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Brief Report

3D-printed protected face shields for health care workers in Covid-19 pandemic

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A B S T R A C T

The coronavirus pandemic resulted in a shortage of protective equipment. To meet the request of eye-protecting devices, an interdisciplinary consortium involving practitioners, researchers, engineers and technicians developed and manufactured thousands of inexpensive 3D-printed face shields, inside hospital setting. This action leads to the concept of "concurrent, agile, and rapid engineering".

INTRODUCTION

Coronavirus outbreak (COVID-19) has spread rapidly around the world and has been considered as a pandemic by WHO in March 2020.[1] The transmission occurs from person to person through droplets when an infected person coughs or sneezes, or through contact of contaminated surfaces and then touching one's mouth, nose, or eyes.[2] To date, there is no vaccine or treatment, so that preventative measures are crucial.

A single-center case series suspected that 29% of hospital-associated transmission involved health professionals.[3] Aerosol-generating procedures particularly expose health care workers at high risk of contagion. Thus, personal protective equipment is essential to limit virus transmission. Masks and respirators have shown their ability to protect from respiratory infections. Eye-protecting devices, such as goggles or face shields, are also essential to cut off conjunctival transmission route.[4] In particular, face shields demonstrated several interests: they avoid inoculation of droplets through the conjunctiva, prevent inadvertent touching of eyes or face with contaminated hands[5] and protect the facemasks, whose efficacy decreases after wetting.

However, the pandemic crisis has resulted in a shortage of protective equipment. To meet the request, an interdisciplinary consortium (3D4Care[6]) has been formed, to develop ergonomic and inexpensive 3D-printed face shields.[7]

METHODS

Our 3D-printed face shield consists of a 3D-printed headband, a shield and an elastic strap. The prototype is inspired by the open-

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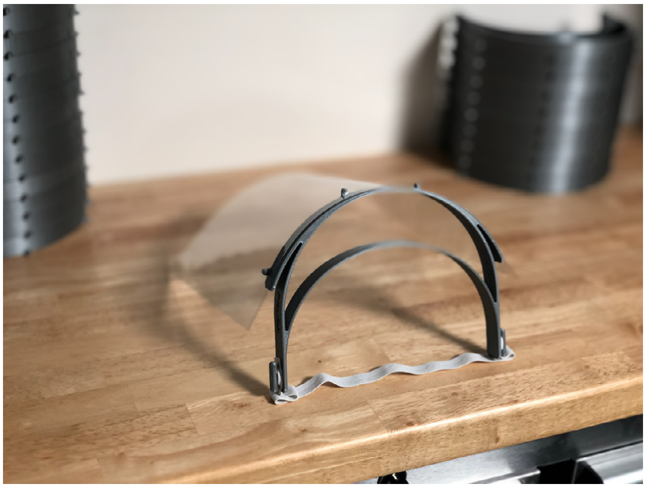

Fig 1. The 3D-printed headband of the face shield is composed of 2 arches.

source "PRUSA RC2" and "PRUSA RC3" models,[8] with several design changes.

The headband is composed of a first arch of forehead support and a second arch to deflect the shied from the face (avoiding fogging and feeling of being closed) (Fig 1). It is obtained by fused deposition modeling (material extrusion technique) (Fig 2) using polylactic acid, polyethylene terephthalate glycol or acrylonitrile butadiene styrene. This model requires around 3 hours of printing. The printer fleet includes various brands such as Ultimaker (Nederland), Creality (China) or Raise 3D (United States), with their own slicing parameters. Printing parameters defined in the software have a great

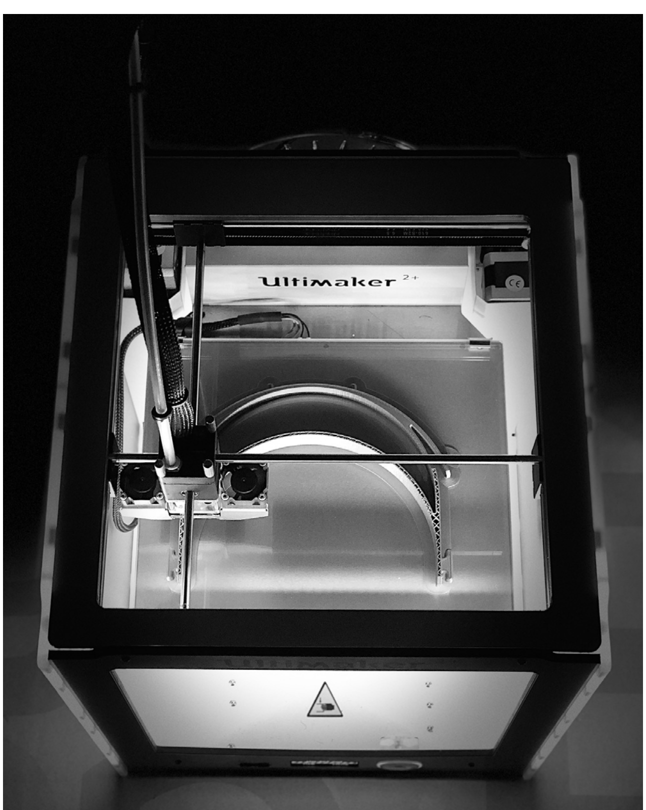

Fig 2. The 3D-printing of the headband by fused deposition modeling.

influence on the behavior of the material.[9] Thus, the choice of material is left to the manufacturer, whereas a guideline on the recommended printing setting is widely described through the consortium's website. An argument for polylactic acid is its lower environmental impact thanks to its biodegradable properties. Regarding the economic aspect, these materials allowed to print a headband for a cost of $1-1.10 per piece. The shield are standard transparent PVC sheets (A4 size, 0.2 or 0.3 mm thickness), which are perforated, then horizontally attached on anti-return spikes. The elastic strap is cut from a buttonhole elastic roll or a tourniquet.

The production sites are: makers, that are individuals with their own prototyping facilities; teachers making on equipment relocated to their homes; schools, universities and research centers mobilizing their resources implemented by students and/or teachers; and companies using their means of production.

3D-productions and purchases are sent to an assembly facility (at the University of Paris), in sanitary conditions avoiding the spread of the virus. The pieces are put together, then subjected to a quality control by checking:

- the flexibility of the 2 arches after several loadings;
- the mechanical resistance of the positioning pins for the shield and the elastic band;
- the rectification of the shape defects (edge and surface smoothing).

Disinfection is performed at the receipt and prior the dispatch (15 minutes in sodium hypochlorite at 0,5%).

Before they were sent to hospital department and health services, the face shields were tested in realistic conditions intentionally made as harsh as possible, namely by in the interventional radiology ward of the European Georges Pompidou hospital during 2-3-hour-long vascular interventions. Interventional radiologists wore the shield in addition to the nose-mask, lead-glass goggles and head caps.[10] After minor adaptations, i.e. change of the elastic strap and addition of a half-transparent sheet placed upright over the forehead, the shields were tested by various personnel (doctors, nurses, n = 14) during 48 hours in the emergency department and anesthesia-intensive care units.

Then, they were sent to many other hospitals in priority to emergencies, resuscitation and geriatrics departments, but also in nursing homes, Covid testing centers and humanitarian aid associations, for all types of health care workers (doctor, nurses, care assistants, hospital porters...).

RESULTS

The first week of manufacture has produced 1,547 face shields, the second week 2,989, to reach a total of 10,151 at 5 weeks. After use, the headband can be disinfected during 15 minutes in sodium hypochlorite (0,5%), the shield is changed and the elastic strap can be changed or washed at 60°C.

The switch of production from RC2 to RC3 Prusa's version decreased the scrap rate from 35 to less than 10% per week. Improved design can also reduce production time, such as a lower shield height without loss of comfort. However, relevance of using 3D-printing parts is more discussed regarding their strength after repeated exposition to various chemicals in comparison with molded parts.[11]

DISCUSSION

The face shield production was carried out in 3 stages:

- Creation of an interdisciplinary group—mainly from academics, involving practitioners, researchers, engineers and technicians—

to identify and clarify unfulfilled medical needs, prototype various solutions and quickly start manufacturing parts for practitioners.
- Design and pre-industrialization of a mass-produced solution, while continuing to iterate on other possible solutions.
- Industrialization of an approved solution for mass production.

3D4Care success relied on the direct integration of interdisciplinary teams into hospital and medical facilities. Key aspects of our action clearly emerged, leading to the concept of “concurrent, agile and rapid engineering”:

- The simultaneous mobilization of various skills (medical, engineering, materials, biocompatibility, and hygiene) covering the entire life cycle of the product improved the quality of the face shield (“concurrent engineering”). Indeed, the approved solution met the health care worker expectations, could be fast manufactured and provided satisfying mechanical and comfort properties.
- The ongoing dialogue between caregivers and engineers was source of iterative improvements (“agile engineering”). During the crisis, caregivers expressed their evolving needs (equipment shortage, material adjustment for new treatments) to the engineers who improved the designs in compliance with sanitary practices and prioritizing product reliability.
- Installation, as close as possible to the practitioners, of prototyping means to manufacture, try and validate alternative or emerging solution fastened the development (“rapid prototyping”).

CONCLUSION

The fast provisioning of 3D-printed face shields during Covid-19 pandemic highlights the interest of using 3D-printing inside hospital setting, supported by an interdisciplinary consortium, to rapidly manufacture alternative resources at a large scale. Many other devices can also be developed such as 3D-printed masks, connections for respirators, adaptation valves.

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