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3D Printing for COVID pandemic response: laryngoscopes, ventilators, and beyond

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Abstract: The COVID-19 global pandemic has placed an unprecedented strain upon global medical resources, resulting in shortages of both, everyday disposable medical items, and specialized devices and materials that are often crucial to patient survival. In this work, we discuss the most acute needs faced by the Intensive Care Unit physicians in Canada and the mitigation steps our group undertook to address these needs. We provide several practical examples of devices developed and manufactured within our group and discuss some of the associated implementation challenges.

I. Introduction

The global COVID-19 pandemic resulted in a disruption of global medical equipment supply chains at a scale not seen in recent history. Due to its versatility and distributed nature, 3D printing has proven indispensable in the development and manufacture of stopgap devices and solutions to help address acute clinical needs while traditional manufacturing has been ramping up [1]. While materials and equipment provided by traditional manufacturer is clearly preferable for medical use, numerous hospitals and clinical teams have had to face the dilemma of using stopgap 3D-printed devices created in-house or risking their patients' lives. This work details the solutions identified to address this dilemma, in the Canadian context.

II. Materials and methods

Despite physical distancing policies, COVID has resulted in temporary and intermediate-term disruptions in medical supplies in Canada. At our local level, our laboratory has had to address three major shortages: 1) disposable and reusable laryngoscope blades 2) protective equipment for the clinicians and patients, and 3) ventilators, connectors, and related equipment. Chemical equipment sterilization and disinfection was assumed by the receiving units, in compliance with published material properties.

II.I. Laryngoscopes

Video laryngoscopes are devices used for patient intubation, with a camera allowing direct visualization of the pharynx and the larynx to enable direct, accurate placement of an endotracheal tube into an airway instead of the esophagus, with minimal trauma. Misplacement of the tube has ample negative consequences for the patient and the intubating clinician. Traditional injection-molded disposable video laryngoscopy blades have an inner hollow cavity for placement of the reusable camera, a clear window to protect the camera, and a long hook to assist in guiding the device in place to visualize the vocal cords. Our hospital was unsuccessful in procuring sufficient numbers of laryngoscope blades from the original manufacturer, prompting the need for in-house production. As a starting point, a disposable laryngoscope blade was scanned on a first-generation 320 x 0.5 mm multi-detector computed tomography (CT) system (Aquilion ONE, Canon Medical Systems, Otawara, Japan) at 140kVp and 200mA and reconstructed at 0.5mm axial slice thickness using bone and soft tissue algorithms. DICOM images were segmented using 3D Slicer 4.8.1 [2]. The resultant geometry was then used as a starting point for redesign in Blender 2.8. Due to the inability to postprocess MED610 sufficiently to allow for clear visualization through a window while protecting the laryngoscope, an insert mechanism was designed to hold a clear polycarbonate window in place. Due to medical compatibility and sterilization requirements, we used PolyJet Connex3 Object500 with the MED610 material with the SUP705 support material and glossy finish (Stratasys, Rehovot, Israel). Laryngoscope strength was tested using weight loading and manual feedback on mannequins. Laryngoscopes were produced in batches of 12 in a single build. Each blade was individually manually inspected and tested by a trained laboratory associate.

II.II. Protective equipment

At our institution, cost effectiveness and rapid assembly of non-3D printed face shields was recognized early on and such designs were deployed widely, relieving 3D printing efforts. Our laboratory thus focused on N95 masks and oxygen tents. We adapted community snorkeling mask modification designs for use as respirators for patients and N95 respirators for clinicians, using Blender 2.8 for CAD and PolyJet technology printing with VeroWhite material as above. In testing, several issues specific to our printing hardware were identified and rectified using structural reinforcement and manual CAD, including structural weak points at apparatus junctions resulting in rapid junction

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failure and compatibility issues. Additionally, patient oxygen tents were created by welding plastic sheets and 3D printed connectors. All designs were tested in compliance with quantitative testing standards at a N95 fitting facility.

II.III. Ventilators and connectors

Equipment shortages exposed several possible uses of existing equipment, including connecting older but functional systems, surplus air filters, suction apparatus, and additional patient outlets into respiratory circuits, pending the availability of interconnecting adapters. We designed several connecting tubes and adapters and printed these using the same process as that employed for laryngoscopes. Additionally, we adapted and modified the Illinois RapidVent design (University of Illinois, IL, USA) for local use using the same manufacturing process.

III. Results and discussion

The production of disposable laryngoscope blades has been successful, with no reported failures in clinical use (Fig. 1). A batch of 12 laryngoscope blades requires 1268g of MED610 material and 2054g of SUP705 material, as well as 30.2 hours of print time and 2 hours of post-processing time which includes support material removal and manual window placement, as well as manual inspection for integrity and residual support. A limited run manufacturing approximately 40 laryngoscope blades per week has been sufficient to address local shortages as an adjunct measure.

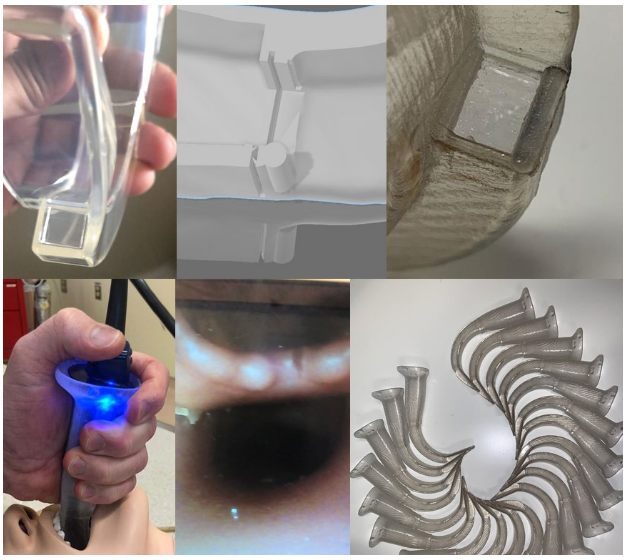

Figure 1: From left to right, original laryngoscope blade with transparent window; cross-section of a design with a trap for a transparent polycarbonate insert; assembled product; testing laryngoscope on a dummy; dummy larynx; delivery batch.

Despite successful testing of various prototypes of oxygen tents, snorkeling mask adapters, and experimentation with reusable masks (Fig. 2), practical considerations of build times and cost, as well as local availability of alternative equipment have limited the need for such devices. On the other hand, simpler components such as connectors, have enjoyed excellent uptake in practice, where they allowed the reuse or repurposing existing materials and equipment.

Similarly, despite the successful manufacture of the RapidVent design with modifications for local connector sizes, filters, and instruments (Fig. 3), practical application has been limited by low demand against a background of ramping up manufacturing capacities, existing stockpiles, material reuse, and levels of admissions for COVID.

Figure 2: Left to right, makeshift oxygen tent with 3D-printed connectors and welded plastic holders; examples of various 3D printed adapters, locally modified snorkeling mask adapter.

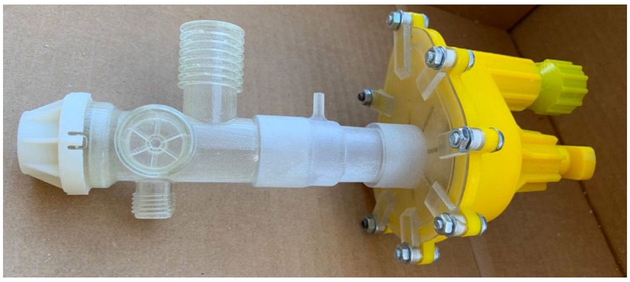

Figure 3: Locally adapted Illinois RapidVent model.

IV. Conclusions

In our experience, 3D printing has been helpful in rapidly addressing acute shortages of vital materials. Continuing importance of 3D printing in similar relief efforts can be assured by adhering to ongoing quality control procedures at every step of manufacturing, sterilization, and delivery to minimize failure rates of 3D printed parts in clinical settings. By avoiding applications of 3D printing for purposes that could be addressed without it (e.g. face shields), we have been able to focus our throughput on the most acute equipment shortages at our institution. Thus, applications of 3D printing at our institution primarily supported the extension of the lifecycle of existing equipment, extension of the applications of the existing equipment, or the support for more complex platforms such as video laryngoscopy. A holistic approach to equipment shortages, where 3D printing is a flexible supportive tool is likely advisable. In all cases, usual medical equipment suppliers should be preferred over 3D printing laboratories. The 3D printed parts should be used only in a setting of a dire emergency and only after following all applicable safety protocols and regulations.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Not applicable. Ethical approval: Not applicable.

References

[1] R. Tino, R. Moore, S. Antoline, P. Ravi, N. Wake, C.N. Ionita, J.M. Morris, S.J. Decker, A. Sheikh, F.J. Rybicki FJ, L.L. Chepelev, *COVID-19 and the role of 3D printing in medicine,* 3D Printing in Medicine, 6(1):11, Apr. 2020.

[2] A. Fedorov et al., *3D Slicer as an Image Computing Platform for the Quantitative Imaging Network,* Magnetic Resonance Imaging, 30(9):1323-41, Nov. 2012.