prosthesis

Article

3D Printing beyond Dentistry during COVID 19 Epidemic: A Technical Note for Producing Connectors to Breathing Devices

Leonardo Cavallo [1], Antonia Marcianò [2], Marco Cicciù [3,*] and Giacomo Oteri [3]

[1] Master Dental Technician, Private Practice, 98050 Terme Vigliatore(ME), Italy; cavaleo72@gmail.com
[2] Department of Clinical and Experimental Medicine, University of Messina, 98100 Messina, Italy; antmarciano@unime.it
[3] Department of Biomedical and Dental Sciences and Morphofunctional Imaging, University of Messina, 98100 Messina, Italy; giacomo.oteri@unime.it
* Correspondence: acromarco@yahoo.it or mcicciu@unime.it

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Abstract: **(1)** Background: To mitigate the shortage of respiratory devices during the Covid-19 epidemic, dental professional volunteers can contribute to create printed plastic valves, adapting the dental digital workflow and converting snorkeling masks in emergency CPAP (continuous positive airways pressure) devices. The objective of this report was to provide the specific settings to optimize printing with the 3D printers of the dental industry. **(2)** Methods: In order to provide comprehensive technical notes to volunteer dental professionals interested in printing Charlotte and Dave connectors to breathing devices, the entire digital workflow is reported. **(3)** Results: The present paper introduces an alternative use of the dental Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) machinery, and reports on the fabrication of a 3D printed connection prototypes suitable for connection to face masks, thereby demonstrating the feasibility of this application. **(4)** Conclusions: This call for action was addressed to dentists and dental laboratories who are willing to making available their experience, facilities and machinery for the benefit of patients, even way beyond dentistry.

Keywords: Covid-19; CAD/CAM; 3D printing; dental prostheses; resin printed device

1. Introduction

The pandemic outbreak of a severe acute respiratory syndrome (SARS) associated with the novel coronavirus (2019-nCoV) poses a serious public health risk due to the high number of patients demand for ICU admission and mechanical ventilation [1,2].

To date (28 March 2020) in Italy 26,676 patients are hospitalized without mechanical ventilation, and 39,533 are advised to recover at home without continuous medical care, although in many of these cases, a support for spontaneous ventilation is needed [3].

CPAP (continuous positive airways pressure) allows the insufflation of air and oxygen at positive pressure in a continuous and non-invasive way for the duration of the respiratory cycle. The CPAP can be delivered through a mask (facial or nasal), flow and oxygen dispenser or with a mechanical fan. The choice of device depends on the patient's clinical condition, the environment in which it is delivered and the technological resources available [4].

In emergency settings, CPAP is an important alternative to invasive mechanical ventilation. Nevertheless, it can be used in several acute and chronic respiratory diseases, and also at home with a portable oxygen source, as provided in obstructive sleep apnea treatment [5].

At the moment, given the serious coronavirus pandemic, the majority of Italian hospitals do not have sufficient equipment to assist patients affected by respiratory failure, by reducing alveolar compression and supporting breathing [6].

In order to find an urgent solution to the need of respiratory devices, an Italian engineer (Dr. Eng. C. Fracassi) has ideated a respiratory device consisting of a commercially available snorkeling face mask *Easybreath* (Decathlon-Villeneuve-d'Ascq, France) in which the respiratory tube is replaced with a plastic support suitable to be connected to medical oxygen supply pipes.

The project of the connector has been designed by the Italian company ISINNOVA (Brescia, Italy), which has released on the web the related "standard triangulation language" STL files for free.

Consequently, in order to have the facial mask available for the conversion into a CPAP, it is necessary to apply the specifically designed fitting component consisting of two connection pieces that are printable with modern three-dimensional printers (3D).

The developed respiratory device is the result of the application of two 3D printed plastic valves *"Charlotte"* and *"Dave"* to the *Easybreath mask* (Model *Subea 1*).

The entire system set-up is made up as follows:

- Oxygen source
- Venturi valve
- *Dave* valve (to be connected with both inspiratory tube and reservoir)
- Connector tube
- *Charlotte* valve (to be connected to the inspiratory and expiratory branches of the breathing circuit)
- *Face mask* (in this case a snorkeling mask in which the internal valves direction needs to be reversed, allowing oxygen to flow inside) [7].
- Filter
- PEEP (positive end-expiratory pressure) valve

Considering the growing Covid-19 epidemic and the consequent exceptional case of necessity, the Italian Ministry of Health allows the use of these non-certified biomedical devices for compassionate care.

The application of an information procedure and a specific patient's informed consent is requested before using these devices [8].

Because of Covid-19, hospitals are urgently requesting breathing devices; groups of volunteers working in research centers, companies, individuals and among them also dentists and dental technicians have joined together to quickly create 3D printing fittings.

The present paper introduces an alternative use of the dental CAD/CAM machinery, reporting on the fabrication of a 3D printed connections prototype suitable for connection to snorkeling face masks, demonstrating the feasibility of the application. 3D printing companies act as central hubs connecting makers and hospitals in need by crowdsourcing a list of professional additive manufacturing (AM) providers who have suiTable 3D printers. Dentists and dental laboratories who are willing to making available their experience, facilities and machinery for the fight against the coronavirus can sign up at https://www.3dsystems.com/covid-19-response#signUp [9].

The objective of this report was to present the specific workflow to be applied for printing the connectors with Dental 3D Printers that meet the reported setting requirements. Medical-grade materials must be used.

2. Results

In order to provide comprehensive technical notes to volunteer dental professionals interested in printing Charlotte and Dave connectors to breathing devices, the entire digital workflow is reported.

Step by Step Procedure

The steps leading to the resulting pieces are described below.

The STL file available by ISINNOVA srl. of the "*Charlotte*" valve and "*Dave*" valve is imported to the 3D printer software(PreForm 3.4.3 Formlabs Inc.) (Figures 1 and 2).

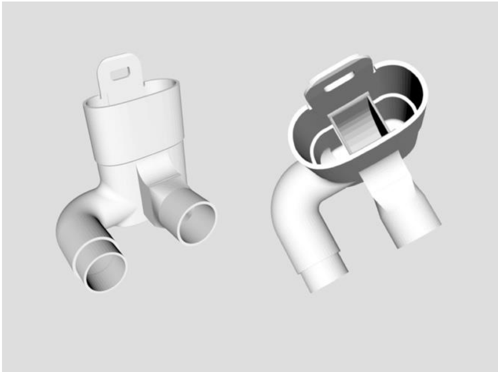

Figure 1. STL file of "*Charlotte*" valve (made available by ISINNOVA srl.).

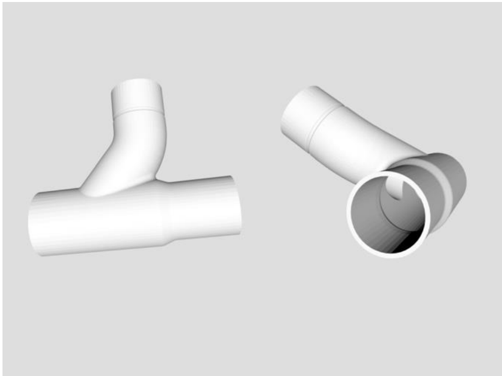

Figure 2. STL file of "*Dave*" valve (made available by ISINNOVA srl.).

The corrected position of the pieces in the printer plate (Figure 3) and the number, position, height and diameter of the supporting pins are checked according to instructions.

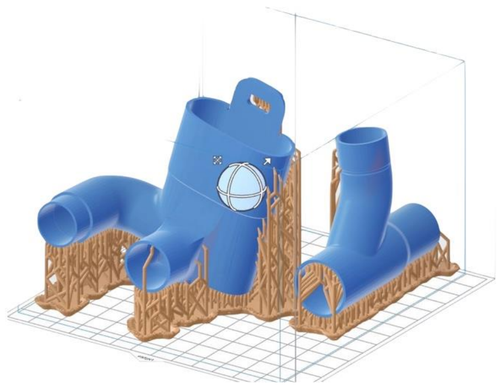

Figure 3. "*Charlotte*" and "*Dave*" valves leaning on the printer terminal plate.

The print is then launched at a predetermined operating time (5 h 15 min).

At the end of the printing, (Figure 4) a post-production phase is required.

The polymerized components are removed from the printer and washed in **Isopropyl alcohol** in an ultrasound tank for 5–15 min.

Subsequently, they are cured and dried in the UV curing system Meccatronicore BB Cure Dental (Meccatronicore, Trento, Italy).

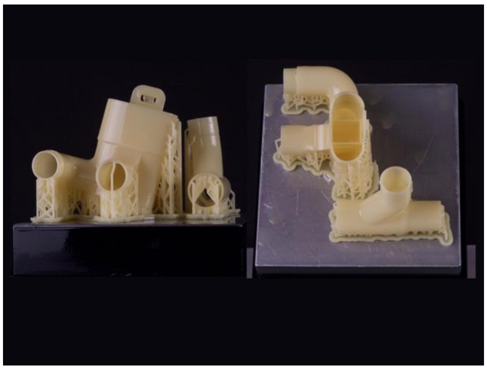

Figure 4. Printed vales external and internal vision.

All supporting pins are removed, and the external surfaces of the plastic devices are finished using conventional dental methods, with rotating burs and brushes (Figure 5).

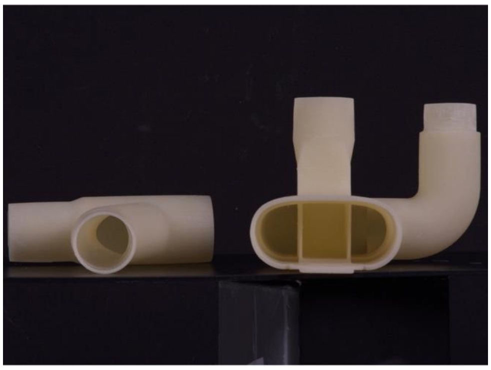

Figure 5. Finishing.

The last step is cleaning with a broad-spectrum disinfectant hydroalcoholic solution (**Bactisan Spray, Amedics**).

Finally, the valves, stored in sterilization tubing to avoid contamination, are ready for delivery, since correct adaptation to the mask is ensured. (Figures 6–8).

Figure 6. Insertion of "*Charlotte*" valve to the mask.

Figure 7. Printed connector detail comparison to *Subea 1*.

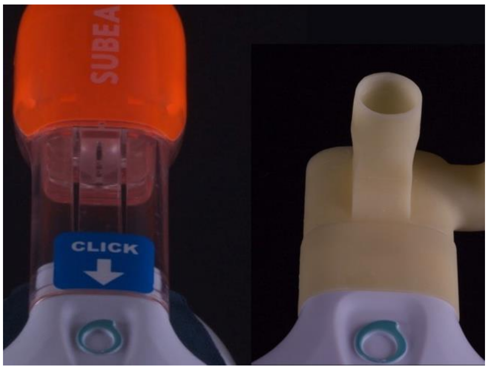

Figure 8. Comparison between "*Charlotte*" and *Subea* 1 insertion.

3. Discussion

The severe and widespread Covid-19 pandemic puts many people's lives at risk all over the world. The insufficient number of beds in Intensive Care Units associated with the huge demand for assisted breathing devices cannot be met by factory supplies in a short time.

Alternative and emergency respiratory apparatuses can help the breathing of many patients who are affected by coronavirus.

However, it is noteworthy to mention that in Covid-19 patients with acute respiratory failure, CPAP may not be an adequate treatment. Therefore, since it is difficult to predict what these cases are, the decision to try this treatment is up to the intensive care specialist and they need to provide close monitoring, including preparations for prompt intubation.

3D printing translates computer-aided design (CAD) virtual 3D models into physical objects. 3D printing is used in the manufacturing industry, medical and pharmaceutical research, drug production, clinical medicine and dentistry, with implications for precision and personalized medicine [10,11].

The term 3D printing with the alias Customized Additive Manufacturing (AM) is used to describe the same general manufacturing principle that builds objects layer by layer.

AM techniques include vat photopolymerization (stereolithography), powder bed fusion (SLS), material and binder jetting (inkjet and aerosol 3D printing), sheet lamination (LOM), extrusion (FDM, 3D dispensing, 3D fiber deposition and 3D plotting) and 3D bio printing [12].

With the advent of computer-aided design/computer-aided manufacturing (CAD/CAM) protocols, it became quite popular in dentistry, especially for implant prosthodontics [13,14].

Dental professionals have a deep awareness of digital workflow for 3D printing, since the use of it to build dental models, fixed prostheses, full-arch implant supported rehabilitation and others is nowadays routine in the daily dental practice.

Volunteer dental professionals can contribute to creating printed plastic valves, adapting the dental digital workflow and converting snorkeling masks in emergency CPAP devices.

The role of the dentist and the dental laboratory is only limited to making available their experience, facilities and machinery for helping doctors and patients, even way beyond dentistry [15–17].

4. Materials and Methods

The free STL files of Charlotte and Dave valves were downloaded from the link: https://drive.google.com/drive/folders/14Q3TEl5JVeN2QpDpKo1AIx_wnGeolKlK?usp=sharing.

The low force stereolithography (LFS) Formlabs Form 2 printer (Formlabs Inc., Somerville, MA, USA) was used. Stereolithography is an additive manufacturing process that, in its most common form, works by focusing an ultraviolet (UV) laser on to a vat of photopolymer resin; the resin is photochemically solidified and forms a single layer of the desired 3D object from the computer-aided design (CAM/CAD) software. This process is repeated for each layer of the design until the 3D object is complete [13].

In the design phase, the option "automatically generates everything" allows us to take advantage of the pre-defined settings for the creation of the supports.

The following basic settings were used:

Density: 1.00
Size of the contact points: 0.90
Internal supports: on
Spacing from the plane: 5.00
Inclination multiplier: 1.00
Height above the base: 5.00
Base thickness: 2.00
Layer thickness: 0.1 mm
Print time: 5 h 15 min
Layers: 932
Volume: 60.52 mL

The printer is used in "open mod" activity to allow the use of resins other than the original ones supplied by Formlabs.

In this case, the employed printing material was NextDentTM C&B (NextDent B.V., 3769 AV Soesterberg, Netherlands), a micro filled hybrid (MFH) class II a printing material suitable for medical devices, biocompatible and CE certified in accordance with Medical Device Directive 93/42/EEC, listed by the FDA and registered in various other countries.

For this prototype, the color A 3,5 was chosen.

This material reflects the characteristics of the ideal material for this use, which should be odorless, biocompatible, biocomposable and relatively flexible to easily connect with the mask component.

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