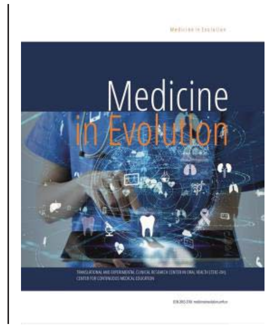
Usefulness of digital light processing based three-dimensional printing in the digital production of provisional restorations



Burde A.V.[1], Vigu A.L.[2], Sava S.[2]

[1]Department of Propaedeutics and Aesthetic Dentistry, Faculty of Dental Medicine, "Iuliu Haţieganu" University of Medicine and Pharmacy Cluj-Napoca, Romania
[2]Department of Dental Materials, Ergonomics, Faculty of Dental Medicine, "Iuliu Haţieganu" University of Medicine and Pharmacy Cluj-Napoca, Romania

Correspondence to:
Name: Vigu Alexandra Lucia
Address: Avram Iancu St, No. 31, Cluj-Napoca, Romania
Phone: +40 745 571 377
E-mail address: alexandravigu@yahoo.com

Abstract

Digital light processing (DLP) based 3D printing is an additive digital technique that allows manufacturing of a complex three-dimensional structure by projecting light on a light cured resin. After each exposure, the platform of the printer descends, with a distance equal to the thickness of a layer, and the process repeats until the final product is obtained. Our study aims to present the laboratory steps necessary for the manufacturing of temporary restorations consisting of provisional crowns by DLP based 3D printing. The temporary restorations obtained fulfilled the targeted aesthetic and functional characteristics and restored the morphological and functional integrity of the maxillary arch, until the application of the final fixed dental prostheses. In addition to ease and accuracy, significant time saving can be achieved for both the dental office and the laboratory, as well as for the patient, eliminating a number of steps by the advantages of 3D printing technology over conventional techniques.

Keywords: 3D printing, provisional restorations, additive manufacturing

INTRODUCTION

There are multiple advantages to using three-dimensional (3D) printing in the digital workflow of the dental laboratory in general and for provisional restorations in particular. This type of restorations is an essential part of the therapeutic process. Technological developments are directly proportional to the quality of treatment, which has reached high levels over time. The patient's comfort is linked to the preservation of his social life, implicitly of the functions of the dento-maxillary apparatus, by avoiding the unwanted impact of the appearance of an edentation or of a prepared tooth for a future prosthetic restoration, on the patient's psyche. Along with the emotional aspect, the provisional restoration assures the protection of the remaining dental tissues and, to the same extent, the verification of the correctness of the future final restoration. Thus, the dental protocols recommend the application of temporary restorations in case of dental procedures that will disturb the integrity and function of the dental organ [1]. If we draw a parallel with the conventional workflow, we will be able to identify a series of benefits, which will position the digital manufacturing processes ahead of the conventional procedures. Starting with the financial advantage, provided by the lower cost of materials used in three-dimensional printing, and continuing with the accuracy of the restorations created through this process. The fact that several prosthetic restorations can be produced simultaneously through 3D printing is also a significant advantage. These are some of the reasons why more and more conventional steps are eliminated and replaced by digital protocols [2].

By comparison to the substractive manufacturing technology- CAD-CAM (Computer Assisted Design - Computer Assisted Manufacturing) which is based on computer numerical control (CNC) milling, 3D printing offers the advantage of unlimited design flexibility, a single stage process necessary for prosthetic restorations of great structural complexity and ease of use, thanks to the processing of files accessed in STL (Standard Triangle Language) format. Thus, it is easy to perceive 3D printing as a preferred solution for provisional restorations, followed by CAD-CAM milling, and conventional manufacturing [3]. Recent data ranks the top additive manufacturing processes preferred by dental practitioners: Vat Photopolymerization, Fused Filament Fabrication (FFF), Photopolymer Jetting (Poly jet), Binder Jetting and Powder Bed Fusion (PBF) [4].

There are 2 technological variants of the Vat Photopolymerization process: Stereolithography (SLA) and Digital Light Processing (DLP). Derived from SLA, DLP has the same principle of use and identical components. The difference lies in the light radiation source, which in this case will be a projector or a mono or multi-chrome screen. Therefore, the light curing will be done by projecting a black and white image of each layer on the surface of the resin placed in the printer’s tank. Gradually, after each brief exposure to the projected light beam, the workbench will descend with a distance equal to the thickness of a layer and the process is resumed until the final product is obtained. The improved working speed of DLP printers, as well as the tendency to have a lower price than those based on stereolithography, determine their predominant acquisition by laboratories [5].

In 3D printing, the material of choice is light-cured resins, along with different types of plastics, metallic alloys or ceramics [6, 7]. Polymethyl methacrylate (PMMA) is characterized by increased hardness, rigidity and strength, reduced water absorption and is a scratch-resistant material. For these reasons, temporary 3D printed restorations made of PMMA are often used [8].

Aim and objectives

Our study aims to present the laboratory steps necessary for the manufacturing of temporary restorations, consisting of provisional crowns, through the use of DLP based 3D printing technology in combination with a light-cured acrylic resin, with a wavelength spectrum between 390-405 nm.

MATERIAL AND METHODS

The case described in this study concerns a patient with multiple wear lesions, mainly in the frontal area, palatal abrasions and an unsatisfactory aesthetic appearance as a whole, both in terms of colour and shape of the maxillary arch.

After the removal of periodontal irritation factors such as supra and subgingival calculus deposits and the dental treatment for restoring and filling the multiple maxillary cervical lesions was done, the treatment continued with the preparation of teeth 1.6 to 2.6. The proposed treatment for the prepared teeth was a series of full coverage crowns fixed partial manufactured out of lithium disilicate, treatment protocol which was explained to and accepted by the patient.

The moment of transition to the final fixed restorations is the subject of this study and it involves the manufacturing of the temporary restorations by DLP based 3D printing. The technique of indirect manufacturing of the provisional crowns will require the design of a digital mock-up in a CAD software, based on the scanned maxillary dental cast with removable dies, which reproduces the preparations made by the dentist.

Impressions and dental casts

The conventional impressions of the 2 arches arrived in the dental laboratory and went through the disinfection phase (Figure 1-A). Next, the models were cast using type IV gypsum. The working cast was sectioned in order to obtain the removable dies, by using the Willi Geller method. The obtained removable dies were repositioned in the maxillary impression (Figure 1-B).

In order to maintain the precise position of the abutments, a wax rod of 5 mm was applied to the end of each abutment, then the root portion of the mobile abutments was insulated and at the end the individual rods were secured by a wax rod that followed the curvature of the maxillary arch (Figure 1-C, D).

The maxillary impression was coated with a silicone impression material to obtain the base of the final cast and the model containing the dies was cast using type IV extra hard gypsum,(Figure 1-E).

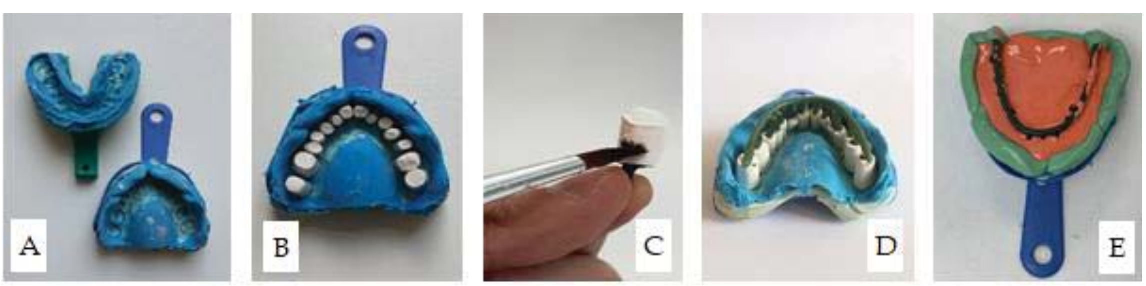


Figure 1. A– The impressions of the 2 arches; B- Removable dies positioned in the maxillary impression; C- Insulation of the root portion of the removable dies; D- Individual wax sprues secured together; E– The casting of the model with removable dies

After casting the mandibular model, the maxillary and mandibular models were finished in order to have uniform edges and bases (Figure 2-A). The articulator used was an articulator with average values, programmed with the slope of the articular tubercle of 33 degrees, the Bennett angle between 15 and 18 degrees, and the fixed intercondylar distance of 105 mm (Figure 2-B). The bite registration, made of wax foil with aluminium, was used to mount the mandibular cast.

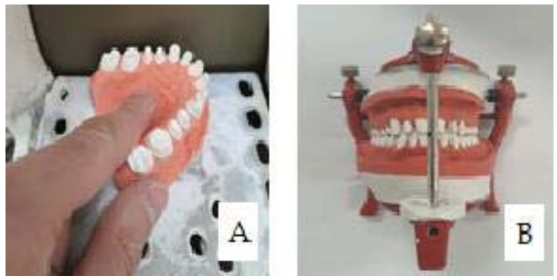


Figure 2. A- The maxillary final cast; B- Casts and articulator with average values

Scanning and design

The inEos X5 (Sirona Dental Systems Gmbh, Bensheim, Germany) scanner was used to scan the working cast, the removable dies and, the antagonist cast and the occlusion (Figure 3-A, B, C, D).

Figure 3. A- SIRONA inEos X5 Scanner; B- Working cast scanning; C- Mobile abutments scanning; D- Occlusion scanning

The Computer Assisted Design (CAD) stage followed, in which the structure of the future restorations was made, according to the requirements of the case. The inLab CAD software version 4.2 (Sirona Dental Systems Gmbh, Bensheim, Germany) was used and after loading the case, the first stage of – *Administration* - began (Figure 4-A). In this stage the restorations were defined, and the printer and the material were selected. For the design mode, - *Biogeneric individual* - was chosen and for the type of restoration – *Dental crown* – was selected. The – *Scan* - stage followed, in which the scans of the 2 arches, maxillary and mandibular, and bite registration were uploaded in the system (Figure 4-B).

Figure 4. A- Administration stage; B- Scan stage - maxillary scan

The next stage was the – *Model* - stage. Tracing the margins of the provisional restorations, for each tooth is the first step, followed by the adjustment of the insertion axis for each provisional crown (Figure 5-A, B).

Figure 5. A- Tracing the margins of the restorations; B- Setting the insertion axis for the provisional crown for 2.6.

In the -*Tools*- section, there is also the - *Buccal Bite Registration* - option, which displays the existing contact points between the maxillary and mandibular casts (Figure 6-A). These contacts can be noticed at the level of the second molars of both arches, having variable intensity. From the same section of tools, there is also the possibility to set the cast axis according to the antagonist arch position, through the - *Set Model Axis* - function (Figure 6-B).

Figure 6. A- Model stage - intermaxillary contact points; B- Cast axis selection

The actual design stage followed. At the beginning, the parameters of the restoration can be set for all the provisional restorations: the space allowed for the luting cement can be adjusted, how tight the proximal and occlusal contacts are or the minimum thickness of the restoration (Figure 7A). These parameters were adjusted as needed by the - Restoration Parameters - function.

In the next stage, the design of each provisional restoration was performed, checking both the morphology and the contacts with the neighbouring and antagonists teeth (Figure 7 B, C). For a better view of the tooth on which changes were made, the - Colour Model – option was checked. The tools that helped to create the shape of the restoration (- Shape -) were selected from the - Tools - section. These actions were performed under the - Edit Restoration - option. Immediately after this stage, each restoration was saved as a STL (Standard Triangle Language) file.

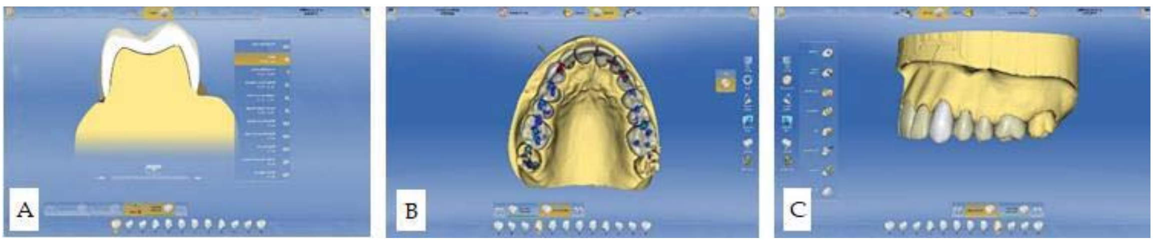


Figure 7. A– Adjustable parameters of the restoration; B- Restoration design for 1.3 - occlusal view; C- Restoration design for 1.3 - right side view

CAM file preparation

After the design stage has been completed, the CAM (Computer Aided Manufacturing) stage started and the STL files were imported into the CAM software, in order to prepare them for printing. From the CAM software interface, the Asiga Max UV 385 (Asiga, Alexandria, Australia) was selected and the chosen material was polymethyl methacrylate (PMMA) - Asiga DentaTOOTH (Asiga, Alexandria, Australia). The thickness of the layers can also be set, which in this case was 0.05 mm.

In the context of this 3D printing technology, supports must be generated for each restoration through the - *Generate Support* - function and then the parameters for the supports can be adjusted. The role of the supports is to hold up the future provisional crowns on the printer's workbench and to distribute the internal tensions resulting from the printing process.

After the settings were saved by pressing the - *Save Settings* - button, the software generated the supports, which were displayed in a purple colour and were distributed below the incisal edges and occlusal surfaces of the provisional crowns about to be printed (Figure 8 B). The shape of the supports is conical, with the base placed in contact with the platform. The initial position and number of the supports can be changed manually by adding or removing supports, as needed.

If support overlays occur, the – *Remove* - function can be used to select and delete unnecessary supports. Thus, out of 2 superimposed supports, only one will be printed. In the same way, in the areas where there are no supports, the – *Add* - function can be used, adding supports in the desired number and areas. The following stage was the generation of the printing strategy using the - *Build Wizard* - function, which will specify the printer for the process - *Destination Printer* - and will specify the estimated time, which in our case was one hour, 13 minutes and 10 seconds (Figure 8 C).

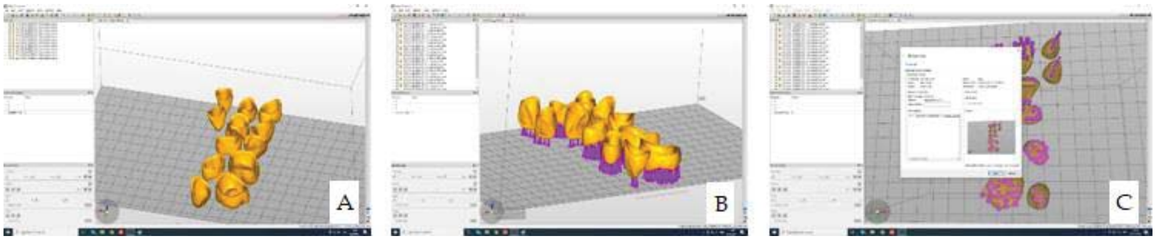


Figure 8. A- The designed provisional crowns on the digital workbench; B -Initial design of supports; C- Printing strategy selection

Also, within the printing strategy, there is the possibility to adjust some parameters, as well as to check the - *Fast Print Mode* - which registers the delamination of the layer at the end of the printing process and results in a shorter printing time. The - *Separation Detect mode* – can also be checked, in order to know when the resin can be detached from the printer's workbench.

At this stage, the design of the provisional crowns was converted to a series of black and white images, each corresponding with one layer (Figure 9 A). The portions represented in white are the target areas for light curing, and the black portions will not cure. After pressing the - *Next* – button, the summary of the printing process was displayed and the information package was sent to the 3D printer.

Printer preparation, printing and post-processing

The 3D printing was performed in this case with the Asiga Max UV 385 printer and a type of acrylic resin for provisional crowns Asiga DentaTOOTH (color A2) was used (Figure 9- B, C).

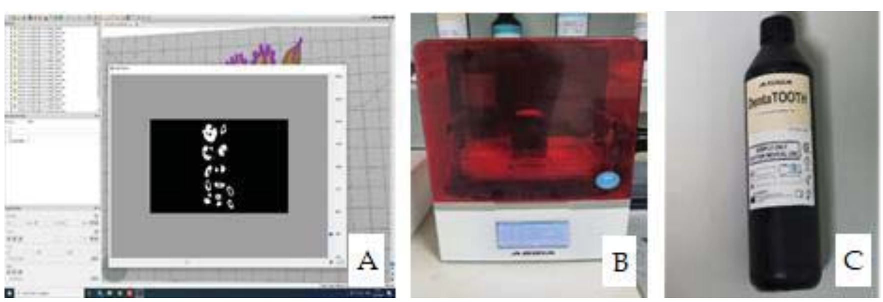


Figure 9. A- 2D image of the designed provisional crowns in black and white format; B- Asiga Max UV 385 printer; C- Acrylic resin for provisional crowns Asiga DentaTOOTH

It is recommended to wipe down the workbench of the printer with a roll of cotton with isopropylic alcohol, in order to avoid the contamination with traces of grease or other impurities (Figure 10 A). Inside the printer, the transparent borosilicate glass can be observed underneath of the vat, under which there is the ultraviolet (UV) light projector, which will perform light curing. The liquid resin tank was placed over this borosilicate glass. Before starting the printing process, it is recommended to evaluate that the resin is completely clear, with no residue adhering to the bottom of the container in which it is located. A spatula can be used for this purpose (Figure 10 B). The platform was positioned in the 3D printer, the enclosure was closed and the printing process started (Figure 10 C).

After the printing chamber was closed, the resin started the gradual heating process (Figure 10 D). Only after this phase is completed does printing actually begin. During printing, the display shows the name of the case, the temperature of the resin (30.3 degrees Celsius), the number of the layer being printed (1/294) and the remaining time until production is completed (1 hour and 15 minutes) (Figure 10 - E, F).

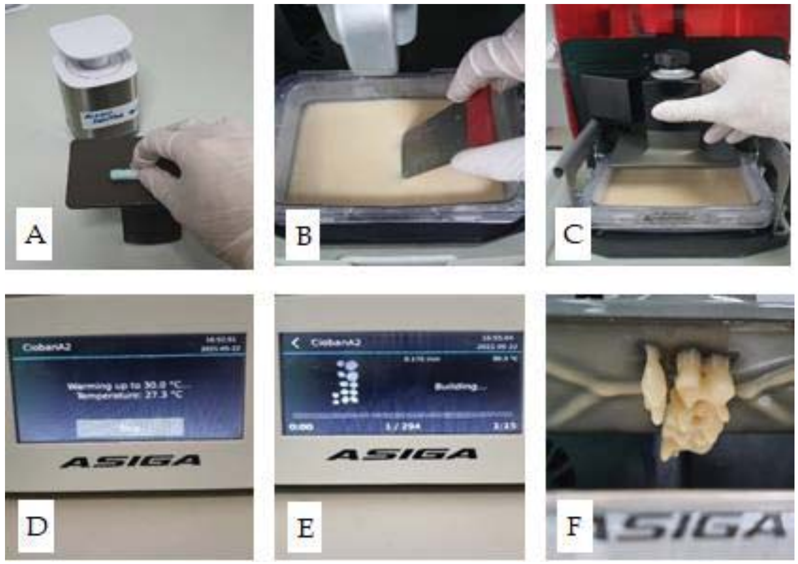


Figure 10. A - Cleaning the printer workbench with sanitary alcohol; B- Checking the purity of the resin in the liquid resin tank; C- Placing the workbench in the printer; D- The heating of the resin; E- Start of printing process; F- Printed provisional restorations attached to the workbench

At the end of the printing process, the provisional restorations were attached to the platform inside the printer, and once the platform was removed from the printer, the resin supports could be removed also and the conventional post-processing steps begun (Figure 11 A, B, C). The provisional restorations can be removed off the workbench with the help of a spatula, kept in close contact with the workbench, in order to avoid damage of the restorations.

Immediately after being removed from the platform, the printed provisional restorations were treated with isopropyl alcohol for 2 minutes (Figure 11 D). Finally, after being dried very well with compressed air, the printed provisional restorations were removed from the isopropyl alcohol and placed in the light curing chamber (Figure 11 E). The final light curing took place in an Otoflash (Bego GmbH, Bremen, Germany) post curing light pulsing unit, under nitrogen protection (N2) and at 2000 pulses (Figure 11 F).

The last stage was the fit adjustment and finishing of the printed provisional restorations obtained. They crowns were placed on the removable dies, and their shape and contacts with neighbouring and antagonist teeth and restorations were checked (Figure 11 F). The needed adjustments were performed with the help of small diamond dental burs, after which other finishes were made with various diamond discs, brushes and polishing paste.

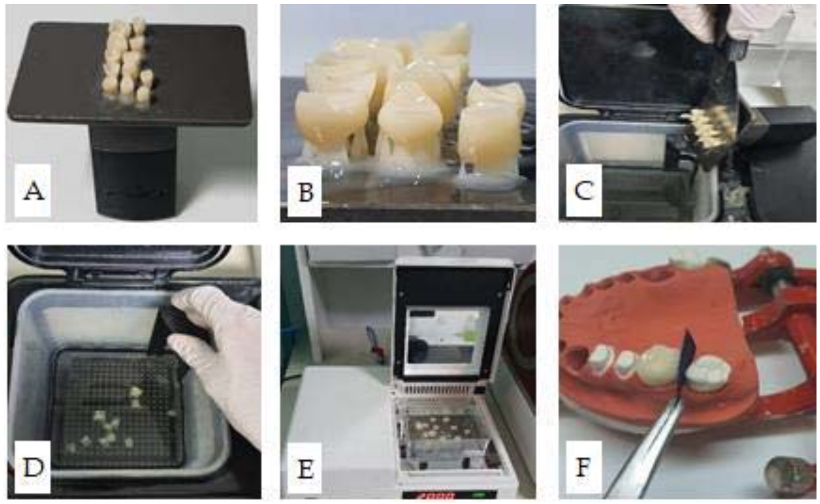


Figure 11. A - Printed provisional crowns attached to the platform; B- Detailed view of the printed provisional crowns; C- Removing the provisional crowns from the platform; D- Rinsing in isopropyl alcohol; E- Final light curing; F- Verification of the proximal contacts

At the end, the marginal fit of the provisional crowns on the abutments, the occlusion and the colour were checked for the printed provisional crowns and, also, the way in which the printed provisional crowns restored the morphology and functional integrity of the maxillary dental arch until the application of the final prosthetic restoration (Figure 12. A-D).

After handing over the case to the dental office, the patient's feedback was positive. It should also be noted that the printed provisional crowns did not need other adjustments in terms of contacts and shape, ensuring satisfactory comfort for the patient.

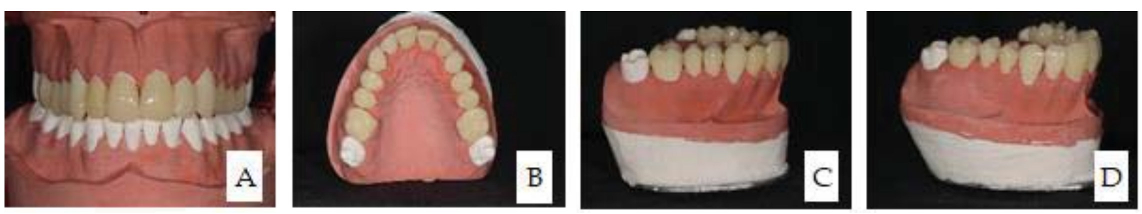


Figure 12. A - Frontal occlusion; B- Provisional crowns - occlusal view; C- Provisional crowns - left side view; D- Provisional crowns - right side view

DISCUSSIONS

Conventional processes for obtaining provisional crowns are expensive, both in terms of production (materials) and time (steps). 3D printing has made a significant contribution in this area, greatly simplifying the production process of provisional crowns [9]. It should be noted that 3D printing still has a number of limitations, such as the need to use support structures during the printing process and post-processing operations. There is a need to eliminate the additional support structures mentioned above, the excess material or to increase the mechanical strength of the structures generated by additive manufacturing. The rapid advancement of 3D printing technology will eliminate these considerations over time, by improving printer resolution and powder size [10]. Temporary restorations made with DLP and SLA technologies provide adequate flexural strength. 3D printed provisional crowns have improved than the conventional ones [11]. The continuous evolution of the printing parameters (thickness, mechanical strength, colour, accuracy, resolution, adaptability, materials) makes 3D printing the best option for manufacturing provisional crowns [12].

CONCLUSIONS

The DLP based 3D printing technology used in this study for the production of provisional fixed restorations demonstrated a predictable and simplistic digital workflow. In addition to this, we achieved a significant time reduction, both for the dental office and laboratory, by comparison with the traditional workflow, eliminating a number of technical steps through the advancements of 3D printing. The temporary restorations obtained with the technical 3D printing protocol described in this study, met the intended aesthetic and functional characteristics and were well integrated by the patient.

Acknowledgments

All 3 authors have the same contribution in this study.

REFERENCES

1. Bhargav A, Sanjairaj V, Rosa V, Feng LW, Fuh Yh J. Applications of additive manufacturing in dentistry: A review. J Biomed Mater Res B Appl Biomater. 2018 Jul;106(5):2058-2064.
2. Tahayeri A, Morgan M, Fugolin AP, Bompolaki D, Athirasala A, Pfeifer CS, Ferracane JL, Bertassoni LE. 3D printed versus conventionally cured provisional crown and bridge dental materials. Dent Mater. 2018 Feb;34(2):192-200.
3. Jaroslow B, Lambertson C, Frye C, Weatherby S. A dental technician's guide to 3D printing. Dental Technology Solutions, WhipMix, 2017, 50-62.
4. Hisham HH, Shafiee SA, Patel AA, Bhavik A.3D printable conductive materials for the fabrication of electrochemical sensors: A mini review. Electrochemistry Communications. 2018;96(1): 27–371.
5. Wu D, Zhao Z, Zhang Q, Qi HJ, Fang D. Mechanics of shape distortion of DLP 3D printed structures during UV post-curing. Soft Matter. 2019 ;15(30):6151-6159.
6. Sing SL, Yeong, WY. Laser powder bed fusion for metal additive manufacturing: perspectives on recent developments. Virtual and Physical Prototyping.2020: 15(3); 359–370.
7. Methani MM, Revilla-León M, Zandinejad A. The potential of additive manufacturing technologies and their processing parameters for the fabrication of all-ceramic crowns: A review. J Esthet Restor Dent. 2020 Mar;32(2):182-192.
8. Jockusch J, Özcan M. Additive manufacturing of dental polymers: An overview on processes, materials and applications. Dent Mater J. 2020 Jun 5;39(3):345-354.
9. Barazanchi A, Li KC, Al-Amleh B, Lyons K, Waddell JN. Additive Technology: Update on Current Materials and Applications in Dentistry. J Prosthodont. 2017 Feb;26(2):156-163.
10. Kessler A, Hickel R, Reymus M. 3D Printing in Dentistry-State of the Art. Oper Dent. 2020;45(1):30-40.
11. Park SM, Park JM, Kim SK, Heo SJ, Koak JY. Flexural Strength of 3D-Printing Resin Materials for Provisional Fixed Dental Prostheses. Materials (Basel). 2020;13(18):3970.
12. Tahayeri A, Morgan M, Fugolin AP, Bompolaki D, Athirasala A, Pfeifer CS, Ferracane JL, Bertassoni LE. 3D printed versus conventionally cured provisional crown and bridge dental materials. Dent Mater. 2018 Feb;34(2):192-200.