Dimensional stability of 3D-printed fixed prosthetic restorations

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ABSTRACT

Aim The aim of the present *in vitro* study was to compare the accuracy and stability of four 3D printed resin full arch restorations at 24 hours and 7 days from fabrication.
Materials and methods A full arch gypsum reference model was scanned with Aadva lab scanner (Gc Co. Tokyo, Japan) . A complete maxillary arch restoration was designed using the CAD software Exocad (Exocad GmbH, Germany, 2010). After the designing procedure, the STL file was exported to the DLP printer. Four biocompatible (II class) resins developed for temporary crown and bridges were chosen to realize the prosthetic restorations. Eight models were printed for each resin using the DLP printer Asiga MAX UV (Asiga, NSW, Australia) (wavelength= 385nm; pixel resolution = 62 µm). A total of 32 printed restorations were included in this study. The surface was lightly dusted with powder (Occlusal Spray,Larident srl, Genoa, Italy) and then were scanned using the lab scanner Aadva Lab Scanner 2 to generate STL files. The scans were performed in four different moments: Time 0 (T0): scans are done immediately after printing; Time 24h (T24h): scans are done 24 hours after the first scan; Time 48h (T48h): scans are done 48 hours after the first scan; 4. Time 7days (T7days): scans are done 7 days after the first scan. Eight models for each resin were scanned in four different moments, for a total of 32 scans for each resin and 128 total scans. The STL files were exported to a surface matching software (Geomagic Control X; 3D systems, Rock Hill, USA). The scan at T0 of each model was taken as the reference model, while the 24h scan was superimposed to the refence model. After the superimposition, the 3D comparison function was used to create color surface maps. A maximum critical value of ± 100 µm (0,100mm) and a maximum nominal value of ± 25 µm (0,025mm) was set for color spectra. Each superimposition allows to obtain two percentage (%) values: correspondence and variation. Thanks to these two values it was possible to measure the behavior of tested prosthetic restorations over the first day (T24h), the second day (T48h), and the seven following days (T7days) since printing. In order to analyse each resin, the two percentages values (correspondence and variation) of each 3D printing were collected and their arithmetic mean was calculated to have one percentage for each resin in each of the four times. One-way ANOVA was used for comparing different measurement errors between groups.
Results For all 3D-printed resins a change of stability was recorded; these changes were affected by time and type of resin. There were statistically significant differences among the four resins after 24 hours and 7 days.
Conclusions Within the limitations of the present study, the result rejected two null hypothesis as the time factor and different resins had effect on the stability of the 3D printed resin restorations. Tempt PRINT resin showed do be more stable than the other three tested resins after 1 and 7 days. The variance in stability of FreePrint, C&B MFH and Temp PRINT was not statistically significant between 1 and 7 days, whilst VarseoSmile Crown showed a statistically significant change at first and last controls.

INTRODUCTION

Since the late '90s, various techniques of 3D printing have revolutionized the medical and dental disciplines, promoting the design of new devices. 3D printing finds numerous applications in different fields of dentistry, especially in fixed and removable prosthodontics, but also in surgery, endodontics and implantology.
Beside the production of dental casts and surgical guides, 3D printing is a very useful technique to produce fixed prosthetic restorations especially as temporary restorations in full mouth rehabilitations.
3D printing can be used to produce dental casts in a very easy way since it is possible to obtain a printed model of the patients' mouth simply by taking an impression with an intraoral scanner and send it to the printer. This procedure is considered to be much more comfortable for the patients and reduces several laboratory procedures.
In terms of efficiency, the digitalization of the patients' data allows the preliminary planning of the rehabilitation and allows the clinician to show the patient a simulation of the final treatment before and during the procedure.
As the dentist collects the whole patient's mouth data, he can easily plan a full mouth rehabilitation and realize a printed resin temporary bridge that can be relined directly in the mouth. 3D printing can be

Material	Type	Manufacter
FreePrint Temp	45 - <60 wt% Iso- propylidenediphenol Peg-2 Dimethacry lat, 1 - < 5 wt% 2 Hydrox- yethylmethacrylat, 1 - < 5 wt% Diphenyl(2,4,6 trimethylbenzoyl) phosphinoxid, 1 - <5 wt% Hydrox- ypropylmethacrylat, < 1 wt% Phenyl-bis(2,4,6- trimethylbenzoyl)phosphinoxid	Detax, Ettlingen, Germany
C&B MFH (Micro Filled Hybrid)	Methacrylic oligomers, Phosphine oxides	Nextdent, Soesterberg, Netherlands
Temp PRINT	Urethane Dimethacrylate (UDMA) Quartz 2,2'-ethylenedioxydiethyl dimethacrylate 2-(2H-benzotriazol-2-yl)-p-creso	GC EUROPE N .V, Leuven, Belgium
VarseoSmile Crown plus	4.4'-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid. Silanized dental glass, methyl benzoylformate, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide.	Bego, Bremen, Germany

TABLE 1 The three materials tested.

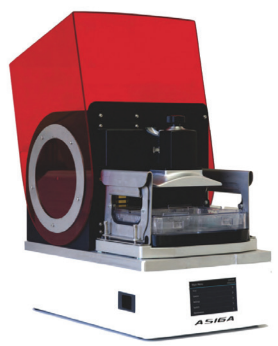


FIG. 1 DLP printer-Asiga Max UV (Asiga, NSW, Australia).

very useful in full mouth rehabilitation, where patients have to stay for a long period of time with temporary bridges on, still they have high aesthetic demands .As a matter of fact the clinician can quickly take an intraoral scan immediately after teeth preparation and provide a provisional 3D printed resin, once he/she finished the designing phase on the .stl file of the preps. These types of provisional prosthesis will be perfectly adapted to the finishing line on the abutment, polished, and customised according to the aesthetic demands, since the patient can preview the project on the computer before 3Dprinting.
Thanks to the increasing demand of 3D printing, various types of 3D printing techniques and new materials are continuously developed.
At the moment, digital light processing (DLP) is the 3D printing technique spreading faster in prosthodontics. It is a technology that uses the principle of light-curing, that is considered the most efficient method to transform liquid resins in solid polymers. DLP is a 3D printing technology used to rapidly produce photopolymer parts. It is very similar to stereolithography (SLA) with one significant difference, where SLA machines use a laser that traces a layer, a DLP machine uses a projected light source to cure the entire layer at once. The part is formed layer by layer. So in DLP, the printing phase occurs thanks to a light source that irradiate a tank containing a photopolymerisable resin based on acrylic or epoxy.
Moreover, the DLP technology, besides being fast, guarantees a great accuracy as proved in numerous studies (1-2).
Having established the accuracy of the printing technology, the research has focused on the dimensional stability of the prosthetic restorations. Data on the accuracy of scanning and printing technologies on 3D printed and digital casts are sparse (3-7). Also, it is important to assess the accuracy of complete arch scanning since greater deviations have been recorded in full arch than in single tooth scanning especially by intraoral scanners (8-12).
It is important to evaluate if there are divergences among different types of resin, since the composition of the polymer can affect the manufacturing process and dimensional stability of the restorations.
Therefore, the aim of this study is to analyse dimensional stability and accuracy of 3D-printed fixed prosthetic restorations. The two null hypothesis were:
1. that time has no effect on the stability and accuracy of the 3D-printed restorations,
2. that there were no differences among the four 3D printer resins analysed.

MATERIALS AND METHODS

A full arch gypsum reference model was scanned with Aadva lab scanner (Gc Co. Tokyo, Japan).
A complete maxillary arch restoration was designed using the CAD software Exocad (Exocad GmbH, Germany, 2010). After the designing procedure, the STL file was exported to DLP printer. Four biocompatible (II class) resins developed for temporary crown and bridges were chosen to print the prosthetic restorations.
Resins have characteristics related to: polymer

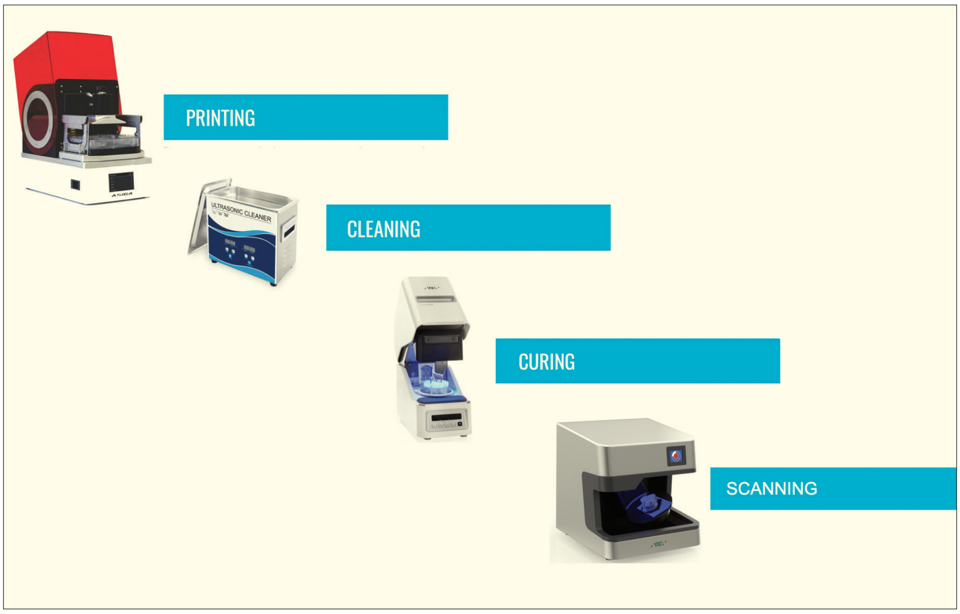


FIG. 2 Sequence of the procedure.

composition, mechanical properties (flexural strength > 90-100MPa) and wavelength of the printing process (385nm).
The compositions of the four resins are shown in the Table 1.
Eight models were printed for each resin by using the DLP printer Asiga MAX UV (Asiga, NSW, Australia) (wavelength= 385nm; pixel resolution = 62 µm) (Fig. 1).
To avoid an overload on the printing plate, the printing process (n. 8 models for each resin) was divided into two phases. In each phase 4 models (n4) were printed with the support structure positioned on the occlusal surface.
At the end of the printing process, the models were removed from the printing plate and soaked into an isopropanol solution using an ultrasonic cleaner, in order to remove any uncured resin residues.
After cleaning, a post-curing procedure was done with the LED curing unit "LaboLight DUO" (Gc Co. Tokyo , Japan)(13). Each printed restoration was exposed to the LED source for a total of 6 minutes: 3 minutes on the occlusal surface and 3 minutes on the internal surface (Fig. 2).
A total of 32 printed restorations were included in this

FIG. 3 The scans were performed at four different moments.

FIG. 4,5 3D printed restorations.

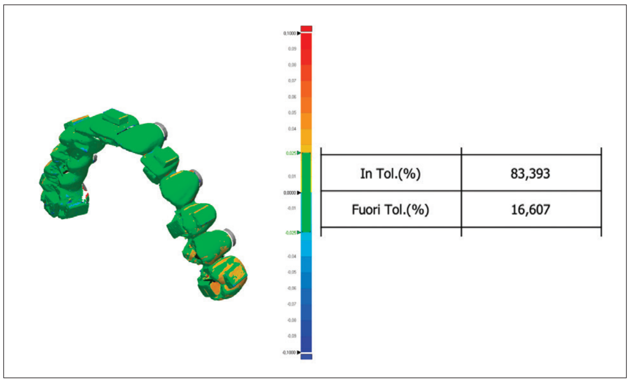


FIG. 6 An example of superimposition.

study.
The surface of the restorations was lightly dusted with powder (Occlusal Spray, Larident srl, Genoa, Italy) to reduce light reflection and then restorations were scanned using the lab scanner Aadva Lab Scanner 2 (Gc Co. Tokyo , Japan) to generate STL files (14). The scans were performed at four different time points (Fig. 3) as follows.
- Time 0: scans were done immediately after printing (T0);
- Time 1: scans were done 24 hours after the first scan(T24);
- Time 2: scans were done 48 hours after the first scan (T48).
- Time 3: scans were done 7 days after the first scan (T7days).
Eight models for each resin were scanned in four different moments (Fig. 4), for a total of 32 scans for each resin and 128 total scans (Fig. 5).
The STL files were exported to a surface matching software (Geomagic Control X; 3D systems, Rock Hill, USA) (14,15).
The scan at T0 of each model was taken as reference because the model didn't undergo any dimensional variation.
The 24h scan was superimposed to the refence model. After the superimposition, the 3D comparison function was used to create color surface maps. A maximum critical value of ± 100 µm (0,100mm) and a maximum nominal value of ± 25 µm (0,025mm) was set for color spectra.
Each superimposition allows to obtain two percentages values: correspondence and variation.
The correspondence indicates the percentage of the models that corresponds to the refence model in the tolerance range of ± 25 µm.
The variation indicates the percentage of the models that varies from the reference model in the tolerance range of ± 25 m.
Thanks to these 2 values it was possible to quantify the behavior of tested prosthetic restorations over the first day (T24h), the second day (T48h), and the seven following days (T7days) since printing.
The newly printed scan at T0 of each model (reference model) was used as a basis of comparison, present the maximum correspondence percentage of 100% and the minimum variation of 0 %, given the absence of the time variable.
The scans reflected the behavior of the resin they are made of, which is therefore closely related to their monomeric composition and was different for each of the 4 resins.
The same superimposition procedure was carried out with the scans at T48h and T7days.
In order to analyse each resin, the 2 percentages values (correspondence and variation) of each 3D printing were collected and their arithmetic mean was calculated to have one percentage for each resin in each of the 4 times.
Values in µm or dimensional errors expressed in percentages were used in the measurement for the comparison of 3D printing techniques (16)
In this study, the percentage values, obtained from the superimposition, were (Figures. 6-9):
1. In Tol. (%): the percentages of correspondence of prosthetic restorations in the tolerance range ± 25 µm.
2. Out Tol. (%): the percentages of variation of our prosthetic restorations in the tolerance range ± 25 µm.

One-way ANOVA test was used to compare different measurement errors among groups. Linear regression was performed to determine the relation among different explanatory variables, and the average measurement

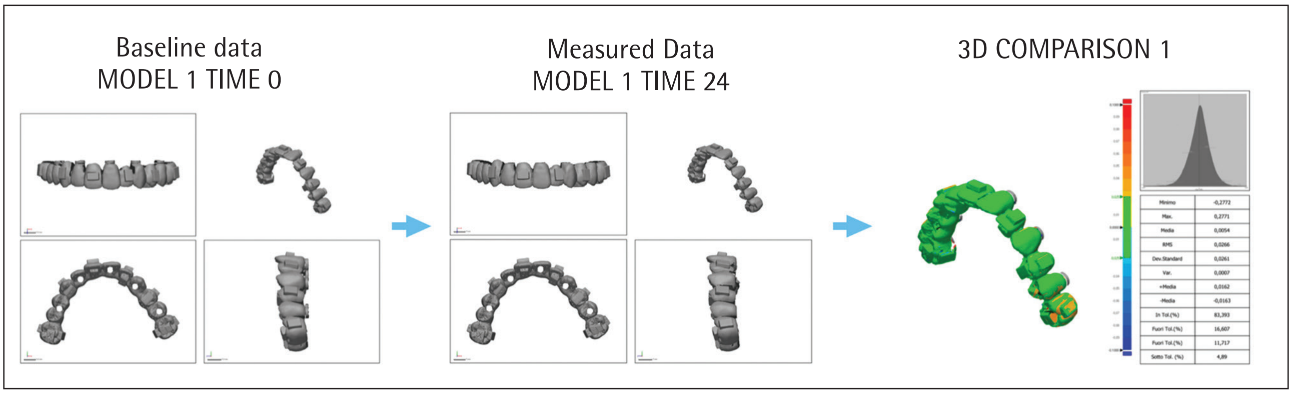


FIG. 7 The superimposition at T24 hours with the 3D comparison function.

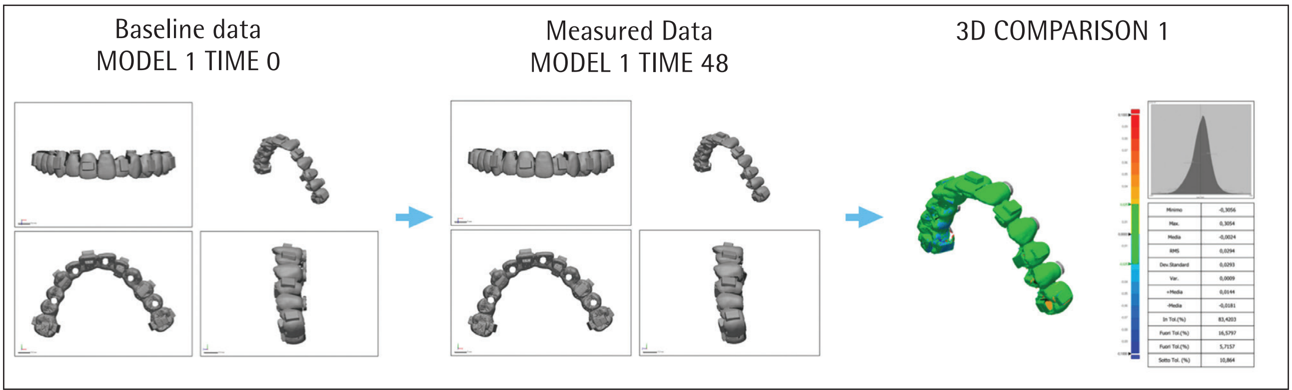


FIG. 8 The superimposition at T48 hours with the 3D comparison function.

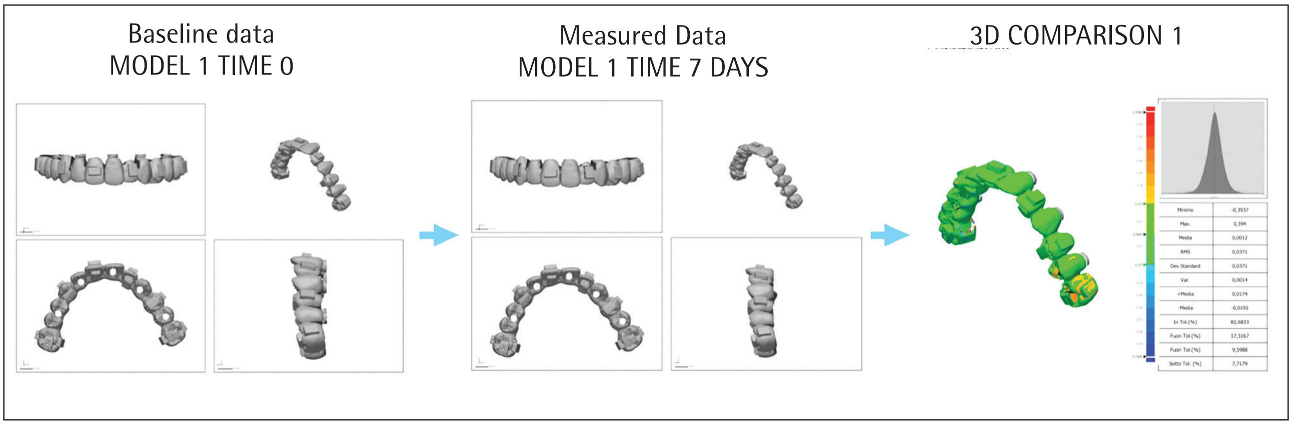


FIG. 9 The superimposition at T7 days with the 3D comparison function.

errors (dependent variable) adjusted to reference cast measurements. Regression coefficients (B) and 95% confidence intervals (CI) were calculated. Significance was set at P <0.05. Data were analyzed using SPSS for Windows Software (Microsoft, Washington, USA), version 23.0.

RESULTS

The results have been reported in the following graphs and tables to better analyse their trend.

The variation between the model scanned at T24h and the reference model (T0) of FreePrint-TEMP (Detax, Ettlingen, Germany) resin shows a variation of 19.6% and a correspondence of 79.3% over the 24 hours following printing (Table 2).

The variation on the seventh day from printing is 25.8%, with an increase of approximately 6%.

The C&B MFH (Nextdent, Soesterberg, Netherlands) (Micro Filled Hybrid) resin shows a variation of 34.5%, and a correspondence of 64.5%, over the 24 hours after

TABLE 2

FREEPRINT®

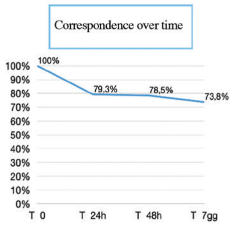
Correspondence over time

	T 0	T 24h	T 48h	T 7days
Mean n=1-6	100 %	79,3 %	78,5 %	73,8 %

Variation over time

	T 0	T 24h	T 48h	T 7days
Media n=1-6	0 %	19,6 %	20,5 %	25,8 %

FREEPRINT®



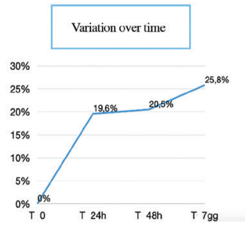


TABLE 3

C&B MFH

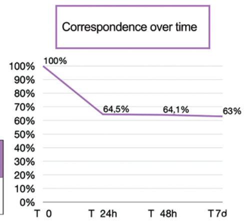
Correspondence over time

	T 0	T 24h	T 48h	T 7gg
Media n=1-6	100 %	64,5 %	64,1 %	63 %

Variation over time

	T 0	T 24h	T 48h	T 7gg
Media n=1-6	0 %	34,5 %	34,8 %	36 %

C&B MFH



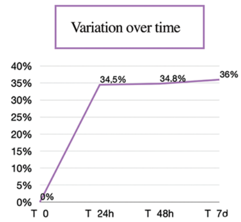


TABLE 4

Temp PRINT

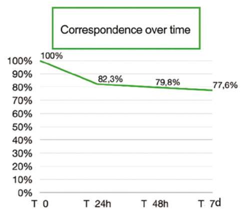
Correspondence over time

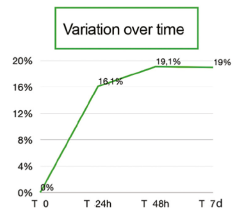
	T 0	T 24h	T 48h	T 7d
Mean n=1-6	100 %	82.3 %	79.8 %	77.6 %

Variation over time

	T 0	T 24h	T 48h	T 7d
Mean n=1-6	0 %	16.1 %	19.1 %	19 %

Temp PRINT





printing (Table 3). This means that the model scanned at T24h differs from the one scanned immediately after printing (T0), in the range of ± 25µm, for 34.5%; while it corresponds for 64.5% (Table 3).
The variation on the seventh day from printing is 36%, with an increase of approximately 1.5%.
The TempPRINT (GC EUROPE N .V, Leuven, Belgium) resin shows a variation of 16.1%, and a correspondence of 82.3%, over the 24 hours after printing (Table 4). This means that the model scanned at T24h differs from the one scanned immediately after printing (T0), in the range of ± 25µm, for 16.1%; while it corresponds for 82.3% (Table 4).
The variation on the seventh day from printing is 19%, with an increase of approximately 2.9%.
The VarseoSmile Crownplus (Bego, Bremen, Germany) resin shows a variation of 23.6%, and a correspondence of 75.3%, over the 24 hours after printing. This means that the model scanned at T24h differs from the one scanned immediately after printing (T0), in the range of ± 25µm, of 23.6%; while it corresponds for 75.3% (Table 5).
The variation on the seventh day from printing is 32.1%, with an increase of approximately 9 %.
All variations and times are represented in Table 6 and Figure 10.

The graph above highlights the percantage variation out of the tolerance range of ± 25 µm (Out Tol.) recorded 24 hours after printing and on the seventh day.
Also, the variation of the tolerance interval of ± 25µm was mostly represented in the posterior area of all prosthetic restorations.
Figure 10 reports all variation of four 3D printed resins together.
There were statistically significant differences among the four resins after 24 hours and 7 days.

DISCUSSION

The aim of this study was to analyze the dimensional stability of fixed prosthetic restorations created using DLP technology. The first null hypothesis, that the time factor has no effect on the stability of influence on the 3D printed restorations was rejected. Also, the second null hypothesis that there were no difference on dimensional stability among the four 3D printed resins was rejected.
If the time factor is irrelevant, the percentage values at T0 would be equal or very similar to the one obtained at T24h and/or at T7days.

TABLE 5

VarseoSmile Crown plus

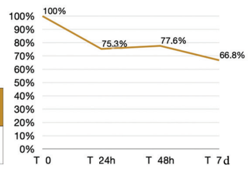
Correspondence over time

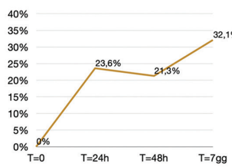
	T 0	T 24h	T 48h	T 7d
Mean n=1-6	100 %	75,3 %	77,6 %	66,8 %

Variation over time

	T 0	T 24h	T 48h	T 7d
Mean n=1-6	0 %	23,6 %	21,3 %	32,1 %

VarseoSmile Crown plus





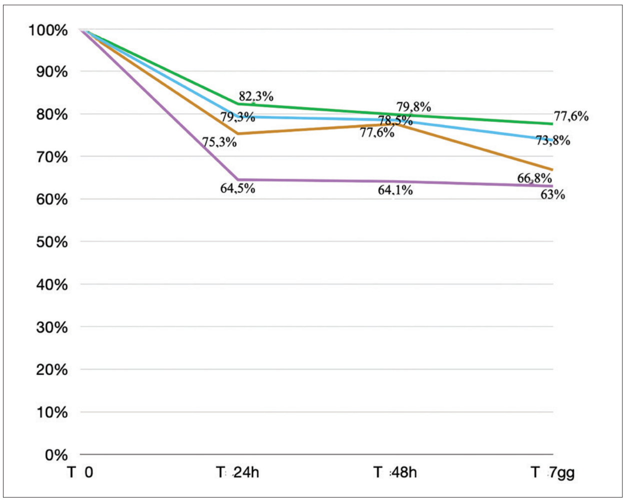


TABLE 6 Summary of variation in dimension of all four 3D printed resins related to observation times.

Considering the time variable (T24h), it was possible to observe how the correspondence value of the 4 resins has lowered from 100%, in our tolerance range, to values between 82% and 64%.

In particular, at 24h, the four materials have the % variation of 16% (TempPRINT), 19.6% (FreePrint), 23.6% (Bego-VarseoSmile), 34.6% (C&B MFH).

In continuing to analyze the dimensional stability in other times it was possible to appreciate that there were no further remarkable variations. After the deformation in the first 24 hours, all 4 resin materials remained stable until the seventh day. It was possible to observe how the four materials increased the percentage variation on the seventh day around 10% (Bego-VarseoSmile), 6% (FreePrint), 3% (TempPRINT) and 2% (C&B MFH).

This further confirms the assumption that the main variation in terms of dimensional stability occurs on the first day of printing (T24h), reaching values between 16% and 34%. At 7 days (T 7days) from printing, there is a stabilization of the prosthetic restorations, and the values have minimal increases between 2% and 10%.

Statistical analysis confirmed that they were significant differences between the four 3D printed resins at 24 hours and 7 days.

Thanks to the color map created by the software Geomagic® Control XTM, it was possible to identify the areas outside the tolerance range (Out Tol.%). It follows that the variation of the tolerance interval of ± 25μm is mostly represented in the posterior area of all prosthetic restorations.

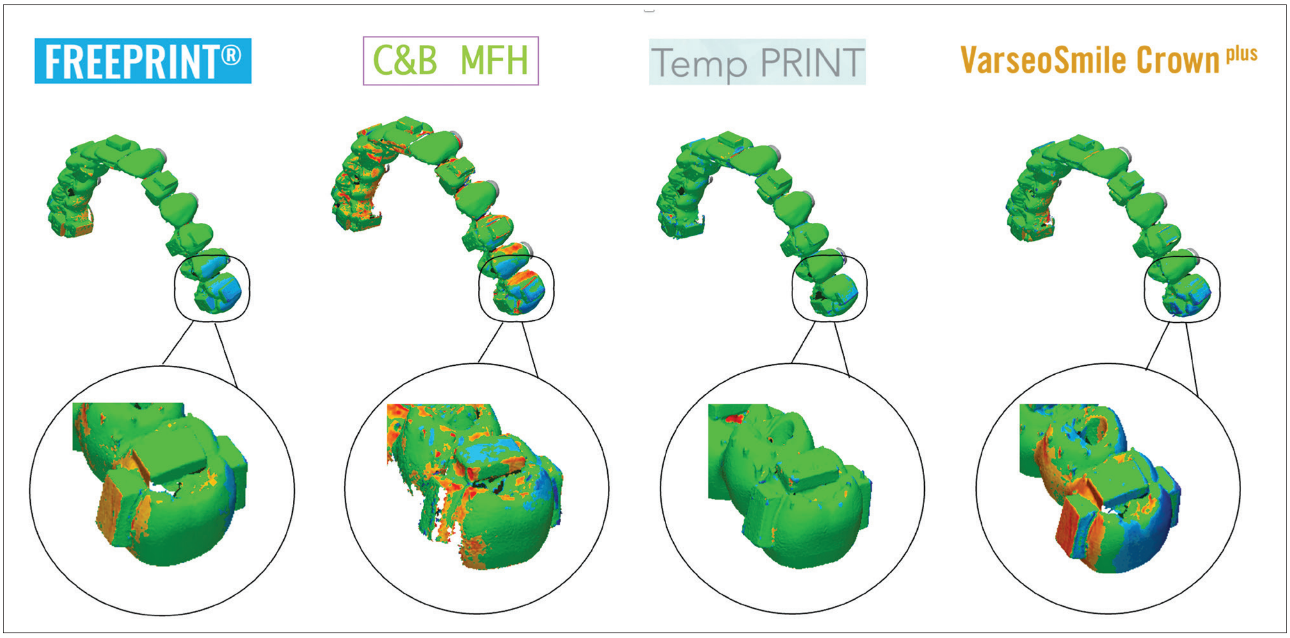


FIG. 10 Summary of variation in dimension of all four 3D printed resins at 24 hours.

This result can be explained by the presence of a higher density of polymers in the posterior region than in the anterior region (17).
Therefore, the rectangular structures added in the design phase, on the vestibular and palatal surface of the molars, increase the diameter of the posterior region and therefore the quantity of resin present in that area.
The color displayed in the 3D color map is the effect of the setting color spectra. In this study, the maximum critical value was set to be ± 100 µm (0,100mm).
According to the color map, all points in the tolerance range of ± 25 µm were marked as green. Those between ± 25 and ± 100 µm are blue if values are negative (expressing a shrinkage) and orange / red if values are positive (expressing an expansion). The prosthetic restorations have a particular chromatic variation in the posterior region. As a matter of facts, especially 24h after printing, the color map showed a contraction (blue) localized on the posterior buccal region and an expansion (orange-red) on the opposite side.
Park et al. suggested that models made with the DLP technology tend to contract, while those made with MJP and SLA expand buccolingually (18). This was partially confirmed in the present study, in fact, the 3D restorations made with DLP, showed a negative variation (contraction) buccolingually rather than a positive one.
In addition to the DLP technology, it is also important to consider the geometry of the prosthetic restorations printed (19) show how digital light processing (DLP) is much more accurate than liquid crystal display (LCD) when used for restorations of a few units. In the case of 6-unit or full-arch restorations, as in this study, the DLP print shows higher error values. By creating complex prosthetic restorations (6 units or full-arch) using the DLP printing technology it is possible to appreciate dimensional variations over time. These mostly occur over the first 24 hours and remain constant until the seventh day.
Another influential factor is the build angle of the 3D printed products which is 180° in the study. This means that the base of the model is flat on the printing platform, with the supports positioned occlusally. Osman et al. (20) reported on the effect of the build angle on dimensional accuracy of 3D printed restorations, recommending that the build angle for full coverage restorations should be 135° when used for DLP system.

CONCLUSIONS

Within the limitations of this study, the results of the present research rejected both two null hypothesis as the time factor and different resins had effect on the stability of the 3D printed resin restorations. The most relevant change of dimensional stability occurred within first 24 hours in all tested resins. The Tempt PRINT resin showed to be more stable than the other three tested resins after 24 hours and 7 days.

REFERENCES

1. 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 Feb;29(2):124-128.
2. Park M, Shin S. Three-dimensional comparative study on the accuracy and reproducibility of dental casts fabricated by 3D printers. J Prosthet Dent 2018 May;119(5):861.e1-861.e7.
3. Ender A, Mehl A. In-vitro evaluation of the accuracy of conventional and digital methods of obtaining full-arch dental impressions. Quintessence Int 2015;46:9-17. 4. Aly P, Mohsen C: Comparison of the accuracy of three-dimensional printed casts, digital, and conventional casts: an in vitro dtudy. Eur J Dent 2020;14:189-193.
5. Stansbury JW, Idacavage MJ: 3D printing with polymers: Challenges among expanding options and opportunities. Dent Mater 2016;32:54-64.
6. Yan C, Shi Y, Yang J. Multiphase Polymeric materials for rapid prototyping and tooling technologies and their applications. Compos Interfaces 2010;17:257-271.
7. Ellakany P, Alharbi F, El Tantawi M. Evaluation of the accuracy of digital and 3D- printed casts compared with conventional stone casts. J Prosthet Dent 2020:S0022- 3913:30623-5.
8. Wesemann C, Muallah J, May J. Accuracy and efficiency of full arch digitization and 3D printing: A comparison between desktop model scanners, an intraoral scanner, a CBCT model scan, and stereolithographic 3D printing. Quintessence Int 2017;48:41-50.
9. Ellakany P, Alharbi F, El Tantawi M, et al: Evaluation of the accuracy of digital and 3D- printed casts compared with conventional stone casts. J Prosthet Dent 2020:S0022- 3913:30623-5.
10. Su T shu, Sun J: Comparison of repeatability between intraoral digital scanner and extraoral digital scanner: An in-vitro study. J Prosthodont Res 2015;59:236-242. 11. Güth JF, Runkel C, Beuer F, et al: Accuracy of five intraoral scanners compared to indirect digitalization. Clin Oral Investig 2017;21:1445-1455.
12. Solaberrieta E, Arias A, Brizuela A, et al: Determining the requirements, section quantity, and dimension of the virtual occlusal record. J Prosthet Dent 2016;115:52-56.
13. M.Reymus, N.Lumkemann, B.Stawarczyk; 3D-printed material for temporary restorations: impact of print layer thickness and post-curing method on degree of conversion. Int J Comput Dent 2019;22(3):231-237.
14. Mandelli F, Gherlone E, Gastaldi G, Ferrari M. Evaluation of the accuracy of extraoral laboratory scanners with a single-tooth abutment model: A 3D analysis. J. Prosthodont Res 2017 Oct;61(4):363-370.
15. Malik J, Rodriguez J, Weisbloon M, Petridis H. Comparison of accuracy between a conventional and two digital intraoral impression techniques. Int J Prosthodont 2018;31(2):17-113.
16. Yoo SY, Kim SK, Heo SJ, Koak JY, Kim JG. Dimensional Accuracy of Dental Models for Three-Unit Prostheses Fabricated by Various 3D Printing Technologies. Materials (Basel). 2021 Mar 22;14(6):1550.
17. 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. J Prosthodont 2020;29:12.
18. Park JM, Jeon J, Koak JY, Kim SK, Heo SJ. Dimensional accuracy and surface characteristics of 3D-printed dental casts. J Prosthet Dent 2021 Sep;126(3):427-437.
19. 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 Mar 18;14(6):1487.
20. Osman RB, Alharbi N, Wismeijer D. Build angle: does it influence the accuracy of 3d-printed dental restorations using digital light-processing technology. Int J Prosthodont 2017;30:182-188.