https://doi.org/10.4047/jap.2022.14.6.379

Evaluation of the accuracy of dental casts manufactured with 3D printing technique in the All-on-4 treatment concept

Hilin Tas[1]*, Fatih Demirci[1], Mesut Tuzlali[1], Erkan Bahce[2], Guler Yildirim Avcu[3]

[1]Department of Prosthodontics, Faculty of Dentistry, Inonu University, Malatya, Turkey
[2]Department of Mechanical Engineering, Faculty of Engineering, Inonu University, Malatya, Turkey
[3]Department of Prosthodontics, Faculty of Dentistry, Okan University, Istanbul, Turkey

ORCID
Hilin Tas
https://orcid.org/0000-0002-4972-2907
Fatih Demirci
https://orcid.org/0000-0002-8744-5592
Mesut Tuzlali
https://orcid.org/0000-0002-7602-8101
Erkan Bahce
https://orcid.org/0000-0001-5389-5571
Guler Yildirim Avcu
https://orcid.org/0000-0002-8461-7774

Corresponding author
Hilin Tas
Department of Prosthodontics, Faculty of Dentistry, Inonu University, Malatya, Turkey, 44280, Turkey
Tel +905362733226
E-mail hilintas@outlook.com

Received August 5, 2022 / **Last Revision** November 12, 2022 / **Accepted** December 15, 2022

This study was supported by grant No. TDH-2021-2668 from Inonu University Scientific Research Projects Unit, Malatya, Turkey.

PURPOSE. The aim of this study is to compare the casts obtained by using conventional techniques and liquid crystal display (LCD) three-dimensional (3D) print techniques in the All-on-4 treatment concept of the edentulous mandibular jaw. **MATERIALS AND METHODS.** In this study, a completely edentulous mandibular acrylic cast (typodont) with bone-level implants placed with the All-on-4 technique served as a reference cast. In this typodont, impressions were taken with the conventional technique and dental stone casts were obtained. In addition, after scanning the acrylic cast in a dental laboratory scanner and obtaining the Standard Tessellation Language (STL) data, 3D printed casts were manufactured with a 3D printing device based on the design. The stone and 3D printed casts were scanned in the laboratory scanner and STL data were obtained, and then the interimplant distances were measured using Geomagic Control X v2020 (3D Systems, Rock Hill, SC, USA) analysis software (n = 60). The obtained data were statistically evaluated with one-way analysis of variance (ANOVA) and Tukey's pairwise comparison tests. **RESULTS.** As a result of the one-way ANOVA test, it was determined that the stone casts, 3D printed casts, and reference cast values in all distance intervals conformed to the normal distribution and these values had a significant difference among them in all distance intervals. In Tukey pairwise comparison test, significant differences were found between casts at all distance intervals. In all analyses, the level of significance was determined as .05. **CONCLUSION.** 3D printed casts obtained with a 3D LCD printing device can be an alternative to stone casts when implants are placed in edentulous jaws. [J Adv Prosthodont 2022;14:379-87]

KEYWORDS

Accuracy; All-on-4; Dental implant; Digital dentistry; Three-dimensional printing

https://doi.org/10.4047/jap.2022.14.6.379

INTRODUCTION

In the All-on-4 treatment concept developed by Maló *et al.*,[1] it has become possible to install a fixed dental prosthesis with the support of 4 implants in the completely edentulous jaw. The posterior implants are tilted up to 45° distally to move away from the mental foramen areas in the mandible and the sinus cavities in the maxilla, while anterior implants are placed vertically in both jaws. Angulation of posterior implants is tolerated with angled abutments. A single guide could be used in the surgical protocol of this treatment concept. The distally angled placement of posterior implants allows the use of a prosthesis long enough to support a full-arch fixed prosthesis.[2,3] As the number of dental implants used is less and no advanced surgery like sinus elevation or additional bone augmentation is applied, the operation is much easier for both patients and dentists. It also offers cost-efficient treatment in a relatively short time. Despite the lack of long-term evidence, many studies show the All-on-4 treatment concept has been a reliable and predictable procedure in the long-term outcome for nearly the past 20 years.[4-6]

Three-dimensional (3D) printing is a manufacturing process that creates an object by adding material in layers, which technique is thought to be more comfortable for dentists and patients compared to the manufacturing process with conventional methods, and has replaced most laboratory work.[7] The development of printing technologies provides great advantages in terms of clinical conditions, dental casting and 3D printing techniques.[8] Some of these include digitizing patient data, bringing costs to acceptable levels, and allowing pre-planning, modification, and simulation during the manufacturing procedure. Various 3D printing techniques are constantly being developed, among which the most popular are digital light processing (DLP) and liquid crystal display (LCD).[9] Previous studies have shown that dental casts manufactured with both types of devices are sufficient for diagnostic and treatment planning purposes.[10-12]

Dental stone casts are, considered the current gold standard, generated by using conventional impressions and then pouring the stone. The correct transfer of the 3D position of the implant and its proper angulation in the cast is very important for the manufacturing of a prosthesis with high passive fit.[13] For this purpose, various impression materials, trays, and techniques have been developed.[14-16]

Technology can be used as an evaluation method to analyze geometric changes. In dentistry, this technology opens new opportunities for 3D evaluation of the entire surface, such as detecting irregularities between the original preparation and the stone cast. Laboratory digitization replaces either a conventional impression and stone casting,[17] using one of several optical and mechanical systems, or a combination of conventional and digital impressions.[18] In addition, some systems offer direct impression scanning without stone casting, but this is not recommended for implant treatment of complete edentulism.[19-21] Conventional stone casts have disadvantages such as the need for storage space and the possibility of wear of the stone. Besides, the use of stone cast can create difficulties in establishing communication between the dentist and the technician.[22-24] In addition, physical storage is not required for digital casts, and storing patient records in digital media is possible with external hard disk or digital storage systems. With proper backups and data management, the probability of losing digital records is extremely low. More predictable and viable prosthetic designs can be made with digital working casts. Furthermore, by evaluating the patient's expectations, and the treatment options offered by the physician and visual information can be provided to the patient. Moreover, digital impressions and prosthetic designs can be shared with other dentists and laboratories via an internet connection.[25]

According to the International Organization for Standardization (ISO), (ISO 5725-1), accuracy refers to the closeness of the measurements made to the reference values. Precision refers to the similarity between repeated measurements[26] and accuracy is also an important concept for implant-supported prostheses.[2] In the past, different methods and devices such as 3D photogrammetry, computed tomography, and microscope have been used for accurate measurement, but it has been determined that adequate data cannot be obtained with these methods. Nowadays, the accuracy of objects is detected by scanning them with scanners with high sensitivity.[27] Minimum dimensional differences occur in optical scanners, as a result of scanning the cast. However, these differences are at the micron level and are not clinically significant. For this reason, optical scanners are considered more successful than other methods in current accuracy comparisons.[28] The material difference in the diagnostic casts, the change in the number of teeth in the jaw or the application of implant treatment cause a change in the accuracy of the obtained casts.[12,29-33] In order to determine the accuracy of the impression in implant-supported treatments, virtual measurements of 3D surface deviations between scan bodies and test casts, and digital caliper both in the tooth and arch can be used, or linear measurements can be done in the digital design of the stone by using 3D analysis software.[29-31,34-38]

In this context, the aim of this study is to compare the dental casts obtained by using conventional techniques (stone cast) and liquid crystal display (LCD) 3D print techniques (3D printed cast) in the All-on-4 treatment concept of the edentulous mandibular jaw. The null hypothesis is that the amount of accuracy of the 3D printed casts manufactured by 3D dental printing devices is similar to the routinely used dental stone casts.

MATERIALS AND METHODS

In this study, a completely edentulous mandibular acrylic cast (typodont) with bone-level implants (Multifix®; MIS Implant Technologies, C1®; MIS Implant Technologies, Bar Lev, Israel) placed with the All-on-4 technique served as a reference cast. The effect size was 0.25; the α value was set at 0.05, and the power of the study was calculated as 95%. Sample size estimation was performed using the G*Power software program. In the typodont reference cast, twenty dental stone casts were obtained with polyether dental impression in a stock tray and poured with Type IV dental stone by the conventional impression technique, and twenty 3D printed casts were obtained using a digital impression and LCD 3D printing methods. Casts were obtained using a digital impression and LCD 3D printing methods (Fig. 1). All casts were digitized and Standard Tessellation Language (STL) data was obtained by scanning in a laboratory scanner. Before scanning each group, the lab scanner was calibrated according to the manufacturer's instructions. The STL data of both groups of casts were compared with the data obtained by scanning the reference cast twenty separate times (control group) in terms of the measurements of the distances between the implants. All software and devices used in this study are shown in Table 1.

Open tray impression posts were screwed to all abutments in the reference cast. Impression posts were connected to each other with dental floss (Colgate Interface Floss; New York, NY, USA) and coated with a brush using splint material (GC pattern resin;

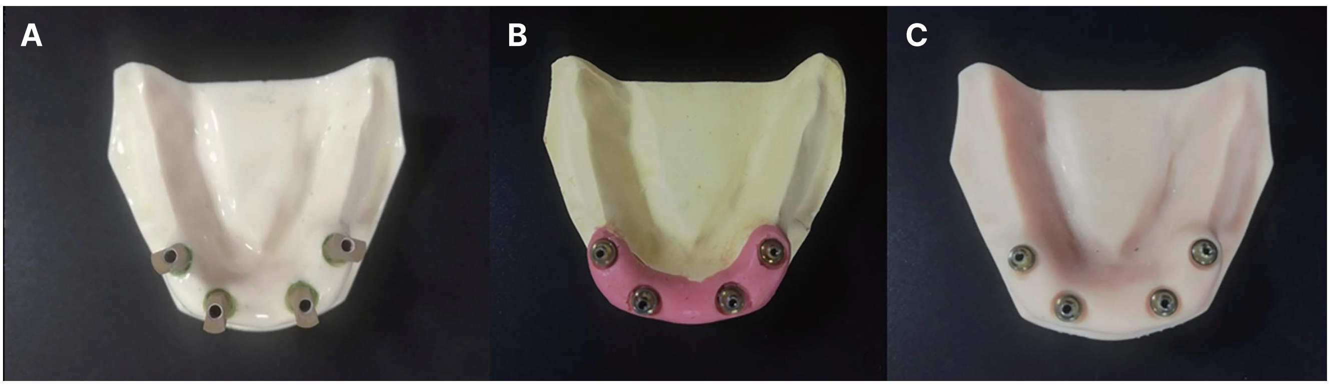

Fig. 1. (A) Reference cast used in this study. (B) Stone cast obtained by taking conventional impressions from the reference cast. (C) Resin cast manufactured by printing technique.

Table 1. Devices and software used in this study

Device/Software	Type of Device/Analysis Method	Manufacturer
Ackuretta Freeshape 120	LCD 3D Print Device	Ackuretta, Taiperi, Taiwan
Dental Wings 7SERIES	Laboratory Scanner	Dental Wings Inc., Montreal, Canada
Anycubic Wash & Cure 2.0	Washing/Curing Device	Anycubic, Shenzhen, China
Exocad Cast Creator	3D Cast Software	Exocad GmbH, Darmstadt, Germany
Geomagic Control X	3D Cast Analysis/Measurement	3D Systems, Rock Hill, SC, USA
SOLIDWORKS 2020	3B CAD Software	Dassault Systemes, Vélizy-Villacoublay, France
Minitab 17	Statistical Analysis	Minitab Inc., State College, PA, USA

GC Corp., Tokyo, Japan). Thus, all the impression posts were connected to each other. Since the splint material is resin-based, in order to rule out polymerization shrinkage, the splint materials between the posts were cut in the middle to create gaps with 0.5-millimeter (mm) diameter double-faced diamond disc (Hager & Meisinger GmbH, Hansemannstr, Neuss, Germany). Then all these gaps were filled with splint materials, and the impression posts were connected to each other again. Conventional impressions of the reference cast were taken with custom open trays prepared with universal tray adhesive (Universal Tray Adhesive; Zhermack SpA, Badia Polesine, Italy) and polyvinylsiloxane (PVS) material (Hydrorise Implant Heavy Body and Hydrorise Implant Light Body, Zhermack SpA; Badia Polesine, Italy) using a one-step two-viscosity technique. Conventional implant analogs and impression posts were carefully screwed. The gingival mask material (Gingifast Rigid; Zhermack SpA; Badia Polesine, Italy) was applied around the impression posts. Then, type IV stone mixture (Moldano; Heraeus Kulzer GmbH Wehrheim, Germany) was prepared in accordance with the manufacturer's instructions at the water/powder ratio recommended by the company and poured the stone into the impression. All stone casts were obtained according to this procedure.

The digital scan bodies were screwed to the implants in the reference cast. A scanning powder (Dr. MAT Dental White Scan Spray; MAT Chemical Industry Products Food, and Cosmetics Industry, Trade Limited Company, Istanbul, Turkey) was applied to the surface of the cast to prevent reflection. The reference cast was digitized using a scanning laboratory scanner (Dental Wings 7 SERIES; Dental Wings Inc., Montreal, Canada) with a precision of 15 micrometers (µm). The reference cast was scanned twenty times to confirm that the scanner to be used in the study achieved reliable and reproducible results. The data in STL format obtained from the reference cast scan was transferred to the 3D dental Computer-Aided-Design (CAD) software (Exocad DentalCAD 2.4 Plovdiv; Exocad GmbH, Darmstadt, Germany). The slots where the digital implant analogs will be placed were determined in the design (Fig. 2). The obtained data were transferred to a 3D printing device (Accuretta Freeshape 120; Accuretta, Taiperi, Taiwan) with the help of a USB device and then the 3D production started.

The layer thickness of all casts was 70 µm and the number of layers was 369. All casts are designed to be placed in a parallel orientation on the build platform in the 3D printing software. 3D printer resins (MACK 4D Model Resin; MACK4D GmbH, Neukieritzsch, Ger-

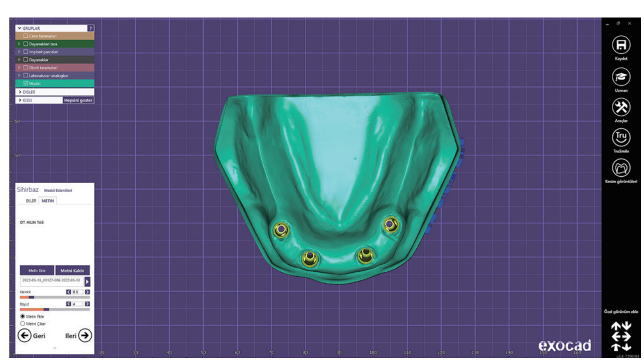

Fig. 2. View of the cast designed to be printed in a 3D software program.

many) specially manufactured by the companies for the cast were used in the 3D printing device. After printing, the printed casts were treated with a 10-minute alcohol washing (Wogens Pure Ipa 99.9% Iso Propyl Alcohol; Wogens Chemistry and Engineering, Konya, Turkey) and cured using a UV irradiation device (Anycubic Wash & Cure 2.0 Washing and Curing Device; Anycubic, Shenzhen, China) for 30 minutes. The UV irradiation device uses a UV light lamp with a wavelength of 405 nm. As a result, the polymerization of the casts was completed.

Two scanning groups (3D printed casts and stone casts) were created in the software of the laboratory scanner. Scanning powder was applied to each of the casts and scanning processes were performed. All implants were represented by a letter (A, B, C, and D). The STL data of all casts and reference cast were imported into the 3D CAD analysis program (Solidworks 2020; Dassault Systemes, Vélizy-Villacoublay, France). Each cast was placed on a flat surface at a specified offset plane so that its measurements were performed at a standard location. All these data were imported into the 3D analysis program (Geomagic Control X v2020; 3D Systems, Rock Hill, SC, USA) to be measured (Fig. 3). The measurement of the distances between the scan posts fixed to the screw-retained abutments was performed with an accuracy of ± 0.01 µm. Measurements were done with reference to the midpoint of the screw entry at the top of the scan posts. The distance measurements were grouped as A-B, B-C, C-D, A-C, B-D, and A-D. The mean of measurement values (mm) of all stone casts and 3D printed groups were compared with the mean of measurement values of the reference group.

All analyses were made using Minitab 17 (Minitab Inc.; State College, PA, USA) statistical analysis program. Levene's test was used for evaluating the homogeneity of variance distributions on interimplant distances values for each group and it was seen that variances were normal in distribution. The distributions of the stone cast, 3D printed cast, and reference cast measurement values were made by one-way ANOVA test. Tukey's test was performed in order to compare the values of stone and 3D printed casts according to the reference cast values for each distance. The significance level of the P value was determined as .05.

RESULTS

The conformity of the measurement values of the stone casts, 3D printed casts, and reference cast groups to the normal distribution for the A-B, B-C, C-D, A-C, B-D, and A-D distances was evaluated with a one-way ANOVA test ($P < .001$). The mean and standard deviation values were determined in all groups (Table 2). It was seen that a statistically significant difference was found in the measurement values of the

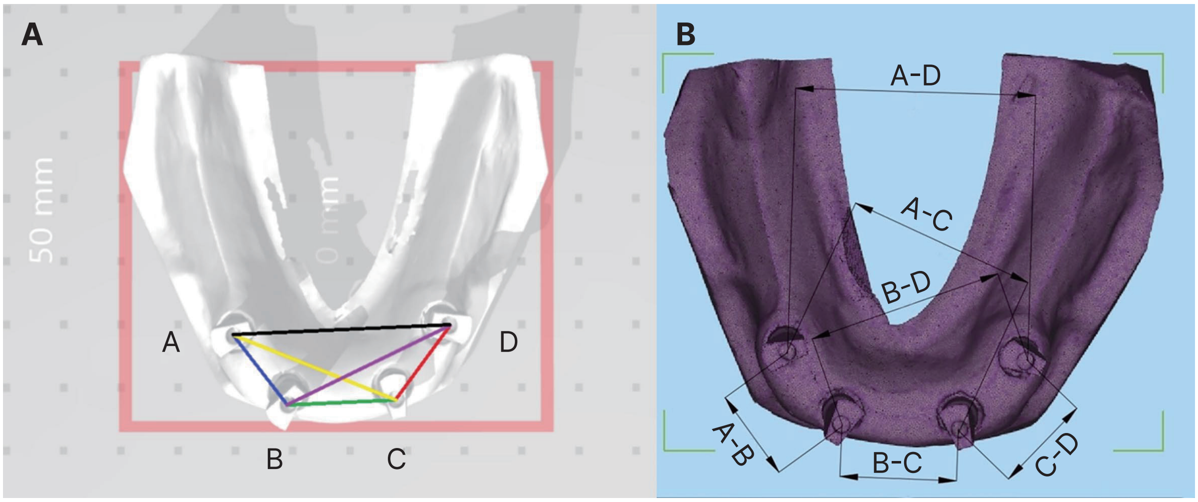

Fig. 3. (A) Visualization the interimplant distances measured on the STL data of the reference cast. (B) Reference cast's interimplant distance measurement in Geomagic Control X 3D analysis software.

 https://doi.org/10.4047/jap.2022.14.6.379

Table 2. The mean measurement, SD, and *P* values in all cast groups

	Distances	M ± SD (mm)	*P*
Reference Cast	A-B	12.67 ± 0.0845 *	< .05
	B-C	16.35 ± 0.0934 †	
	C-D	13.16 ± 0.1254 ‡	
	A-C	26.30 ± 0.2098 §	
	B-D	27.00 ± 0.1892 ¶	
	A-D	33.16 ± 0.1782 **	
Stone Cast	A-B	12.5391 ± 0.1093 *	
	B-C	16.4647 ± 0.0792 †	
	C-D	13.0043 ± 0.0882 ‡	
	A-C	26.1658 ± 0.1814 §	
	B-D	27.0936 ± 0.0494 ¶	
	A-D	33.0043 ± 0.1015 **	
Printed Cast	A-B	12.7306 ± 0.0940 *	
	B-C	16.5446 ± 0.1107 †	
	C-D	13.0667 ± 0.1527 ‡	
	A-C	26.3677 ± 0.2202 §	
	B-D	27.2541 ± 0.3196 ¶	
	A-D	33.3157 ± 0.2946 **	

The superscript symbols indicate statistically significant differences between groups. A-B, B-C, C-D, A-C, B-D, and A-D indicate distance measurement points. M = Mean value, SD = Standard Deviation.

interimplant distances between the measurement values of cast groups and the reference cast (Tukey's test, $P < .05$).

DISCUSSION

In this study, the accuracy of conventional stone and 3D printed casts was compared. The null hypothesis of this study is printed casts with 3D printing devices do not differ significantly from conventional stone casts in terms of accuracy. According to the results of this study, the null hypothesis was rejected.

According to the current literature, there are numerous studies that examined the 3D printing technology, while there is no study so far that compared the accuracy of conventional stone cast and LCD 3D printing technology in the All-on-4 treatment concept for full-arch rehabilitation.

In the systematic review published by Zhang *et al*.,[20] the accuracy of full-arch digital implant measurements taken using intraoral scanners was evaluated and related variables were analyzed. As a result, it has been found that many factors such as the scanning arch, scanning order, scanning distance, implant position, implant angle, implant depth, implant connection, and operator experience affect the accuracy of the impressions taken with intraoral scanners. Accordingly, the use of intraoral scanners in full-arch digital implant impressions cannot yet provide sufficient accuracy.[19] For this reason, a fully digital workflow is still not recommended in the production of full-arch implant-supported prostheses. According to recent limited studies, though the digital impression is still prone to inaccuracies and not as precise and clinically successful as conventional impressions, it appears to be promising and comparable to conventional methods.[18,39-41] Revilla-León *et al*.[21] used a laboratory scanner to digitize the artificial jaw in the production of 3D printed specimens. As a rationale, it has been reported that laboratory scanners have a higher scanning accuracy than intraoral scanners and eliminate many errors that may occur (scan protocol, ambient light scanning conditions, etc). In this study, a mandibular cast implanted with the All-on-4 concept was digitized using a laboratory scanner in accordance with the semi-digital workflow.

In 2022, Kang *et al*.[42] showed that the light intensity of the post-curing device influences the final mechanical properties of the 3D printed production and so post-curing can be made more efficient by optimizing the light intensity and post-curing time.

There are studies on the accuracy of 3D-printed casts compared to stone casts. They concluded that 3D-printed casts can be used instead of stone casts.[9,29,43] As a result of this study, it was confirmed that 3D-printed casts can be an alternative to conventional stone casts in the All-on-4 treatment concept.

The researchers put forward the technique of attaching ball-metal beams to pre-calibrate to the reference cast and measure its coordinate after scanning them with digital scanners.[44] In some studies, measurement accuracy was evaluated by virtual measurement of 3D surface deviations between scan bodies screwed into implants in reference casts and test casts.[35-37] On the other hand, linear measurements were performed on both the tooth and the arch with a digital caliper[30,38] or on the digital design of the cast using 3D analysis software.[10,29,31] In this study, a fixed point was determined on the scan bodies screwed to the implants of all casts in the reference and test groups, and then the distances between these points were measured. The points were determined to pass through the center of the circular area at the screw entrance at the top of the scan body. All measurements were performed by a single researcher using the 3D analysis program Geomagic Control X.

Since the prosthesis' surface areas are quite large in implant and tissue-supported or cement-retained implant-supported prostheses, surface matching is more understandable in controlling the dental cast fit of these prostheses.

Besides, passive screwing of the prosthetic screw to the abutment in screw-retention prostheses indicates that the prosthesis has a passive fit. Therefore, evaluating the position of the implants in the cast was considered more critical for accuracy analysis.

In accuracy analysis studies on 3D printing molds, mostly full dentate molds were used.[12,29,30,32] In some studies, different numbers of tooth loss were simulated in these casts and the treatments where implants were applied in the tooth loss areas were evaluated.[29,31,33] Papaspyridakos *et al*.[33] performed a digital scan using an intraoral scanner after placing 4 abutment-level implant analogs in an edentulous mandibular jaw. The generated (STL) datasets were transferred to the CAD software program via 3D printing technology and the twenty-five 3D printed casts and mandibular control casts were further digitized using a laboratory scanner. These STL datasets' surface matching was performed only on the scan bodies. Surface overlays were performed by creating an average plane. In this study, casts were positioned on a standard plane using a CAD software program,[45] and then precise measurements were made by referring to the points determined in the midline of the entrance path of the scanned parts in the 3D analysis program.

The possibility of making mistakes at different stages such as the impression material used, the powder-liquid ratio of the stone, and the hand sensitivity of the applicator who performs this whole process is a limitation of this study. In addition, since our study was *in vitro*, intraoral conditions could not be exactly simulated in digital and conventional impression stages. In order to eliminate these limitations and increase the reliability of the study, the number of specimens was increased. Industrial scanners with much higher sensitivity can also be used in *in vitro* studies on this subject. In this study, a laboratory scanner capable of precision scanning was used. By performing scans twenty times repeatedly in the control group, the precision of the device used was verified.

Further studies are needed to evaluate how to cope with accuracy errors in LCD printed casts. Also, clinical studies are needed to analyze the accuracy in terms of trueness and precision of conventional and digital manufacturing comparing not only the different intraoral scanners and 3D printing devices but various materials as well. This may aim to decide whether 3D printed casts can replace conventional stone cast.

CONCLUSION

The values obtained in terms of accuracy of the casts obtained by the 3D printing technique were found closer to the reference casts compared to the conventional stone casts. The values of the 3D printed casts are similar in accuracy to the values of the stone casts. As a result of these results, the use of 3D printed casts, like stone casts, could be preferred.

The result obtained by this *in vitro* study implies that 3D-printed casts can be preferred over stone casts clinically.

REFERENCES

1. Maló P, Rangert B, Nobre M. "All-on-Four" immediate-function concept with Brånemark system implants for completely edentulous mandibles: a retrospective clinical study. Clin Implant Dent Relat Res 2003;5 Suppl 1:2-9.
2. Krekmanov L, Kahn M, Rangert B, Lindström H. Tilting of posterior mandibular and maxillary implants for improved prosthesis support. Int J Oral Maxillofac Implants 2000;15:405-14.
3. Bevilacqua M, Tealdo T, Menini M, Pera F, Mossolov A,

Drago C, Pera P. The influence of cantilever length and implant inclination on stress distribution in maxillary implant-supported fixed dentures. J Prosthet Dent 2011;105:5-13.
4. 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;21:565-77.
5. Maló P, de Araújo Nobre M, Lopes A, Ferro A, Nunes M. The All-on-4 concept for full-arch rehabilitation of the edentulous maxillae: A longitudinal study with 5-13 years of follow-up. Clin Implant Dent Relat Res 2019; 21:538-49.
6. Maló P, de Araújo Nobre M, Lopes A, Moss SM, Molina GJ. A longitudinal study of the survival of All-on-4 implants in the mandible with up to 10 years of follow-up. J Am Dent Assoc 2011;142:310-20.
7. Dawood A, Marti Marti B, Sauret-Jackson V, Darwood A. 3D printing in dentistry. Br Dent J 2015;219:521-9.
8. Moon W, Kim S, Lim BS, Park YS, Kim RJ, Chung SH. Dimensional accuracy evaluation of temporary dental restorations with different 3D printing systems. Materials (Basel) 2021;14:1487.
9. Zhang ZC, Li PL, Chu FT, Shen G. Influence of the three-dimensional printing technique and printing layer thickness on model accuracy. J Orofac Orthop 2019;80:194-204.
10. 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.
11. 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 Dentofacial Orthop 2017; 152:557-65.
12. Hazeveld A, Huddleston Slater JJ, Ren Y. Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques. Am J Orthod Dentofacial Orthop 2014;145:108-15.
13. Lee H, So JS, Hochstedler JL, Ercoli C. The accuracy of implant impressions: a systematic review. J Prosthet Dent 2008;100:285-91.
14. Aljohani MS, Bukhari HA, Alshehri M, Alamoudi A. Accuracy of the different materials used to fabricate a verification jig of implant-supported fixed complete dental prostheses: An in vitro study. Cureus 2022;14: e29794.
15. Fernandes DS, Anasane NS, Jagtap AK. Splinting open tray impression copings using long shank carbide burs during definitive impression: A dental technique. J Contemp Dent Pract 2022;23:566-8.
16. Lee H, Kwon KR, Paek J, Pae A, Noh K. A method for minimizing rotational errors of implant prostheses. Int J Oral Maxillofac Implants 2017;32:1018-22.
17. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J 2008;204:505-11.
18. Hong SJ, Lee H, Paek J, Pae A, Kim HS, Kwon KR, Noh K. Combining conventional impressions and intraoral scans: a technique for the treatment of complete denture patients with flabby tissue. J Prosthodont 2019; 28:592-5.
19. Quaas S, Rudolph H, Luthardt RG. Direct mechanical data acquisition of dental impressions for the manufacturing of CAD/CAM restorations. J Dent 2007;35: 903-8.
20. Zhang YJ, Shi JY, Qian SJ, Qiao SC, Lai HC. Accuracy of full-arch digital implant impressions taken using intraoral scanners and related variables: A systematic review. Int J Oral Implantol (Berl) 2021;14:157-79.
21. 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: 202-10.
22. Lemos LS, Rebello IM, Vogel CJ, Barbosa MC. Reliability of measurements made on scanned cast models using the 3 Shape R 700 scanner. Dentomaxillofac Radiol 2015;44:20140337.
23. Kumar A, Ghafoor H. Rapid prototyping: a future in orthodontics. J Orthod Res 2016;4:1-7.
24. Wiranto MG, Engelbrecht WP, Tutein Nolthenius HE, van der Meer WJ, Ren Y. Validity, reliability, and reproducibility of linear measurements on digital models obtained from intraoral and cone-beam computed tomography scans of alginate impressions. Am J Orthod Dentofacial Orthop 2013;143:140-7.
25. Suese K. Progress in digital dentistry: The practical use of intraoral scanners. Dent Mater J 2020;39:52-56.

26. Eckert SE, Koka S. Osseointegrated dental implants. The Bionic Human: Springer 2006. p. 603-18.
27. Maxwell SK, Charles PH, Cassim N, Kairn T, Crowe SB. Assessing the fit of 3D printed bolus from CT, optical scanner and photogrammetry methods. Phys Eng Sci Med 2020;43:601-7.
28. Mendricky R. Determination of measurement accuracy of optical 3D scanners. MM Sci J 2016:1565-72.
29. 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 Dentofacial Orthop 2017;151:1178-87.
30. Camardella LT, Vilella OV, van Hezel MM, Breuning KH. Accuracy of stereolithographically printed digital models compared to plaster models. J Orofac Orthop 2017;78:394-402.
31. Bohner L, Hanisch M, De Luca Canto G, Mukai E, Sesma N, Neto PT. Accuracy of casts fabricated by digital and conventional implant impressions. J Oral Implantol 2019;45:94-9.
32. Nestler N, Wesemann C, Spies BC, Beuer F, Bumann A. Dimensional accuracy of extrusion- and photopolymerization-based 3D printers: In vitro study comparing printed casts. J Prosthet Dent 2021;125:103-10.
33. Papaspyridakos P, Chen YW, Alshawaf B, Kang K, Finkelman M, Chronopoulos V, Weber HP. Digital workflow: In vitro accuracy of 3D printed casts generated from complete-arch digital implant scans. J Prosthet Dent 2020;124:589-93.
34. 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 Dentofac 2018;153:144-53.
35. Kurtulmus-Yilmaz S, Ozan O, Ozcelik TB, Yagiz A. Digital evaluation of the accuracy of impression techniques and materials in angulated implants. J Dent 2014;42:1551-9.
36. Lee SJ, Betensky RA, Gianneschi GE, Gallucci GO. Accuracy of digital versus conventional implant impressions. Clin Oral Implants Res 2015;26:715-9.
37. Papaspyridakos P, Benic GI, Hogsett VL, White GS, Lal K, Gallucci GO. Accuracy of implant casts generated with splinted and non-splinted impression techniques for edentulous patients: an optical scanning study. Clin Oral Implants Res 2012;23:676-81.
38. Aly P, Mohsen C. Comparison of the accuracy of three-dimensional printed casts, digital, and conventional casts: an in vitro study. Eur J Dent 2020;14:189-93.
39. Amin S, Weber HP, Finkelman M, El Rafie K, Kudara Y, Papaspyridakos P. Digital vs. conventional full-arch implant impressions: a comparative study. Clin Oral Implants Res 2017;28:1360-7.
40. 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;31:324-30.
41. Papaspyridakos P, Gallucci GO, Chen CJ, Hanssen S, Naert I, Vandenberghe B. Digital versus conventional implant impressions for edentulous patients: accuracy outcomes. Clin Oral Implants Res 2016;27:465-72.
42. Kang MJ, Lim JH, Lee CG, Kim JE. Effects of post-curing light intensity on the mechanical properties and three-dimensional printing accuracy of interim dental material. Materials (Basel) 2022;15:6889.
43. 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.
44. Kuhr F, Schmidt A, Rehmann P, Wöstmann B. A new method for assessing the accuracy of full arch impressions in patients. J Dent 2016;55:68-74.
45. Oliva B, Sferra S, Greco AL, Valente F, Grippaudo C. Three-dimensional analysis of dental arch forms in Italian population. Prog Orthod 2018;19:34.