges separately for 3D comparison. Instead, all points at the margins were extracted and evaluated for accuracy using the function of boundary deviation in the software, thus simplifying the detection process and incorporating data at all margins in this study.

There are some limitations to this study. The included printing systems and internal structures design are still incomplete. We created hollow models with the default system parameters for hollow models, whereas in practice, laboratories adjust different parameters to achieve the desired satisfaction level for resin models based on their printer customization. In this study, the investigation of the deformation of hollow models with different wall thicknesses is missing.

In this study, three printing systems and three internal structures were selected. Previous studies suggest that many factors affect the printing accuracy of resin models, and printing accuracy differs between different printing technologies or different manufacturers and material types. Therefore, it is necessary to explore the effect of internal structure on resin model accuracy under different printing systems.

CONCLUSION

Based on the results of this study, the following are derived:

The internal structures affect the accuracy of 3D printed full-arch preparation models and the effect of internal structure on model accuracy varies in different printing systems. Furthermore, the accuracy of the hollow model is worse than those of solid and grid in any type of printing system. Besides, the model deformation has a tendency to shrink toward the center.

ACKNOWLEDGMENTS

The authors thank Huaxin Dental Lab and Department of Dental Technology of Yantai Stomatological Hospital for their support in model printing and scanning, as well as Huaxin Wang, Xinxin Liu, and Jing Zhang for their help in this study.

REFERENCES

1. Schweiger J, Edelhoff D, Güth JF. 3D printing in digital prosthetic dentistry: An overview of recent developments in additive manufacturing. J Clin Med 2021;10:2010.
2. 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.
3. Khorsandi D, Fahimipour A, Abasian P, Saber SS, Seyedi M, Ghanavati S, Ahmad A, De Stephanis AA, Taghavinezhaddilami F, Leonova A, Mohammadinejad R, Shabani M, Mazzolai B, Mattoli V, Tay FR, Makvandi P. 3D and 4D printing in dentistry and maxillofacial surgery: Printing techniques, materials, and applications. Acta Biomater 2021;122:26-49.
4. Etemad-Shahidi Y, Qallandar OB, Evenden J, Alifui-Segbaya F, Ahmed KE. Accuracy of 3-dimensionally printed full-arch dental models: a systematic re-

view. J Clin Med 2020;9:3357.
5. Czajkowska M, Walejewska E, Zadrożny Ł, Wieczorek M, Święszkowski W, Wagner L, Mijiritsky E, Markowski J. Comparison of dental stone models and their 3D printed acrylic replicas for the accuracy and mechanical properties. Materials (Basel) 2020;13:4066.
6. Cicciù M, Fiorillo L, D'Amico C, Gambino D, Amantia EM, Laino L, Crimi S, Campagna P, Bianchi A, Herford AS, Cervino G. 3D digital impression systems compared with traditional techniques in dentistry: a recent data systematic review. Materials (Basel) 2020;13:1982.
7. Gao H, Liu X, Liu M, Yang X, Tan J. Accuracy of three digital scanning methods for complete-arch tooth preparation: An in vitro comparison. J Prosthet Dent 2022;128:1001-8.
8. Kim MK, Son K, Yu BY, Lee KB. Effect of the volumetric dimensions of a complete arch on the accuracy of scanners. J Adv Prosthodont 2020;12:361-8.
9. Son K, Jin MU, Lee KB. Feasibility of using an intraoral scanner for a complete arch digital scan, part 2: A comparison of scan strategies. J Prosthet Dent 2023;129:341-9.
10. Baghani MT, Shayegh SS, Johnston WM, Shidfar S, Hakimaneh SMR. In vitro evaluation of the accuracy and precision of intraoral and extraoral complete-arch scans. J Prosthet Dent 2021;126:665-70.
11. Anadioti E, Kane B, Zhang Y, Bergler M, Mante F, Blatz MB. Accuracy of dental and industrial 3D printers. J Prosthodont 2022;31:30-7.
12. Oberoi G, Nitsch S, Edelmayer M, Janjić K, Müller AS, Agis H. 3D printing-encompassing the facets of dentistry. Front Bioeng Biotechnol 2018;6:172.
13. Jeong YG, Lee WS, Lee KB. Accuracy evaluation of dental models manufactured by CAD/CAM milling method and 3D printing method. J Adv Prosthodont 2018;10:245-51.
14. Banjar A, Chen YW, Kostagianni A, Finkelman M, Papathanasiou A, Chochlidakis K, Papaspyridakos P. Accuracy of 3D printed implant casts versus stone casts: a comparative study in the anterior maxilla. J Prosthodont 2021;30:783-8.
15. Ko J, Bloomstein RD, Briss D, Holland JN, Morsy HM, Kasper FK, Huang W. Effect of build angle and layer height on the accuracy of 3-dimensional printed dental models. Am J Orthod Dentofacial Orthop 2021;160:451-8.e2.
16. Dong T, Wang X, Xia L, Yuan L, Ye N, Fang B. Accuracy of different tooth surfaces on 3D printed dental models: orthodontic perspective. BMC Oral Health 2020;20:340.
17. Joda T, Matthisson L, Zitzmann NU. Impact of aging on the accuracy of 3D-printed dental models: an in vitro investigation. J Clin Med 2020;9:1436.
18. Rungrojwittayakul O, Kan JY, Shiozaki K, Swamidass RS, Goodacre BJ, Goodacre CJ, Lozada JL. Accuracy of 3D printed models created by two technologies of printers with different designs of model base. J Prosthodont 2020;29:124-8.
19. Kim SY, Shin YS, Jung HD, Hwang CJ, Baik HS, Cha JY. Precision and trueness of dental models manufactured with different 3-dimensional printing techniques. Am J Orthod Dentofacial Orthop 2018;153:144-53.
20. Shin SH, Lim JH, Kang YJ, Kim JH, Shim JS, Kim JE. Evaluation of the 3D printing accuracy of a dental model according to its internal structure and cross-arch plate design: an in vitro study. Materials (Basel) 2020;13:5433.
21. Faruqi S, Ganji KK, Bandela V, Nagarajappa AK, Mohamed RN, Ahmed MA, Farhan M, Alwakid WN, Al-Hammad KAS, Alam MK. Digital assessment of marginal accuracy in ceramic crowns fabricated with different marginal finish line configurations. J Esthet Restor Dent 2022;34:789-95.
22. Baig MR, Akbar AA, Embaireeg M. Effect of finish line design on the fit accuracy of CAD/CAM monolithic polymer-infiltrated ceramic-network fixed dental prostheses: an in vitro study. Polymers (Basel) 2021;13:4311.
23. Dias Resende CC, Quirino Barbosa TA, Moura GF, Piola Rizzante FA, Mendonça G, Zancopé K, Domingues das Neves F. Cost and effectiveness of 3-dimensionally printed model using three different printing layer parameters and two resins. J Prosthet Dent 2023;129:350-3.
24. Tas H, Demirci F, Tuzlali M, Bahce E, Yildirim Avcu G. Evaluation of the accuracy of dental casts manufactured with 3D printing technique in the All-on-4 treatment concept. J Adv Prosthodont 2022;14:379-87.
25. Reis BS, Portella FF, Rivaldo EG. Precision and accuracy of four current 3D Printers to achieve models for

https://doi.org/10.4047/jap.2023.15.3.145

Fixed Dental Prosthesis. Acta Odontol Latinoam 2020; 33:3-5.
26. Cho SH, Schaefer O, Thompson GA, Guentsch A. Comparison of accuracy and reproducibility of casts made by digital and conventional methods. J Prosthet Dent 2015;113:310-5.
27. Kasparova M, Grafova L, Dvorak P, Dostalova T, Prochazka A, Eliasova H, Prusa J, Kakawand S. Possibility of reconstruction of dental plaster cast from 3D digital study models. Biomed Eng Online 2013;12:49.
28. Park JM, Jeon J, Koak JY, Kim SK, Heo SJ. Dimensional accuracy and surface characteristics of 3D-printed dental casts. J Prosthet Dent 2021;126:427-37.
29. Park ME, Shin SY. Three-dimensional comparative study on the accuracy and reproducibility of dental casts fabricated by 3D printers. J Prosthet Dent 2018; 119:861.e1-7.
30. Muallah J, Wesemann C, Nowak R, Robben J, Mah J, Pospiech P, Bumann A. Accuracy of full-arch scans using intraoral and extraoral scanners: an in vitro study using a new method of evaluation. Int J Comput Dent 2017;20:151-64.
31. Cakmak G, Marques VR, Donmez MB, Lu WE, Abou-Ayash S, Yilmaz B. Comparison of measured deviations in digital implant scans depending on software and operator. J Dent 2022;122:104154.
32. Chiu A, Chen YW, Hayashi J, Sadr A. Accuracy of CAD/CAM digital impressions with different intraoral scanner parameters. Sensors (Basel) 2020;20:1157.