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EFFECT OF LAYER THICKNESS, INNER STRUCTURE, AND IMPLANT ANGULATION ON THE ACCURACY OF 3D PRINTED MODELS WITH IMPLANT ANALOGS

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ABSTRACT

Objective: This study evaluated the effect of layer thickness, model inner structure, and implant angulation on the accuracy of 3D printed models with repositional analogs.

Materials and methods: 126 models designed to receive all-on-4 implant retained fixed dental prosthesis were 3D printed. Models were divided into 2 groups (n=63) according to posterior implant angulation (Group 1; 30˚ and group 2;45˚). The models were then divided into three subgroups (n=21) according to the printing layer thickness (Group a; 50 μm, group b; 100 μm, and group c; 150 μm). Each subgroup was later subdivided into 3 divisions (n=7) according to the model inner structure (Group I; solid, group II; hollow, and group III; honeycomb). Trueness was analyzed using Geomagic controlX analysis software by comparing the model scans to the reference model STL file.

Results: Both inner structure and layer thickness had a significant effect on the final accuracy ($p<0.001$). Distal implant angulation had no effect on the final accuracy of the printed model ($p=0.968$). Regarding layer thickness, tukeys post-hoc test revealed that both 100 μm (24.9 ± 2.4) and 150 μm (24.5 ± 1.1) layer thickness showed higher accuracy than the 50 μm (27.9 ± 2.4) layer thickness. As for model form, tukeys post hoc test revealed that the solid (24.9 ± 1.4) and honeycomb (25 ± 1.5) models were more accurate than the hollow models (27.5±3.3).

Conclusion: Implant angulation had no effect on the final accuracy of the model. Both 50 μm print layer thickness and hollow model inner structure showed the least accuracy.

Clinical relevance: Printing layer thickness of 100 to 150 μm with a solid or honeycomb model inner form will provide the best 3D positional accuracy for implant analogs

KEYWORDS: Implant scanbody, All-on-4, Digital dentistry, Fixed Prosthodontics, Dental implants, Digital impressions, implant analogs

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INTRODUCTION

Application of completely digital workflows in implant dentistry is gaining popularity nowadays. Its easiness, time efficiency, and convenience makes it much more desirable by the clinicians and more satisfactory to the patients.[1-4] However, the level of accuracy or predictability of fully digital workflow in implant dentistry is still experimental. There's a lot of ongoing research, published data and evolving techniques to improve the predictability and validity of fully digital workflows and the results are becoming more and more promising every year.[5-9]

Completely digital workflow in implants dentistry includes 3-dimensional (3D) imaging, computer-guided surgery, digital impressions, and CAD/CAM restorations.[10-12] It should eliminate the need of physical models. This can only be applicable in single restorations. However, in complex multiple and full arch implant cases, checking the restorations on a physical model becomes more necessary during its fabrication process.[13, 14]

Generation of physical model can be through milling or 3D printing.[13, 15] A definitive 3D printed model should accurately represent the 3D implant position.[16] Accuracy of 3D printed models depends on several factors; some related to the accuracy of the digital IOS such as scan bodies positioning, accuracy of merging data to the software, operator's experience and scanning strategy; others related to the implant position such as implant depth, angulation and inter-implant distance and others related to the 3D printing parameters such as the printers resolution, layer thickness, type of resin, amount of polymerization shrinkage, design of inner structure, implant holder offset and direction of printing.[16-25]

The degree of implant angulation can play a role in the accuracy of 3D printed models.[16,26-28] Alshawaf et al, compared the accuracy of 3D printed models with conventional stone casts and found that conventional casts had better accuracy and were not affected by implant angulation in contrast to 3D printed models where implant angulation decreased the accuracy.[27] Banjar et al, compared the accuracy of 3D printed models of 2 anterior implants with conventional casts and found that 3D printed models had similar accuracy to conventional casts.[16]

The design of the model might also affect the accuracy of the 3D printed model such as the amount of support of model base.[20, 29, 30] Solid base models should provide more support to the implant analogs position, while hollow models though more commonly used to reduce material and time consumption may not provide enough support to the implant analogs. Camardella et al, studied the accuracy of 3D printed dental models and found that cross arch base and U shaped base with a bar have similar accuracy and even better than U-shaped base with no support.[30] Shin et al, found that dental models with cross arch palate were more accurate and stable than U shaped model.[31] However, these studies were done on regular dental models.

The printer accuracy is determined by the resolution of the x-, y-, and z- axis, which is related to the characteristics of the printer's light source. XY resolution is defined as the minimum feature size that can be reproduced by a printer horizontally, while the resolution along the Z- axis determines the layer thickness which can be modified depending on the material and the printer selected. Theoretically, a thinner layer should generate a smoother, more detailed and accurate surface, while a thicker layer should result in a stair-stepping effect at the edge that decreases the overall accuracy and surface details.[18,19,32,33]

3D printed implant models' accuracy is more critical than other dental models, as minimal errors in the multistep fabrication process can lead to inaccuracy in the implant analog position which will directly lead to misfit of the implant restoration.[34-38] Insertion of digital implant analogs are guided by the anti-rotational features present in both the model and analog itself after printing and fully polymerization.[20 , 39]

Many dental clinicians go for all-on-X treatments nowadays as a graft less solution which requires placing implants in severe angulations such as 30 and 45 degrees.[40, 41] The effect of implant angulation on the accuracy of implant analog positions in full arch 3D printed models is still not clear. The aim of this in-vitro study was to assess the influence of different printing parameters such as layer thickness and design of inner structure on the accuracy of implant analog positions in 3D printed models with different implant angulations.

The research hypothesis tested were that:

1. The implant angulation will have an effect of the trueness of the printed model
2. Printing layer thickness will have an effect of the trueness of the printed model
3. Model inner structure form will have an effect of the trueness of the printed model

MATERIALS AND METHODS

In this in-vitro study 126 models designed to receive all on four implant retained fixed dental prosthesis were 3D printed (Fig.1). The models were divided into 2 groups (n=63) according to posterior implant angulation (Group 1; 30˚ distal implant angulation, and group 2;45˚ distal implant angulation). The models were then divided into three subgroups (n=21) according to the printing layer thickness (Group a; 50 µm, group b; 100 µm, and group c; 150 µm). Each subgroup was later subdivided into 3 divisions (n=7) according to the model inner structure (Group I; solid, group II; hollow, and group III; honeycomb) (Figs. 2- 4)

The models were designed using DDS pro software (Czestochowa, Poland) to mimic the shape of a maxillary arch. Virtual implant placement was done using 3Shape Dental System V. 2.22.2.0 (3Shape, Copenhagen, Denmark) followed by digital attachment of the scan bodies. The digital files were saved in stereolithography format (stl). Three-dimensional (3D) printing technology was used to manufacture the models using the printer Formlab form 3 (Boston, MA, USA) using a gray standard material.

Four scan bodies were inserted in each model (Cares NC monoscanbody, Straumann, Basel, Switzerland) with diameter of 3.5 and 10 mm in height. Two anterior scan bodies were placed at the canines' positions with 0° horizonal angulation parallel to each other, and two scan bodies were placed in the posterior positions with 30° distal angulation in the first model and 45° in the second. Scan bodies were then screwed onto implant analogues (Straumann, Basel, Switzerland). New

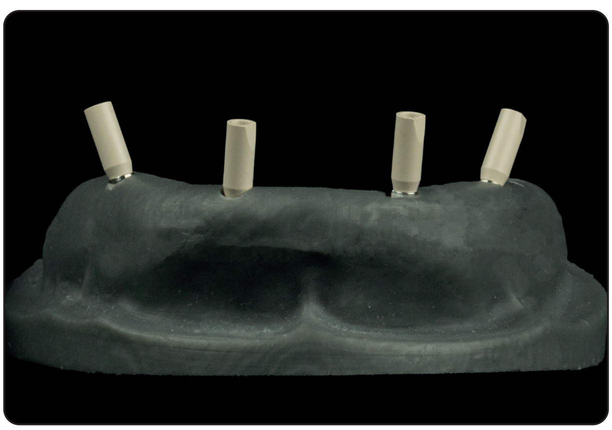

Fig. (1) 3D printed model with analogs and scan bodies

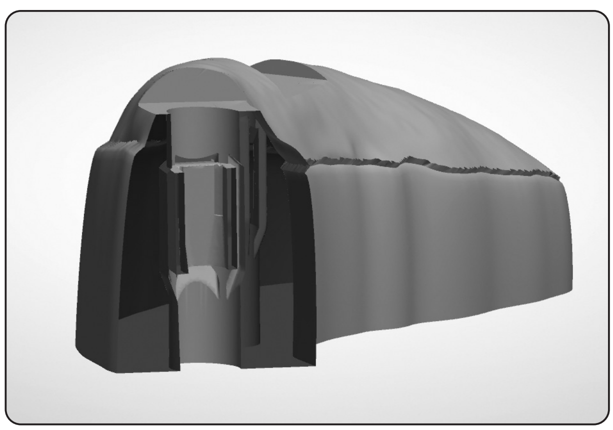

Fig. (2): Design of model with solid inner structure

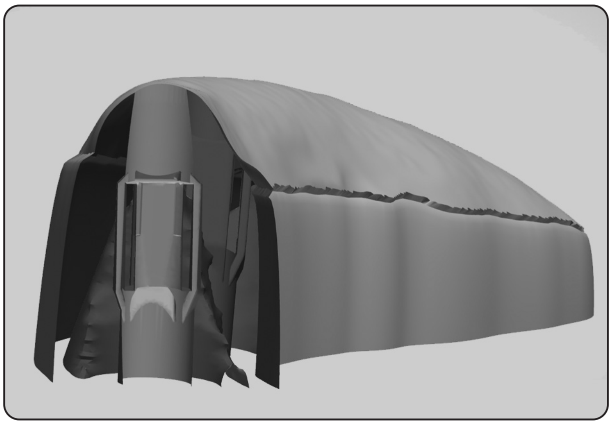

Fig. (3) Design of model with hollow inner structure

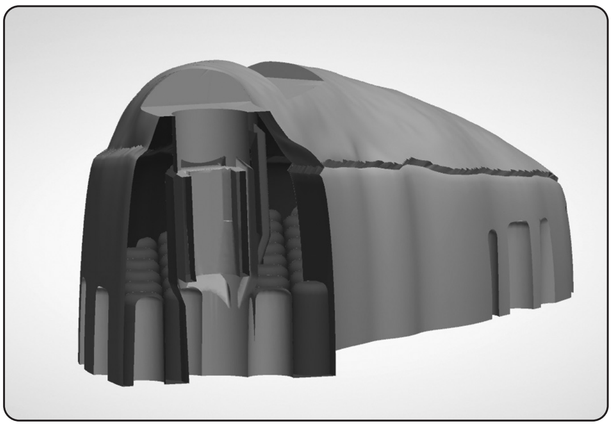

Fig. (4) Design of model with honeycomb inner structure

scan bodies were used for each group to avoid error that might result from possible wear at the implant-scan body interface.

An industrial 3D scanner with structured blue light emitting diode (ATOS Core 200 5M, GOM GmbH, Braunschweig, Germany) was used to scan all the printed models. The original stl file of the model design was used as the reference scan. Data processing was done on cad software to align each scan body of the measured scan to the cad file of the library to allow for digital analogue matching, then accuracy measurement in terms of 3D surface discrepancies was performed after importing all data files to a reverse engineering software Geomagic control X (3D systems, NC, USA).

For trueness measurement, scans were superimposed to the reference stl file obtained the original model design using best fit alignment then 3D deviation along the scan bodies surfaces were only measured by resegmenting the reference file and merging only the assigned areas of interest. The 3D surface discrepancies were measured by the software through the root mean square (RMS) error and the software representing the deviation with a color map showing positive and negative deviation with no specific tolerance.

Numerical data were presented as mean and standard deviation (SD) values. They were explored for normality by checking the data distribution and using Shapiro-Wilk test. Data showed parametric distribution and were analyzed using three-way and one-way ANOVA followed by Tukey's post hoc test. The significance level was set at $p \leq 0.05$.

RESULTS

TABLE (1) Descriptive statistics table showing mean and standard deviation for all subgroups

Angle	Thickness in μm	Form	Mean	Std. Deviation
30	50	Solid	30.9	1.2
		Hollow	26.6	1.1
		Honeycomb	26.1	0.9
	100	Solid	28.2	1.1
		Hollow	23.5	0.6
		Honeycomb	23.2	1.3
	150	Solid	23.5	0.8
		Hollow	24.9	0.5
		Honeycomb	25.2	0.7
45	50	Solid	31.2	1.5
		Hollow	26.7	1.1
		Honeycomb	26.1	0.6
	100	Solid	28.0	0.6
		Hollow	23.3	1.3
		Honeycomb	23.4	1.1
	150	Solid	23.3	1.2
		Hollow	24.8	0.5
		Honeycomb	25.3	1.1

TABLE (2) Three-way ANOVA table

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	524.338[a]	17	30.843	28.431	<.001
Intercept	60072.834	1	60072.834	55375.173	<.001
Angle	.002	1	.002	.002	.968
Thickness	207.104	2	103.552	95.454	<.001
Form	134.934	2	67.467	62.191	<.001
Angle * Thickness	.128	2	.064	.059	.943
Angle * Form	.028	2	.014	.013	.987
Thickness * Form	181.868	4	45.467	41.911	<.001
Angle * Thickness * Form	.274	4	.069	.063	.992
Error	78.108	72	1.085		
Total	60675.280	90			
Corrected Total	602.446	89			

a. R Squared = .870 (Adjusted R Squared = .840)

Descriptive statistics data are listed in Table 1. Three-way ANOVA revealed significant differences between the different variables. Both form and layer thickness had a significant effect on the final accuracy ($p<0.001$). Distal implant angulation had no effect on the final accuracy of the printed model ($p=0.968$). No significant interaction was found between the different variables ($p=0.992$) (Table 2).

Regarding layer thickness, One-way ANOVA revealed significant effect on the final accuracy of the printed model. Tukeys post-hoc test revealed that both 100 μm (24.9 ± 2.4) and 150 μm (24.5 ± 1.1) layer thickness showed higher accuracy than the 50 μm (27.9 ± 2.4) layer thickness.

As for model form, One-way ANOVA revealed significant differences between the different forms. Tukey post hoc test revealed that the solid (24.9 ± 1.4) and honeycomb (25 ± 1.5) models were more accurate than the hollow models (27.5 ± 3.3).

DISCUSSION

3D printing technology has gained more interest recently, especially in its application for models' fabrication. Studies have showed higher accuracy for both 3D printed dentulous and edentulous implant models than conventional models.[37] [38]

The aim of this in-vitro study was to assess the influence of different printing parameters such as layer thickness (50, 100, 150 um) and design of model inner structure (solid, honeycomb, hollow) on the accuracy of implant analog positions in 3D printed models with different implant distal angulations (30° and 45°). The null hypothesis was partially rejected, as the layer thickness and design of inner structure was found to influence the 3D position of implant analogs within the printed models while the implant angulations had no effect.

The results of this in-vitro study showed that implant angulations whether 30 or 45 degrees had no influence on the 3D positional accuracy of implant analogs. Although the printing strategy used in this study was perpendicular to the building platform, one might expect that increasing the implant analog angulation would lessen the accuracy as the build angle might create a rough surface which can affect the insertion and positioning of the implant analogs. However, unlike our study this could be more evident with major differences between the angulations.

No study was found that compared the effect the implant angulation on the accuracy of implant analog position in 3D printed models. However, Implant angulation has been previously reported to increase inaccuracies of impressions.[22, 23] A systematic review by Flügge et al, found that when multiple implants were placed at an angulation between 21° and 45° digital impressions had similar results to conventional ones. [28]

Printing parameters had an influence on the 3D positional accuracy of implant analogs. In this study, cross arch palate models were used as it was reported as necessity for the stability of the printing.[31] Changing the inner structural design of the model base had an impact as we found that printing with solid and honeycomb inner surface structure designs had higher accuracy and less 3D deviations than the hollow design. This can be attributed to the increased amount of support of implant analog holders to the model base as they become completely attached to the base either entirely (solid base) or through a network (honeycomb) rather than being completely unsupported (hollow). Having this kind of support might help in resisting the polymerization shrinkage forces that might change the position of the implant analog holders according to the curing direction. This was consistent with the results of Shin et al who found that fully filled models had higher accuracy than hollow models.[31] On the other hand Rungrojwittayakul et al. didn't find any difference between solid and hollow models when using CLIP and DLP 3D printing technologies.[29]

Layer thickness was also found to influence the 3D positional accuracy of implant analogs in our study. 3D printing with layer thickness of 50 µm showed more deviations than the 100 and 150 µm thicknesses, which was contrary to other studies concluding that the lower the thickness, the higher the accuracy.[18,19,32] This can be explained by as the layer thickness decreases, the number of layers required to print the same model increases. This leads to increasing printing time and increasing curing time which can increase the overall polymerization shrinkage that might lead to minute positional changes of the implant analogs and hence overall less trueness of implant analog positions within the 3D printed models. Also, increasing the number of layers will lessen resiliency of the models, thus more force might be needed to insert the analog within the implant analog holders, this can also cause positional changes in the implant analogs. This was consistent with the results of Jin et al who also found that 100 µm layer thickness had significantly better trueness values than 50 µm layer thickness when using 2 implant analogs in a half arch 3D printed model, however they used DLP printer in their study.[20] Also, Facero et al who found that 25 µm thickness had the least trueness in comparison to 50 and 100 µm in SLA printed orthodontic models.[33] In contrast, Zhang et al. found that a 100 µm layer thickness using a SLA printer was the most inferior in comparison to 25 and 50 µm in terms of printing accuracy of full arch orthodontic models.[32]

Accuracy of the different groups was assessed by superimposing the STL files obtained from the scanned 3D printed models to the reference model STL using the best-fit match algorithm by Geomagic software.[12, 42, 43] An industrial scanner was selected for digitization of the 3D printed models owing to its higher scanning accuracy in contrast to that of intraoral scanners and extra oral scanners thus limiting inaccuracies that can result from the scanning protocol, ambient lighting conditions and operator errors.[24, 25] Root mean square error (RMS) was used to eliminate the inaccuracies that might result due to the cancellation of the positive and negative deviations to each other, which results in a reduced estimation of the actual deviation from the reference cast.[12]

Although the results of this study might be promising, more printing technologies, implant angulations, model build angle may be included in further studies. Also, the use of one 3D printer might be considered as a limitation as other printer with different technologies may affect the final outcome.

CONCLUSIONS

- Implant angulations within the tested range did not have an influence on the accuracy of implant positions in 3D printed models
- Both 100 μm and 150 μm layer thickness showed higher accuracy than the 50 μm layer thickness.
- For model form, the solid and honeycomb models were more accurate than the hollow models

Declarations section

Author Contribution

I.N. did the study design. I.N. and O.E. collected the data. I.N, N.R. and O.E. analyzed the data. I.N. and N.R. prepared the manuscript. All authors reviewed the manuscript

Ethics approval and consent to participate

Not applicable

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Conflict of interest

The authors declare no conflict of interest

REFERENCES

1. Nassani MZ, Ibraheem S, Shamsy E, Darwish M, Faden A, Kujan O. A survey of dentists' perception of chair-side cad/cam technology. Healthc. 2021;9(1).
2. Patzelt SBM, Emmanouilidi A, Stampf S, Strub JR, Att W. Accuracy of full-arch scans using intraoral scanners. Clin Oral Investig. 2014 Jul;18(6):1687–94.
3. Joda T, Brägger U. Patient-centered outcomes comparing digital and conventional implant impression procedures: a randomized crossover trial. Clin Oral Implants Res. 2016;27(12):e185–9.
4. Papaspyridakos P, Rajput N, Kudara Y, Weber HP. Digital Workflow for Fixed Implant Rehabilitation of an Extremely Atrophic Edentulous Mandible in Three Appointments. J Esthet Restor Dent. 2017;29(3).
5. Papaspyridakos P, Vazouras K, Chen Y wei, Kotina E, Natto Z, Kang K, et al. Digital vs Conventional Implant Impressions: A Systematic Review and Meta-Analysis. Vol. 29, Journal of Prosthodontics. 2020.
6. Papaspyridakos P, Chochlidakis K, Kang K, Chen Y wei, Alghfeli A, Kudara Y, et al. Digital Workflow for Implant Rehabilitation with Double Full-Arch Monolithic Zirconia Prostheses. J Prosthodont. 2020;29(6).
7. Papaspyridakos P, Chen Y wei, Gonzalez-Gusmao I, Att W. Complete digital workflow in prosthesis prototype fabrication for complete-arch implant rehabilitation: A technique. J Prosthet Dent. 2019;122(3).
8. Monaco C, Ragazzini N, Scheda L, Evangelisti E. A fully digital approach to replicate functional and aesthetic parameters in implant-supported full-arch rehabilitation. J Prosthodont Res. 2018;62(3).
9. Nedelcu R, Olsson P, Thulin M, Nyström I, Thor A. In vivo trueness and precision of full-arch implant scans using intraoral scanners with three different acquisition protocols. J Dent. 2023;128.
10. Al-Imam H, Gram M, Benetti AR, Gotfredsen K. Accuracy of stereolithography additive casts used in a digital workflow. J Prosthet Dent. 2018;119(4).
11. Ebeid K, Sabet A, El Sergany O, Della Bona A. Accuracy and repeatability of different intraoral instruments on

shade determination compared to visual shade selection. J Esthet Restor Dent. 2022;34(6):988–93.

12. Ebeid K, Nouh I, Ashraf Y, Cesar PF. Accuracy of different laboratory scanners for scanning of implant-supported full arch fixed prosthesis. J Esthet Restor Dent. 2022;34(5):843–8.
13. Gherlone E, Capparé P, Vinci R, Ferrini F, Gastaldi G, Crespi R. Conventional Versus Digital Impressions for “All-on-Four” Restorations. Int J Oral Maxillofac Implants. 2016;
14. Papaspyridakos P, Chen Y wei, Alshawaf B, Kang K, Finkelman M, Chronopoulos V, et al. Digital workflow: In vitro accuracy of 3D printed casts generated from complete-arch digital implant scans. J Prosthet Dent. 2020;124(5).
15. Lin WS, Harris B, Elathamna E, Abdel-Azim T, Morton D. Effect of Implant Divergence on the Accuracy of Definitive Casts Created from Traditional and Digital Implant-Level Impressions: An In Vitro Comparative Study. Int J Oral Maxillofac Implants. 2015;30(1).
16. Banjar A, Chen Y wei, Kostagianni A, Finkelman M, Papathanasiou A, Chochlidakis K, et al. Accuracy of 3D Printed Implant Casts Versus Stone Casts: A Comparative Study in the Anterior Maxilla. J Prosthodont. 2021;30(9).
17. Alharbi N, Osman R, Wismeijer D. Effects of build direction on the mechanical properties of 3D-printed complete coverage interim dental restorations. J Prosthet Dent. 2016;115(6).
18. Arnold C, Monsees D, Hey J, Schweyen R. Surface quality of 3D-printed models as a function of various printing parameters. Materials (Basel). 2019;12(12).
19. Piedra-Cascón W, Krishnamurthy VR, Att W, Revilla-León M. 3D printing parameters, supporting structures, slicing, and post-processing procedures of vat-polymerization additive manufacturing technologies: A narrative review. Vol. 109, Journal of Dentistry. 2021.
20. Jin G, Shin SH, Shim JS, Lee KW, Kim JE. Accuracy of 3D printed models and implant-analog positions according to the implant-analog–holder offset, inner structure, and printing layer thickness: an in-vitro study. J Dent. 2022;125.
21. Revilla-León M, Özcan M. Additive Manufacturing Technologies Used for Processing Polymers: Current Status and Potential Application in Prosthetic Dentistry. Vol. 28, Journal of Prosthodontics. 2019.
22. Sicilia E, Lagreca G, Papaspyridakos P, Finkelman M, Cobo J, Att W, et al. Effect of supramucosal height of a scan body and implant angulation on the accuracy of intraoral scanning: An in vitro study. J Prosthet Dent. 2023 Feb;
23. Gómez-Polo M, Sallorenzo A, Cascos R, Ballesteros J, Barmak AB, Revilla-León M. Conventional and digital complete-arch implant impression techniques: An in vitro study comparing accuracy. J Prosthet Dent. 2022 Dec;
24. Revilla-León M, Kois DE, Kois JC. A guide for maximizing the accuracy of intraoral digital scans. Part 1: Operator factors. J Esthet Restor Dent. 2023 Jan;35(1):230–40.
25. Revilla-León M, Kois DE, Kois JC. A guide for maximizing the accuracy of intraoral digital scans: Part 2—Patient factors. J Esthet Restor Dent. 2023 Jan;35(1):241–9.
26. Arshad M, Asgari A, Kharazifard MJ, Ameri N. Effect of Implant Angulation on the Rotational Displacement of a 3-Unit Bridge after Digital Impression. Int J Dent. 2022;2022.
27. Alshawaf B, Weber HP, Finkelman M, El Rafie K, Kudara Y, Papaspyridakos P. Accuracy of printed casts generated from digital implant impressions versus stone casts from conventional implant impressions: A comparative in vitro study. Clin Oral Implants Res. 2018;29(8).
28. Flügge T, van der Meer WJ, Gonzalez BG, Vach K, Wismeijer D, Wang P. The accuracy of different dental impression techniques for implant-supported dental prostheses: A systematic review and meta-analysis. Vol. 29, Clinical Oral Implants Research. 2018. p. 374–92.
29. Rungrojwittayakul O, Kan JY, Shiozaki K, Swamidass RS, Goodacre BJ, Goodacre CJ, et al. Accuracy of 3D Printed Models Created by Two Technologies of Printers with Different Designs of Model Base. Vol. 29, Journal of Prosthodontics. 2020.
30. Camardella LT, de Vasconcellos Vilella O, Breuning H. Accuracy of printed dental models made with 2 prototype technologies and different designs of model bases. Am J Orthod Dentofac Orthop. 2017;151(6).
31. 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(23).
32. Zhang Z chen, Li P lun, Chu F ting, Shen G. Influence of the three-dimensional printing technique and printing layer thickness on model accuracy. J Orofac Orthop. 2019;80(4).

33. Favero CS, English JD, Cozad BE, Wirthlin JO, Short MM, Kasper FK. Effect of print layer height and printer type on the accuracy of 3-dimensional printed orthodontic models. Am J Orthod Dentofac Orthop Off Publ Am Assoc Orthod its Const Soc Am Board Orthod. 2017 Oct;152(4):557–65.

34. Kim Y, Oh TJ, Misch CE, Wang HL. Occlusal considerations in implant therapy: Clinical guidelines with biomechanical rationale. Vol. 16, Clinical Oral Implants Research. 2005.

35. Buzayan MM, Yunus NB. Passive fit in screw retained multi-unit implant prosthesis understanding and achieving: A review of the literature. Vol. 14, Journal of Indian Prosthodontist Society. 2014.

36. Olea-Vielba M, Jareño-García D, Methani MM, Martinez-Klemm I, Revilla-León M. Accuracy of the Implant Replica Positions on the Complete Edentulous Additive Manufactured Cast. J Prosthodont. 2020;29(9).

37. Revilla-León M, Gonzalez-Martín Ó, Pérez López J, Sánchez-Rubio JL, Özcan M. Position Accuracy of Implant Analogs on 3D Printed Polymer versus Conventional Dental Stone Casts Measured Using a Coordinate Measuring Machine. J Prosthodont. 2018;27(6).

38. Revilla-León M, Fogarty R, Barrington JJ, Zandinejad A, Özcan M. Influence of scan body design and digital implant analogs on implant replica position in additively manufactured casts. J Prosthet Dent. 2020;124(2).

39. Tan S, Tan MY, Wong KM, Maria R, Tan KBC. Comparison of 3D positional accuracy of implant analogs in printed resin models versus conventional stone casts: Effect of implant angulation. J Prosthodont. 2023;

40. Maló P, de Araújo Nobre M, Lopes A, Ferro A, Botto J. The All-on-4 treatment concept for the rehabilitation of the completely edentulous mandible: A longitudinal study with 10 to 18 years of follow-up. Clin Implant Dent Relat Res. 2019 Aug;21(4):565–77.

41. Szabó ÁL, Nagy ÁL, Lászlófy C, Gajdács M, Bencsik P, Kárpáti K, et al. Distally Tilted Implants According to the All-on-Four® Treatment Concept for the Rehabilitation of Complete Edentulism: A 3.5-Year Retrospective Radiographic Study of Clinical Outcomes and Marginal Bone Level Changes. Dent J. 2022;10(5).

42. Yehia A, Abo El Fadl A, El Sergany O, Ebeid K. Effect of different span lengths with different total occlusal convergence on the accuracy of intraoral scanners. J Prosthodont Off J Am Coll Prosthodont. 2023 Mar;

43. Khaled M, Sabet A, Ebeid K, Salah T. Effect of Different Preparation Depths for an Inlay-Retained Fixed Partial Denture on the Accuracy of Different Intraoral Scanners: An In Vitro Study. J Prosthodont. 2022 Nov;31(7):601–5.