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CLINICAL ARTICLE

Laboratory workflow to obtain long-term injected resin composite interim restorations from an additive manufactured esthetic diagnostic template

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Abstract

Objective: An analogue and digital workflow for the fabrication of a diagnostic 3D printed polymer template and its duplication for long-term injected composite resin interim restorations is described, because of the lack of scientific evidence in 3-dimensional (3D) printing applied to dentistry in terms of printer technology, printer parameters, postpolymerization processes, and material characteristics. In addition, in the case of 3D printed temporary resins, they cannot be relined successfully and its mechanical properties in the mouth have not been tested yet.

Conclusions: The main benefits of this approach relate to the improvement of clinical and laboratory procedures, as conventional waxing is eliminated, conventional master casts are not needed and the process is entirely automatized, improving the workflow, with minimal intervention of the laboratory technician.

Clinical Significance: The additive manufactured diagnostic template represents the materialization of the digital diagnostic waxing and provides a powerful tool to visualize the digital diagnostic waxing in the patient's mouth and face. Furthermore, the diagnostic 3D printed template can be used for multiple applications including interim restorations, radiographical, or surgical guide fabrication. The duplication technique described provides a predictable workflow to obtain long-term injected resin composite restorations from an additive manufactured esthetic diagnostic template, improving the laboratory and chairside procedures.

KEYWORDS

3D printing, additive manufacturing technologies, CAD-CAM, esthetic dentistry, fixed prosthodontics, interim restorations

1 | INTRODUCTION

The development of the digital workflow in prosthodontics has allowed an improvement in diagnosis, treatment planning, and clinical procedures,[1] with the incorporation of dental specific softwares and digital tools resulting in more efficient procedures.[2] For the success of a prosthodontic rehabilitation, adequate treatment planning is a key element where the diagnostic waxing represents the initial treatment goals from an esthetic and function considerations.[3,4] The integration of the digital workflow in the diagnostic phase provides more efficient tools compared to conventional diagnostic waxing procedures such as ease of completion exact thickness measurements of materials, simplicity in mirroring, or duplicating the diagnostic waxing on the contralateral teeth[5] or used of preformed tooth shapes.[6]

Confirming the diagnostic waxing in the patient's mouth is an important step in verifying tooth visibility at rest, the relationship between the facial and dental maxillary midline, smile line and lip line, occlusal plane, and position.[7,8] Furthermore, the interim restoration represents the materialization of the diagnostic waxing through the enhancement of esthetics, stabilization and/or function for a limited period of time, after which it is to be replaced by a definitive dental prostheses.[9–12] In a complete arch rehabilitation, long-term interim restorations are recommended[13] and they must fulfill biological, mechanical, and esthetic requirements until definitive restorations can be placed.[14–16] To achieve these targets, special care must be taken when fabricating teeth-supported interim fixed dental prostheses (FDPs) as they should be as precise as the definitive restorations.[10–12] The degree of accuracy of interim restorations depends on the fabrication method and materials used.[14] Direct techniques are rapid and straightforward, but they have disadvantages, such as exothermic heat phase, the presence of residual monomers, and intraoral resin shrinkage,[6] which causes dimensional discrepancies in the marginal, occlusal, and interproximal regions. With indirect methods, the abovementioned disadvantages are avoided, as thermal and chemical risks are eliminated because the polymerization process could take place on a stone cast.[17]

In the early 1980s, computer-aided design/computer-assisted manufacturing (CAD/CAM) technologies were introduced in dentistry.[18–20] The CAD/CAM workflow involves 3 fundamental steps: (1) data acquisition, (2) data processing, and (3) the manufacturing process.[20–22]

CAM fabrication of interim restorations is possible through substractive manufacturing (SM) or additive manufacturing (AM) technologies. AM technologies, also known as 3D printing, is defined as a process of joining material to make objects, from 3D model data, usually layer upon layer as opposed of SM methodologies.[23,24] The accuracy of SM technologies depends on the machining tools and material properties,[20,25] whereas AM technologies allow the manufacture of complex designs, spending less time and less material. This method is, therefore, more economical.[25] For the reasons mentioned, AM technologies have the potential to substitute for the substractive ones in the future.

The American Society for Testing and Materials International Committee F42 has defined 7 categories in AM technologies: stereolitography (SLA), material jetting, material extrusion, binder jetting, powder bed fusion, sheet lamination, and direct energy deposition.[26] Among these categories, SLA technology is one of the most used for 3D printing polymers in dentistry,[25,27] such as occlusal splints, surgical guides, or diagnostic casts.

SLA technology is a resin-based AM technology that turns a polymer into a solid object through the repeated solidification of the liquid resin using an UV laser. The laser polymerizes a cross-section of the object to build up the first layer, after that, the process is repeated until the object is completely fabricated.[28–30] Resolution, precision, and accuracy[31,32] of AM technologies and 3D printers depends on multiple factors such as data processing,[33] CAD design, building orientation,[34,35] layer thickness,[36] postprocessing procedures, and material properties.

The present article describes a technique that combines analogue and digital procedures for the fabrication of a 3D printed diagnostic template, which was used to fabricate long-term injected composite resin interim restorations, improving the laboratory, and chairside procedures.

2 | TECHNIQUE

A 60-year-old man was referred to private practice for prosthodontic treatment. The chief complain of the patient was to improve the esthetics and establish a healthy oral condition. An interdisciplinary extraoral and intraoral evaluation with a radiographical analysis was completed in order to assess a complete diagnosis and to provide different treatment options to the patient. From an esthetic standpoint, the interpupilary line was parallel to the horizon and there was parallelism with the comisural line. Moreover, the patient presented 0 mm of maxillary anterior teeth display at rest, facial midline was not coincident with maxillary dental midline, medium lip line and flat smile line. Also, the patient presented a maxillary and mandibular metal-ceramic FDPs. The FDPs presented with clinically unacceptable marginal integrity and color discoloration associated with plaque accumulation (Figure 1A-C). The initial diagnostic step was to remove the restorations and evaluate remaining tooth structure. A digital diagnostic waxing was required to plan modification of the tooth visibility at rest, the

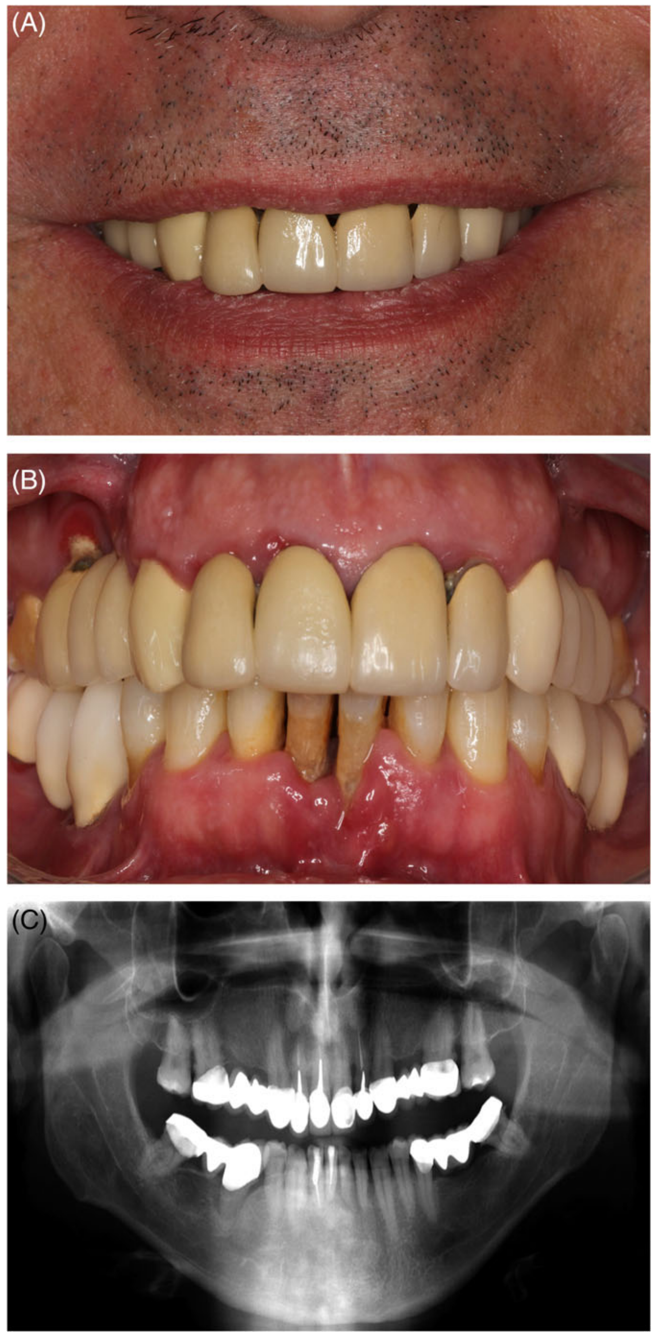

FIGURE 1 (A) Initial lower third patient's smile view. (B) Maxillary and mandibular frontal view. (C) Initial ortopantomography evaluation

dental maxillary midline, correct the occlusal plane discrepancies and correct the mesio-distal width of the teeth. A digital diagnostic waxing was performed and used to manufacture a 3D printed diagnostic template to verify the changes on the patient. After this step was completed, interim restoration was delivered to clinically evaluate the esthetics, function, and acceptability of the restorations.

The following technique describes the workflow to manufacture the 3D printed diagnostic template using a SLA-AM technology that was duplicated with an injected composite resin material to fabricate the long-term interim restorations.

Clinical phase 1

1. Make a conventional impression using heavy-body and light-body polyvinyl-siloxane impression materials (Hydrorise, Zhermack, SpA, Italy) placed into an impression tray to obtain the master cast. Allow it to polymerize for 3 minutes and 30 seconds, which is the time recommended by the manufacturer. For a digital approach, an intraoral digital impression with an intraoral scanning device (Trios, 3Shape, Denmark) can be performed to prepared teeth, following the recommended scanning strategy of the manufacturer.

Laboratory phase 1

2. Digitalize the master impression with an optical laboratory scanner (D2000, 3Shape, Denmark) to obtain the digital master cast, following the manufacturer's instructions (Figure 2A), if a conventional impression was taken.
3. Perform the digital template or digital diagnostic waxing: import the stereolithography (STL) file obtained from the previous step into a specific CAD dental software (Dental System, 3Shape, Denmark). Use the tools of the software to design the restorations (Figure 2B).
4. Import the STL file into a specific printing software (PreForm 2.14.0, FormLabs, Germany; Figure 2C) to manufacture the diagnostic template using a 3D printer. Determine the layer thickness (25 μm) and building orientation (135°). Fabricate the polymer (Nexdent C&B A2, Vertex Dental, Netherlands; Table 1) template using a 3D printer (Form2, Resolution XY: 150 μm and Z:25 μm, Formlabs, Germany) following the manufacturer's instructions. Once printed, immerse the object into an isopropyl bath for no more than 4 minutes and complete the polymerization using an UV cure machine (405 nm, 60 minutes, 36 W; Eurolight, Mestra, Spain) and remove the supporting structures.

Clinical phase 2

5. Try-in the diagnostic template in the patient's mouth: remove the provisional restorations and try-in the 3D printed diagnostic template obtained on step 3 (Figure 3A-C). Check the marginal fit combining an examination probe with a tip of 60 μm and make periapical X-rays to confirm adaptation. Check occlusal contacts with 40 μm articulating paper (Occlusionspapier, Bausch, Germany). Adjust occlusion, if needed, and rescan the diagnostic template with a IOS device (Trios, 3Shape, Denmark).

Laboratory phase 2

6. Manufacture a second diagnostic polymer (Black resin, FormLabs, Germany) template following the instructions of step 3 (Figure 4A,B).

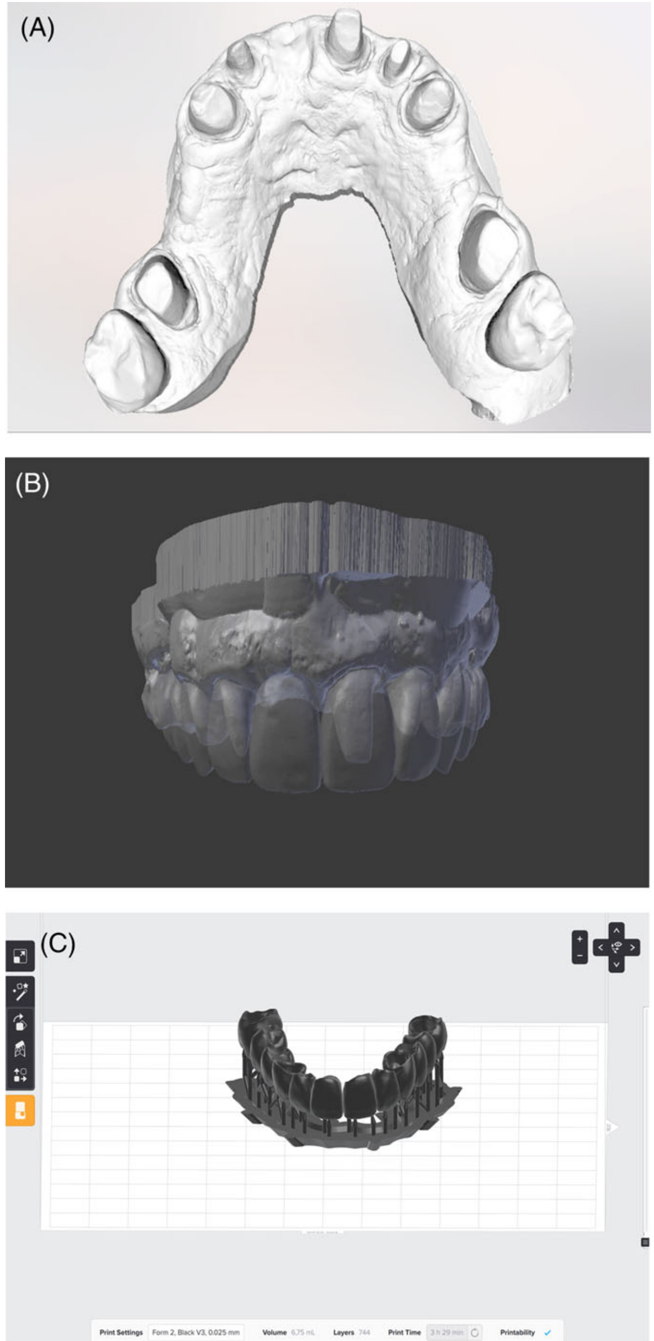

FIGURE 2 (A) Digital maxillary definitive cast obtained using a dental laboratory scanner (D2000, 3Shape). (B) Digital diagnostic template of the maxillary teeth. (C) Diagnostic template on the specific printing CAM software (PreForm, FormLabs)

TABLE 1 Nexdent Crown & Bridge (C&B) specifications[a]

Property	Model
Color	A2
Flexural strength	≥85 MPa
Flexural modulus	≥2100 MPa
Water sorption	≤30 μg/mm^3
Water solubility	≤5 μg/mm^3
Hardness shore *D*	80-90

[a] Manufacture's information.

FIGURE 3 (A) Smile view of the diagnostic template try in. (B) Frontal view of the maxillary anterior teeth. (C) Occlusal view of the diagnostic template on the patient's mouth

7. Manufacture the long-term injected composite resin interim restorations:

First, mix equal parts A and B of high viscosity impression material (Matrix Form 60 A + B, Anaxdent, Germany; hardness shore: 60; ratio A:B = 1:1; color: yellow) and place the mixture in the platform of the flask (AnaxForm Clear Flask, Anaxdent, Germany) and immediately inject the low viscosity impression material (Matrix Flow 70, Anaxdent, Germany; hardness shore: 70; color: pink) on the inner surfaces of the 3D printed diagnostic template and wait for the recommended polymerization time.

Second, place the 2 mm sprues (Bredent, Germany) on the palatal cusps of the diagnostic template and fix them with conventional wax (Miltex, Germany; Figure 5A).

Third, assemble and fix the upper part of the flask (AnaxForm Clear Flask, Anaxdent, Germany; Figure 5B). Mix a low viscosity clear duplication silicone (Matrix Cast Clear A + B; Anaxdent, Germany; hardness shore: 21; ratio A:B = 1:1; color: transparent) following the manufacturers' instructions and dispense it on top of the 3D printed diagnostic template previously assembled in the flask. Wait for recommended polymerization time.

Last, disassemble the flask and remove the 3D printed diagnostic template (Figure 5C). Once again, assemble the upper part of the flask (AnaxForm Clear Flask, Anaxdent, Germany) and inject the flowable composite resin material (Anaxblend Flow; Anaxdent, Germany; Table 2) through the sprues (Bredent, Germany). Afterwards, complete the polymerization of the composite resin with a UV lamp (Light Unit 1, Anaxdent, Germany). (Figure 6A) Finish the interim composite resin restorations obtained with tungsten carbide burs (Horico, Germany) and polishing cups (Eve, Germany; Table 3) to obtain a high-quality texture and brightness (Figure 6B,C).

Clinical phase 2

8. Deliver the interim restorations: verify the marginal adaptation of the interim restorations in the patient's mouth, combining an examination probe with a tip of 60 μm and periapical X-rays to confirm adaptation. Check occlusal contacts with 40 μm articulating paper (Occlusionspapier, Bausch; Germany). Adjust occlusion

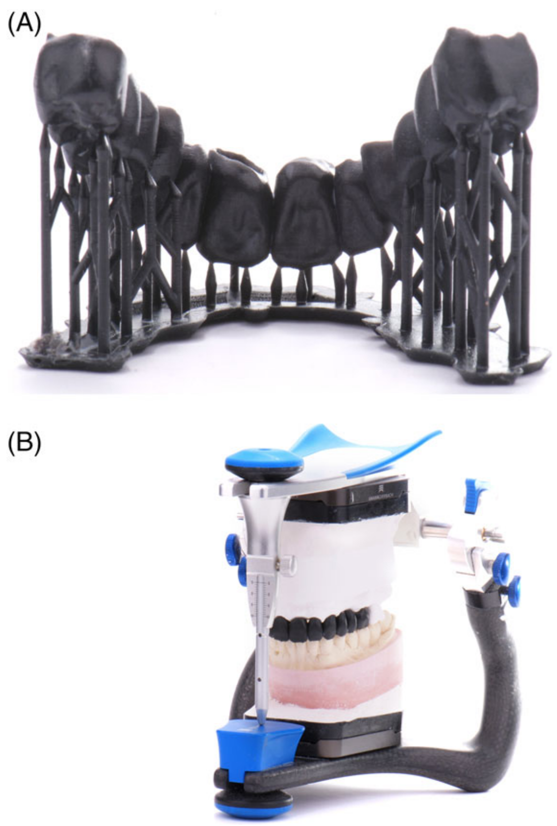

FIGURE 4 (A) Diagnostic template AM using a SLA technology (form 2, Formlabs). (B) 3D diagnostic template after the completion of the postprocessing procedures on the definitive cast mounted in the articulator (Artex CR, AmannGirrbach)

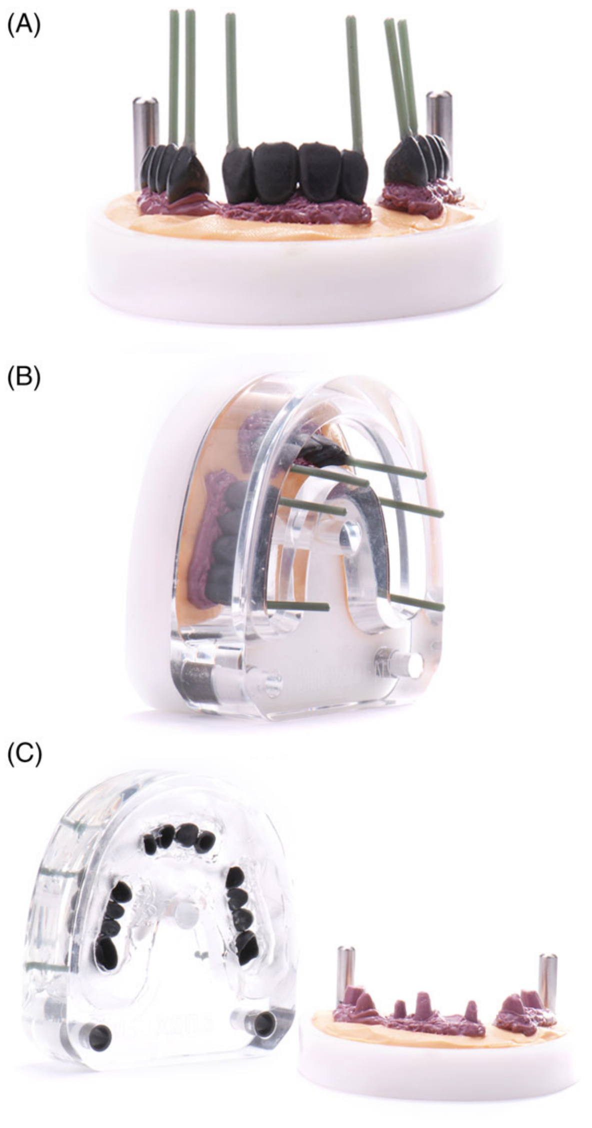

FIGURE 5 (A) Platform of the flask (AnaxForm clear flask, Anaxdent) with the diagnostic template sprued. (B) Upper part of the flask assemble. (C) 3D-printed restorations duplicated with clear silicone

if needed. Deliver the long-term composite resin interim restorations using a provisional cement (TempBond, Kerr; Figure 7A,B) and check again the occlusal contacts.

3 | DISCUSSION

The presented technique describes a combination of analogue and digital procedures from the digitalization of the prepared complete maxillary teeth of the patient to deliver the maxillary interim

TABLE 2 Anaxdent Anaxblend flow specifications[a]

Property	Model
Compressive strength	360 MPa
Bending strength	140 MPa
Modulus of elasticity	6530 MPa
Water sorption	21.1 μg/mm^3
Water solubility	2.8 μg/mm^3
Hardness	365 MPa

[a] Manufacturer's information.

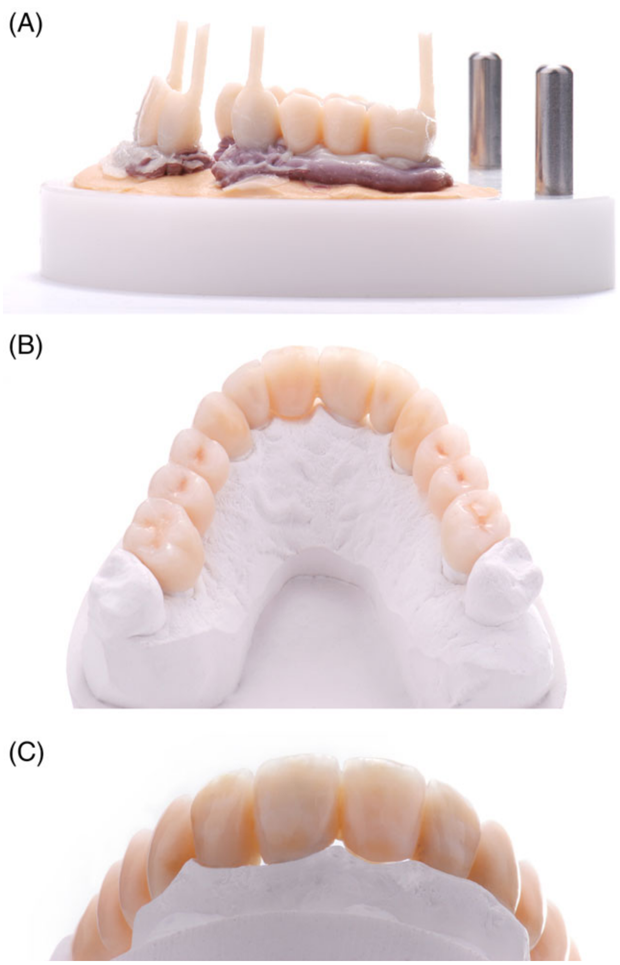

FIGURE 6 (A) Long-term injected composite resin provisional restoration after disassembling of the upper part of the flask (AnaxForm clear flask, Anaxdent). (B) Maxillary occlusal view and, (C) maxillary frontal view of the finished and polished provisional restorations

restorations. There are 2 fundamental digital procedures incorporated on the explained method: the digital diagnostic waxing and the 3D printed diagnostic template.

The available dental CAD software for the design of the digital waxing allows the complete elimination of the conventional waxing procedures. The materialization of the diagnostic waxing coming from a CAD software could be achieved through the manufacturing of the 3D printed diagnostic waxing cast. However, in the presented technique the connection element with the digital CAD waxing is the 3D printed diagnostic template that fits on the prepared teeth.

Certainly, the diagnostic template could have been also manufactured using SM technologies and used as long-term interim restoration. Mai et al.[37] found that 3D printed restorations were more accurate compared with restorations fabricated through milling procedures, because of its limiting factors as bur size, milling bur tolerance and motion range of the cutting device. Conversely, AM technologies allow the fabrication of complex designs[22,23] using less time and less material and, therefore, represent a more economical manufacturing process compared with the milling procedures.[27–29]

A major concern of the dental application of the AM technologies is the lack of data about the clinical outcome of the 3D printed interim

TABLE 3 Material selection

Material	Brand	Reference
Carbide bur #1	Horico, Germany	H98120; model 199; size 012
Carbide bur #2	Horico, Germany	H98114; model 166; size 014C
Polyshing cups #1	Eve, Germany	H14394
Polyshing cups #2	Eve, Germany	H14460

restorations. The available dental materials approved for dental applications are classified as a Class IIa medical device. In 3D printing there are multiple variables that can vary from printer to printer affecting the final quality of the 3D printed parts. From those, it seems to be clear that building orientation is an important factor in 3D printing, as reported by several authors. Alharbi et al.[34] reported that materials printed vertically (90°) had higher compressive strength that the ones printed horizontally (0°). Osman et al.[35] showed that using direct light processing technologies, the recommended build angle for 3D printed restorations was 135°, which may require the use of supportive structures.[21] Tahayeri et al.[38] also showed the importance of printing orientation, but they included resin color setting as an important factor for printing accuracy. These findings suggest that building orientation is not the unique factor related to accuracy in 3D printing. Other factors such as printer technology, light intensity, light wavelength, layer thickness and optimal postpolymerization processes, related to interim restorations, are not well studied yet. Also, once manufactured, 3D printed parts present a characteristic surface texture,[22,23] which is not

FIGURE 7 (A) Smile view of the interim long-term composite resin restorations delivered. (B) Maxillary anterior provisional restorations delivered

recommended for health tissues maintenance. In addition, in vivo mechanical properties in the long-term of the 3D printed temporary resins have not been tested yet. Furthermore, 3D printed temporary resins are not easily relined, resulting in a complicated reparation if needed. Last but not least, the esthetic outcome of these resins are poor due they are monochromatic and usually do not satisfy the requirements of those patients who demands high esthetic results. Because of the lack of data regarding 3D printed provisional materials and the reasons previously mentioned for milling procedures, combining AM technologies with an analogue duplication technique with an injected resin composite, provides an alternative approach in full-coverage crown cases for the fabrication of long-term interim restorations. This technique provides some advantages. Over direct methods, it could eliminate most clinical and laboratory procedures, such as: (1) conventional waxing procedures, (2) exothermic heat phase of the material, (3) residual monomers, and (4) trimming and polishing the finish line. Over indirect methods, this technique could be done without the necessity to have a stone master cast, as the prepared teeth can be obtained injecting a light-body polyvinyl-siloxane impression material into the template to reproduce them. In addition, compared with milling procedures, the template from which the restorations are obtained is more accurate than the milled one. This approach allows the clinician and laboratory technician inject resin composite material to obtain interim restorations, which can be functionalize prior to the fabrication of the definitive ones. In the case presented in this article to illustrate this technique, the interim restoration were functionalize about 3 months, which is the time recommended by the authors. Then, functionalize interim restorations can be scanned to copy esthetic and functional parameters for the definitive restorations. For that, this technique may improve laboratory and chairside procedures, fulfilling biological, mechanical, and esthetic requirements, as well as obtaining greater patient comfort.

The 3D printed diagnostic template can be used, as described, to fabricate the long-term interim restorations following analogue procedures. Furthermore, the diagnostic template may be useful when preparing a radiographical guide, surgical guide or a new interim restoration if needed.

4 | SUMMARY

This article describes an analogue and digital workflow from the CAD design of a digital template for the analogue fabrication of long-term interim injected composite resin restorations. A specific dental CAD software and SLA-AM printer was employed to fabricate the diagnostic template, which was used as a reference to prepare injected composite resin interim restorations. The main benefits of this approach relate to the improvement of clinical and laboratory procedures, as conventional waxing is eliminated, conventional master casts are not needed and the process is entirely automatized, improving the workflow.

DISCLOSURE

The authors do not have any financial interest in the companies or products used in this study.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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