ORIGINAL RESEARCH

Submitted: 23.12.2022; Accepted: 10.01.2023; Published online: 25.02.2023

Accuracy and Precession of 3d Printed Cast Produced by Two Printing Techniques

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Abstract

Aim: This study analyses the tolerance and accuracy of 3D printed casts created by two printing techniques and cast geometry deformations after six months. MISC.

Methodology. An A 28-year-old volunteer with full dentition was scanned using 3shape's TRIOS3.3Shape's Dental System converted the scan to STL. NextDent 5100 DLP and Forms Lab Form 2 SLA printers received the STL file. Each printer made 10 casts. Every cast was scanned using a 3Shape E3 Scanner (E3 Scanner from 3Shape). A cloud comparison tool compared each scan to the volunteer's original scan. The two printers' accuracy was measured at the time of the scan and six months afterward using IBM's SPSS 28 for a one-way ANOVA. Shapiro Wilk statistics were not significant P> 0.05, proving normality. ANOVA was used to compare printers' accuracy.

Results. Table 1 shows the means and SDs. Wilk's Lambda of p. 05 (F = 95.533 and partial eta squared = 0.841) reveals an initial and six-month accuracy difference. A P 0.05 within-subject's tolerance effect was found. P=. 503 demonstrates printer type doesn't affect participation. The study's mean was. 995, with a standard error of. 066 and CI of. 856 to 1.134.

Conclusion. The accuracy measurement decreased significantly between the initial and six-month measurements. There was no difference in accuracy between the two measurements for either printer. There was a statistically significant difference between each cast and each printer's first STL file information. However, the distinction was within the accepted tolerance of -/+ 42 µm (Envision TEC reported an accepted tolerance level).

Keywords

Accuracy; Precession; 3D printed model; Stereolithography printers; Digital light processing; Tolerance; Material dentistry.

Imprint

Walaa Ali Babeer. Accuracy and Precession of 3d Printed Cast Produced by Two Printing Techniques. Cardiometry; Issue No. 26; February 2023; p. 144-150; DOI: 10.18137/cardiometry.2023.26.144150; Available from: http://www.cardiometry.net/issues/no26-february-2023/accuracy-precession-3d-printed

Introduction

Dentistry has undergone continual improvements over the years. The rise of digital dentistry has provided digital alternatives to conventional stone casts. Digital casts can be virtually fabricated by capturing three-dimensional (3D) impressions through intraoral scanners, eliminating the need for stone cast fabrication. [1-3]. The selection of an appropriate 3D printer is complicated. The first attribute to assess is the accuracy of the 3D printer. Accuracy includes the terms precision and trueness used in the intraoral scanner world. Precision describes the reproducibility of the 3D printer, the ability for the 3D printer to duplicate the same cast each time. The cast must also match the initial STL file made by the intraoral scanner. Trueness is how close the cast dimension is to the original STL file. [4] Tolerance is another attribute to consider. Tolerance measures the difference between the original STL file and the cast in microns. Envision TEC considers the approved tolerance +/- 42 µm in the XY axis and it is consistent to what is reported in literature. [5]

The surface finish considers how smooth the cast is established based on the thickness of layers in the z-axis. The XYZ axis determines Voxel size. [6] The printer manufactures the dimensions of the cast in the XY axis. At the same time, the operator uses the software to manipulate the layer thickness while manufacturing the z-axis. The finish of this layer determines the surface coating. Literary works in orthodontics indicate no need to go less than 50 µm in the z-axis. There is no distinction in the accuracy between 100 µm and 50 µm[7]; nonetheless, the 50 µm print has a better surface finish. [8] The smaller the thickness of the layer in the z-axis, the better the surface finishes. [8] This must be balanced against the potential loss of accuracy due to increasing layers when reducing layer thickness as reported by manufacturing companies

The resolution of a 3D printer depends on the resolution of the light or laser source[6]. The light source determines how much light reaches the surface of the resin tank. Resolution in DLP printers is determined by multiplying the number of pixels that define the x-axis by the number of pixels that define the y-axis. Bear in mind that the pixel proportion on the projector is not scaled 1: 1 with the cured cast. Numerous variables affect this proportion, for example, the distance between the projector and the material. The closer the projector to the material tank, the smaller the surface area covered by the light [9].

The difference between voxel and pixel should be understood to further comprehend resolution. Pixel is measured in two dimensions, while the voxel resembles the pixel in 3 dimensions. [10] The term "pixel" is short for "picture element. " Pixel is tiny little dots that make up the photos on computer displays, whether flat-screen (LCD) or tube (CRT) monitors. The screen is divided into a matrix of thousands of pixels. The medical meaning of a pixel is a picture element. A CT scan is composed of an array of squares (pixels), each colored with a uniform color of gray. The image area corresponding to the tissue piece is a volume element called a voxel. [11] A voxel is a unit of visual information that defines a point in three-dimensional space. Since a pixel (picture element) represents a point in two-dimensional space with its x and y coordinates, a third coordinate, z, is needed. In 3D space, each coordinate is defined in terms of its position, color, and density. Therefore, a pixel is square on a flat surface, and a voxel is cubic in 3 dimensions.

A printer can produce digital master casts after capturing the three-dimensional impression. The usual methods used are digital light processing (DLP) or stereolithography (SLA). [1, 11] The STL files are typically developed and transferred to computer-assisted design (CAD) software schemes for prostheses. The benefits of digital scanning include avoiding mistakes throughout the process, eliminating the need for impression materials or disinfection, the convenience of moving to the lab, and patient comfort. [12-14] The scans are distributed and stored online, improving efficiency. [15, 16]

SLA and DLP printers use the same printing procedure but differ in how they transfer curing light to the resin. SLA is the earliest and most used technique for 3D printing. The SLA procedure entails conveying a fast-moving ultraviolet (UV) laser beam of light into a tank filled with a light-sensitive fluid material. One thin layer is cured at a time. The cured layer is attached to the building platform of the printer and not to the material tank. As quickly as each layer is completed, the building platform increases slightly, and a new fresh layer is shaped on top of the old one. This procedure continues until the item is entirely formed. The DLP printer does not scan each layer using a laser light beam. Instead, DLP scans a silhouette of a whole layer and cures it with curing light, which allows for faster printing. [16, 17]

Digital dentistry is becoming a popular trend among prosthodontists. Digital dentistry aims to use modern technology to ease dental procedures for patients. However, there are too few tests and reviews on the accuracy of dental casts fabricated digitally using 3D impression scanners. This study aims to evaluate the master casts manufactured by two 3D printers, one SLA and the other DLP, to compare and assess the accuracy and tolerance of both techniques.

Materials and Methods

This study aimed to compare the accuracy and tolerance of dental casts manufactured using the SLA and DLP 3D printers. Two measurements will be taken, an initial measurement at the time of the intraoral scan and the other after six months, to compare the accuracy and tolerance between the two printers at two different points of time. The study required only one volunteer for the intraoral scan Trios 3 (3shape, Demark), two 3D printers (Forms Lab and Nexdent, United States), a dental designer software (3shape dental designer 2019), and a cloud compare program (by DotProduct, 2G Robotics, Riegl, Geoslam, Kaarta) for the comparisons. For standardization, all the samples and measurements were done by one examiner.

The power analysis was done to determine the sample size, but to show a significant difference between the two groups, 4000 samples are needed, which is not realistic. A post hoc power analysis was done, too, as shown in tables 2, 3, and 4.This finding indicates that the means threat probability of the difference of the two groups to occur is slim.

Printer	Printing technology	Resin	Designer software
Next dent 5100	Digital light processing	Next dent Model resin	3shape dental designer 2019
Forms Lab 2	Stereolithography	Forms Lab model V2 resin (FLDMBE02)	3shape dental designer 2019

Trios 3 (3shape, Demark) was conducted on a 28-year-old volunteer with full dentition intraoral scan.

The scan was exported as STL to digital dental design software to be processed and trimmed. The STL file was transferred to preform (Forms Lab, USA) software, and the scan was multiplied ten times to print ten casts. The same STL file was imported to 3D sprint, and the STL files were again duplicated ten times. Preform and 3D sprint both are slicing software. Slicing STL files for printings by adding the necessary base ensures the flow of resin to the printed layer throughout the printings. The sliced STL files were then transferred to a DLP printer and an SLA printer. Each printer printed ten casts. All models are cleaned in an alcohol bath.

The casts were submerged in ultrasonic cleaner filled with 90 % alcohol for the next dent model material. The baths were done two times to ensure that the uncured resin was removed. All models were dried then transferred to a curing unit LC-3DPrint Box. (Nexdent, United states). All cast were cured for 10 minutes. All cast printed by Forms Lab SLA printer was then submerged in isopropyl alcohol (IPA) path in the form wash machine (Forms Lab, united states) for 15 minutes. All models were then cured in form (Forms Lab, united states) for 13 minutes under 60 Celsius degree temperature. Every cast was scanned by using a desktop computer scanner E3 (3shape, Denmark). A cloud compare program (by DotProduct, 2G Robotics, Riegl, Geoslam, Kaarta, 2.6.3 Windose 64 bites) was used to contrast each scan with the original intraoral scan taken from the volunteer.

CloudCompare is used to compare meshes by using the cloud to mesh distance tool (C2M) tool. The C2M tool compares the two meshes in microns (Fig. 1, Fig. 2).

First, the two meshes are imported to the CloudCompare software. The software will align the two meshes by picking six equivalent points. The software will measure the root mean square of distances between every two points. Then the Cloud Compare

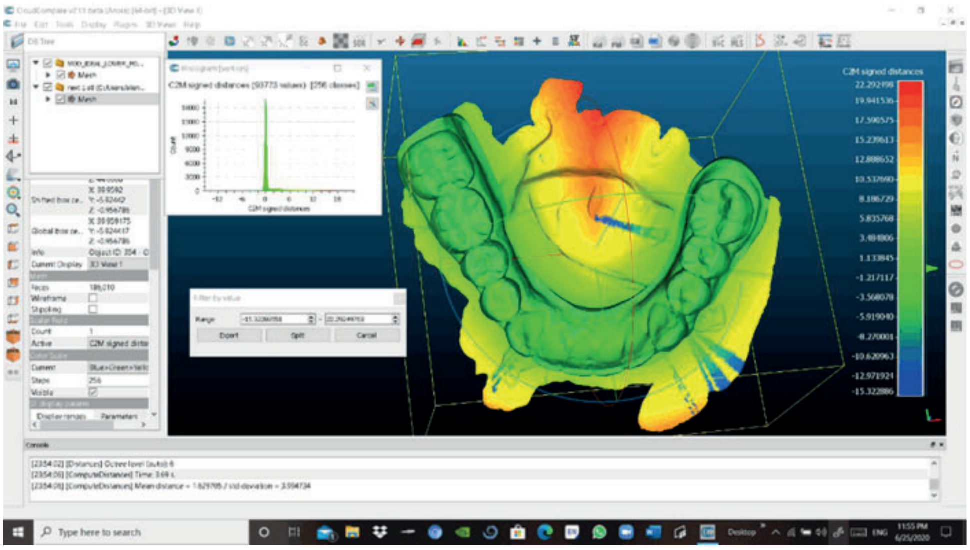

Figure 1. The C2M tool compares the two meshes in microns.

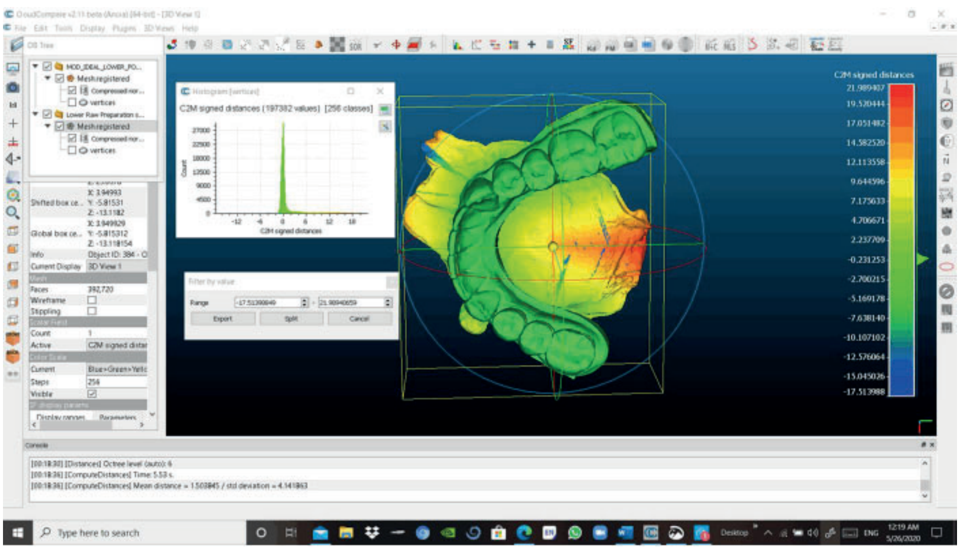

Figure 2. The C2M tool compares the two meshes in microns.

will align the two meshes to the best possible fit. After alignment is done, the original intraoral scan is true every time the test meshes are compared. The C2M tool calculates the distance test mesh and the nearest points on its reference. A one-way ANOVA test was used to compare the measurements. The Shapiro Wilk statistics were not significant, $P > 0.05$, which met the assumption of normality. No assumption of sphericity was required due to a within-subjects factor of only two levels. The one-way ANOVA test was also used to assess the precision comparison between the printers.

Results

The raw data of means and standards deviations are reported in Table 1.

A significant difference in accuracy between the initial and six-month measurements is shown with a Wilk's Lambda of $P <. 05$ (F = 95.533 and partial eta squared = 0.841) (Table 2).

The within-subjects effect of accuracy was significant with $P <. 05$, reported in Table 3.

The effect of printer type between subjects was not significant, $P =. 503$ (Table 4).

Table 1

Means and Standards Descriptive Statistics.

	Printer	Mean	Std. Deviation	N
Mean Distance 1	Forms Lab	1.8178	.52729	10
	Next Dent	1.6530	.29168	10
	Total	1.7359	.42317	20
Mean Distance 2	Forms Lab	.2618	.50560	10
	NextDent	.2471	.43650	10
	Total	.2544	.45978	20

Table 2

Multivariate Tests.

Effect		Value	F[b]	Hypothesis df	Error df	Sig.	Partial Eta Squared	Nocent. Parameter	Observed Power[c]
Accuracy	Pillai's Trace	.841	95.533	1.000	18.000	<.001	.841	95.533	1.000
	Wilk's Lambda	.159	95.533	1.000	18.000	<.001	.841	95.533	1.000
	Hotelling's Trace	5.307	95.533	1.000	18.000	<.001	.841	95.533	1.000
	Roy's Largest Root	5.307	95.533	1.000	18.000	<.001	.841	95.533	1.000
Accuracy * Printer	Pillai's Trace	.013	.243	1.000	18.000	.628	.013	.243	.075
	Wilk's Lambda	.987	.243	1.000	18.000	.628	.013	.243	.075
	Hotelling's Trace	.013	.243	1.000	18.000	.628	.013	.243	.075
	Roy's Largest Root	.013	.243	1.000	18.000	.628	.013	.243	.075

[a] Design: Intercept + Printer. Within subject's design: Accuracy. [b] Exact statistic. [c] Computed using alpha =. 05.

Table 3

Tests of Within-Subjects Effects.

Measure: Measure_1. [a] Computed using alpha =. 05.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Accuracy	Spericity Assumed	21.946	1	21.946	95.533	<.001	.841	95.533	1.000
	Greenhouse-Geisser	21.946	1.000	21.946	95.533	<.001	.841	95.533	1.000
	Huynh-Feldt	21.946	1.000	21.946	95.533	<.001	.841	95.533	1.000
	Lower-bound	21.946	1.000	21.946	95.533	<.001	.841	95.533	1.000
Accuracy * Printer	Spericity Assumed	.056	1	.056	.243	.628	.013	.243	.075
	Greenhouse-Geisser	.056	1.000	.056	.243	.628	.013	.243	.075
	Huynh-Feldt	.056	1.000	.056	.243	.628	.013	.243	.075
	Lower-bound	.056	1.000	.056	.243	.628	.013	.243	.075
Error (Accuracy)	Spericity Assumed	4.135	18	.230					
	Greenhouse-Geisser	4.135	18.000	.230					
	Huynh-Feldt	4.135	18.000	.230					
	Lower-bound	4.135	18.000	.230					

Table 4

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	39.612	1	39.612	226.466	<.001	.926	226.466	1.000
Printer	.080	1	.080	.456	.508	.025	.456	.098
Error	3.148	18	.175					

Measure: Measure_1. Transformed Variable: Average. [a] Computed using alpha =. 05.

The grand mean for the study was. 995 with a standard error of. 066 and a 95% CI of. 856 to 1.134.The estimated means, standard error, and 95% CI for each printer are shown in Table 5.

Table 5

Estimates.

			95% Confidence Interval	
Printer	Mean	Std.Error	Lower Bound	Upper Bound
Forms Lab	1.040	.094	.843	1.236
NextDent	.950	.094	.843	1.147

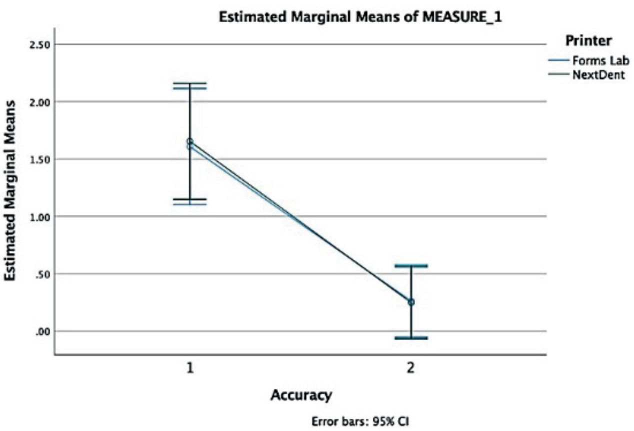

Figure 1. Estimated Marginal means of measure_1.

Discussion

There are many ways to compare meshes resulting from a 3D scanner. Researchers have used root mean square (RMS) and root mean square error (RMS error) methods. This research used a more straightforward tool called a cloud to mesh (C2M) comparison tool. RMS error is defined as the distance between mesh nodes and the desired working surface. [18] RMS means the square root of the average of the squared distances to the referenced surface. The RMS error method is the square root of the mean square (arithmetic mean of the squares of a group of values) between two areas. [19] C2M tools measure the distance between cloud and mesh or between two meshes. One of the meshes will be the reference surface to which the other mesh surface will be compared. The result will be the same as the sum of the measured entities.

The manufacturer of the desktop E3 Scanner, 3Shape, lists the scanner's accuracy as 7 μm. 3Shape emphasizes that the 7-micron accuracy statement means that the 3D image produced by the scanner has a tolerance of +/-7 μm. The C2M tool will also measure the differences in distance between the two meshes in microns. [20] IOS devices should have clinically acceptable accuracy values, usually specified at 100 μm. [21]

All printed casts expanded or contracted within tolerances of 1.040 for the SLA and. 950 for the DLP printers. When the scanner's 7-micron accuracy was added, the trueness increases to 8.04 μm for the SLA casts and 7.95 μm for the DLP cast. The accuracy of the cast produced by both printers exceeds the ADA specification No. 25 for dental gypsum models, which specifies that the expansion should be within 50 μm when reproducing fine details. [22] The ISO 6873: 2013 specification also states that the linear setting expansion should be 15% for type IV stones and 16%–30% for type V stones. Baldi et al. [24] found the linear expansion of the dental gypsum cast to be 135.78 μm for marginal adaptation and 212.31 μm for internal adaptation, both of which were significantly greater than the printed casts. de Freitas et al. [25] found comparable results with the expansions between 242.0 and 257.0 μm. The SLA printer indicated trueness with a tolerance of 1.040 +/-. 094, and DLP showed trueness with a tolerance of. 950 -/+. 094 (Table 5).

Casts produced with such trueness are accepted as casts to fabricate prosthodontic prostheses. The literature review found that DLP and SLA printed casts always deviate from the initially scanned cast. The deviation will always occur, and it should be within the accepted tolerance to be clinically acceptable. [23]

Literature indicates that the acceptable tolerance for prosthodontic clinical use is 250 μm. [24] For fixed dental prostheses, the clinically acceptable discrepancy ranges between 100 and 150 μm. The trueness of all printed working models was found to be less than 100 μm in this study, which was considered clinically acceptable. [25, 26].

The measurement of accuracy decreased significantly between the initial and the six months' later measurements. This result is consistent with the literature, which indicated that accuracy significantly reduced after three weeks of aging. [27] Other research found that restoring the DLP models under a light source over time reduced the accuracy of the cast. [28] Therefore, the printed cast can be used to make a prosthesis within three weeks of its production. [27]

Conclusion

This research made three conclusions. Firstly, the measurement of accuracy decreased significantly over six months from the initial measurement. Secondly, there was no difference in accuracy between the two measurements for either printer. Moreover, there was a statistically significant difference between each cast and each printer's original STL file information. Nevertheless, the distinction was within accepted tolerance which is -/+ 42 μm.

Clinical Implications

3D printer processes using DLP and SLA technology are able to produce prosthodontic casts within clinically acceptable accuracy and tolerance standards. These casts should be used to avoid deteriorating accuracy within the first three weeks after manufacture. There is no difference in the accuracy produced by both printers.

Acknowledgement

Author is thankful to the (Department of Oral and Maxillofacial Prosthodontics) for the continuous support towards this research study.

Authorship Criteria

Author meet the criteria for substantial contributions to conception and design of, or acquisition of data or analysis and interpretation of data, 2) drafting the article or revising it critically for important intellectual content and 3) final approval of the version to be published

Ethical Consent

Not required.

Funding

No Funding Sources Are Reported.

Conflict of Interest

Author do not have any conflict of interest.

Data Availability Statement

Data Is Available in the Submitted Manuscript.

References

1. Aly, P. and C. Mohsen, Comparison of the Accuracy of Three-Dimensional Printed Casts, Digital, and Conventional Casts: An In Vitro Study. European journal of dentistry, 2020. 14(2): p. 189.
2. Güth, J.-F., et al., Accuracy of digital models obtained by direct and indirect data capturing. Clinical oral investigations, 2013. 17(4): p. 1201-1208.
3. Hamid, N.F.A., W.Z.W. Bakar, and Z. Ariffin, Marginal gap evaluation of metal onlays and resin nanoceramic computer-aided design and computer-aided manufacturing blocks onlays. European journal of dentistry, 2019. 13(01): p. 017-021.
4. Ender, A. and A. Mehl, Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. The Journal of prosthetic dentistry, 2013. 109(2): p. 121-128.
5. Reich, S., et al., Accuracy of 3D-Printed Occlusal Devices of Different Volumes Using a Digital Light Processing Printer. Applied Sciences, 2022. 12(3): p. 1576.
6. Brenes, C., et al., The Effect of Print Angulation on the Surface Roughness of 3D-Printed Models. Compendium, 2020. 41(10).
7. Sherman, S.L., et al., Accuracy of digital light processing printing of 3-dimensional dental models. American Journal of Orthodontics and Dentofacial Orthopedics, 2020. 157(3): p. 422-428.
8. Loflin, W.A., et al., Effect of print layer height on the assessment of 3D-printed models. American Journal of Orthodontics and Dentofacial Orthopedics, 2019. 156(2): p. 283-289.
9. Saorin, J.L., et al., Design and Validation of an Open Source 3D Printer Based on Digital Ultraviolet Light Processing (DLP), for the Improvement of Traditional Artistic Casting Techniques for Microsculptures. Applied Sciences, 2021. 11(7): p. 3197.

10. Miller-Keane, O.T.M. and M.T. O'Toole, Miller-Keane encyclopedia and dictionary of medicine, nursing, and allied health. Philadelphia, PA: Saunders, 2003.
11. Etemad-Shahidi, Y., et al., Accuracy of 3-Dimensionally Printed Full-Arch Dental Models: A Systematic Review. Journal of clinical medicine, 2020. 9(10): p. 3357.
12. Chochlidakis, K.M., et al., Digital versus conventional impressions for fixed prosthodontics: A systematic review and meta-analysis. The Journal of prosthetic dentistry, 2016. 116(2): p. 184-190. e12.
13. Joda, T. and U. Brägger, Time-efficiency analysis of the treatment with monolithic implant crowns in a digital workflow: A randomized controlled trial. Clinical oral implants research, 2016. 27(11): p. 1401-1406.
14. Joda, T. and U. Brägger, Patient-centered outcomes comparing digital and conventional implant impression procedures: a randomized crossover trial. Clinical Oral Implants Research, 2016. 27(12): p. e185-e189.
15. Banjar, A., et al., Accuracy of 3D Printed Implant Casts Versus Stone Casts: A Comparative Study in the Anterior Maxilla. Journal of Prosthodontics, 2021.
16. Barazanchi, A., et al., Additive technology: update on current materials and applications in dentistry. Journal of Prosthodontics, 2017. 26(2): p. 156-163.
17. Buda, M., M. Bratos, and J.A. Sorensen, Accuracy of 3-dimensional computer-aided manufactured single-tooth implant definitive casts. The Journal of prosthetic dentistry, 2018. 120(6): p. 913-918.
18. Yuan, S., B. Yang, and H. Fang. Direct Root-Mean-Square Error for Surface Accuracy Evaluation of Large Deployable Mesh Reflectors. in AIAA SciTech 2020 Forum. 2020.
19. Yoo, S.-Y., et al., Dimensional accuracy of dental models for three-unit prostheses fabricated by various 3D printing technologies. Materials, 2021. 14(6): p. 1550.
20. cloud to mesh tool manual. 2015; Available from: https://www.cloudcompare.org/doc/wiki/index.php?title=Cloud-to-Mesh_Distance.
21. Koseoglu, M., E. Kahramanoglu, and H. Akin, Evaluating the effect of ambient and scanning lights on the trueness of the intraoral scanner. Journal of Prosthodontics, 2021.
22. New American Dental Association Specification No. 25 for dental gypsum products. J Am Dent Assoc, 1972. 84(3): p. 640-4.
23. Park, J.-M., et al., Dimensional accuracy and surface characteristics of 3D-printed dental casts. The Journal of prosthetic dentistry, 2021. 126(3): p. 427-437.
24. Hazeveld, A., J.J.H. Slater, and Y. Ren, Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques. American Journal of Orthodontics and Dentofacial Orthopedics, 2014. 145(1): p. 108-115.
25. Emir, F. and S. Ayyildiz, Accuracy evaluation of complete-arch models manufactured by three different 3D printing technologies: A three-dimensional analysis. Journal of Prosthodontic Research, 2021. 65(3): p. 365-370.
26. McLean, J., The estimation of cement film thickness by an in vivo technique. Br dent j, 1971. 131: p. 107-111.
27. Joda, T., L. Matthisson, and N.U. Zitzmann, Impact of aging on the accuracy of 3D-printed dental models: An in vitro investigation. Journal of clinical medicine, 2020. 9(5): p. 1436.
28. Yousef, H., et al., Effect of additive manufacturing process and storage condition on the dimensional accuracy and stability of 3D-printed dental casts. The Journal of Prosthetic Dentistry, 2021.