PPEs From Nigerian Academia: Flattening The COVID-19 Curve With 3D Printing And Locally Sourced Intervention

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Research

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Abstract

Background:

Personal protective equipment (PPE) supply shortages were a big issue in the fight against COVID-19 around the world at the onset of the pandemic, requiring all communities to find innovative ways to make and supply PPE for health workers, vulnerable people and the general public. To this end and in line with the WHO's call for 40% raise in PPE production across the world, we sought to alleviate the PPE shortage and to support our local communities using 3D printing (additive manufacturing) and free and open-source hardware (FOSH).

Methods:

Utilising a 3D printer and off-the-shelf components, reusable face shields and face masks were produced based on open source designs. Off-the-shelf components included transparent polyvinyl chloride (PVC) visor, ribbon tapings and elastic bands for the face shields, as well as cushioning pads (clothed foams) and filters (sensitive tissues) for the face masks. Hygienic measures employed during fabrication included the assembly following safety protocols, disinfection of products with ultraviolet bactericidal lamps, ensuring hygiene during collection and distribution. Users' real-life experience and feedback were utilised to modify and improve on quality and adaptability of the designs.

Results:

In a period of three months, over 400 reusable 3D-printed face shields and face masks were produced by a team of academics, for health practitioners, other professionals and people across the Olabisi Onabanjo University community and other cities within Ogun and Lagos states.

Conclusions:

More awareness is generally required on the potentials of 3D printing and FOSH in the global south, particularly in universities and research institutions where innovative alternatives to expensive equipment remain vital. Our feat corroborated and advocated these potentials in a low-income setting like Nigeria, where the immediate response and synergy between academics, and researchers yielded a substantial number of PPE to front line workers, in a timely manner at the peak of the viral transmission and lockdowns- a period wherein manufacturers of PPEs struggled to establish their commercial logistics. We emphasize the need for university managements to support academics and researchers strongly to deliver on much needed community support in crises time, and encourage governmental and non-governmental bodies to consider investing in this innovative self-reliant perspective through their research funding and managemnt programmes in a bid to achieving a lot more with the less funds.

Trial registration:

Not applicable.

Background

As the infection rates of COVID-19 rose sharply globally, the demand for personal protective equipment (PPE) led to a global shortage, increasing the chances of more infections and of precarious working conditions for health care professionals (1–3). PPE shortages have hindered effective health response systems everywhere(4), and to such extent that the consequential price hikes in surgical masks, N95 respirators and surgical gowns were acknowledged by the World Health Organization (WHO) (5, 6). While some countries battled to guarantee their nationals' access to PPEs by blocking PPE export, other countries were reportedly involved in "modern piracy", intercepting PPEs internationally, to deliver them to the highest bidder(4, 7). To mitigate these issues, the WHO urged industries to raise their production of PPEs by 40% and themselves donated PPE to low-income countries (6).

As alternatives to goggles, face shields are employed in many places to confer protection over the larger area of the face. Their effectiveness against the transmission of viral respiratory diseases has been a subject of research debate, especially in the wake of the COVID-19 pandemic (8). However, accompanying the use of face shields with face masks have been generally advised for better protection (8). Therefore, face shields and face masks are classified as adjunctive personal protective equipment, employed for infection control purposes (8).

We therefore set out to build face shields and face masks (Fig. 1), PPE utilised by many workers across health and non-health related professions when protection of the facial area and associated mucous membranes (such as eyes, nose, and mouth) becomes imperative against splashes, sprays, and spatter of bodily fluids (8). This is especially the case for face shields when acutely expelled aerosols from the body become a highly infectious threat (9).

1.1. Study Site

Ogun state, where this project took place, is a neighbouring state (Fig. 2 (10)) to the northern borders of Lagos - the Nigerian economic capital - where the highest confirmed COVID-19 cases nationwide were recorded. Ogun state has a population of 2.3 million and three of its local government areas (LGAs) share international borders with the Republic of Benin with most of its population involved in daily cross-border socio-economic activities(11). The state thus experienced a total lockdown along with Lagos and the Federal Capital Territory (FCT- the Nigerian administrative capital) as enforced by the federal government on the recommendation of the Federal Ministry of Health and the Nigeria Centre for Disease Control (NCDC). The decision was premised on the number of confirmed COVID-19 cases in the country which increased to 111 as of 29th March, even as more prominent public officials tested positive for the disease (12–15).

Given that there was a shortage of PPE also in Ogun, we leveraged additive manufacturing (a process of making three dimensional solid objects from a digital file, whereby successive layers of material are laid down until the entire object is created (16)) using a 3D printer (Fig. 4) to locally replicate and produce different types of PPE.

To tackle the shortage issue, it became evident that alternative PPE production and distribution methods had to be employed, and following other global initiatives, we set out to use free and open-source hardware (FOSH) in Nigeria, to provide access to PPEs (4–6).

1.2. Objectives

The objective of this project was to directly alleviate the shortage of face shields and reusable face masks in the communities around the Olabisi Onabanjo University using a 3D printer (Fig. 4) together with open-source shield designs and relatively accessible and inexpensive materials. Inspired by timely review by Chgas *et al.* (17) and the efforts of Prusa in the printing and donation of almost 200,000 shields to medics and other professionals in the Czech Republic(18) (see Fig. 1), our vision was to assist as many residents within and outside the Olabisi Onabanjo University community as possible in line with academia's mission to provide assistive service to the community.

While FOSH has gained substantial ground in the global north already (17), awareness about it is rather low in the global south, including Nigeria. With our efforts therefore, we hope to have led by example and inspired others to follow this approach for the many opportunities present in our country.

Methods

2.1. Procurement & Acquisition

A 3D printer, model 'Ender-3 pro High Precision 3D Printer', manufactured by Shenzhen Creality 3D Technology Co. Ltd (19), was acquired from China and assembled at the Neurophytotherapy research unit (NPTRU) in line with the manufacturer's guide (Fig. 3). Spools of RoHS compliant 3D printing filaments (1.75mm) made of either polylactic acid (PLA) or polyethylene terephthalate glycol-modified (PETG) were also acquired from China.

Print files for the face shield frames and face masks were downloaded from 3DVerkstan (20), Thingiverse (21, 22), Prusa (23) in stl formats (Table 1; Fig. 5). The files were modified for sizing and branding as desired using the web-based 'Tinkercad' application (24). Optimised stl files were sliced into g-code using 'Slic3r' 3D printer slicer application (version 1.3.0) (25), and this was transmitted to the 3D printer via an SD card to execute the print.

Table 1
3D Print Files & Tools and their Sources

S/N	File	Source	File Link
1.	Face Shield Visor Frame	3DVerkstan	https://www.youmagine.com/designs/protective-visor-by-3dverkstan
2.		Ric Kolibar	https://www.thingiverse.com/thing:4259253
3.	Face mask	Drew Dupont Face mask	https://www.thingiverse.com/thing:4259614
4.		Prusa	https://www.prusaprinters.org/prints/26251-face-mask-with-filter-active-carbon-anti-covid-19
5.	3D CAD design tool	Tinkercad	https://www.tinkercad.com/
6.	3D slicer application	Slic3r	https://slic3r.org/download/
7.	3D printer	Creality Ender-3 Pro	https://creality3d.shop/products/creality3d-ender-3-pro-high-precision-3d-printer
8.	PLA filament	All3DP	https://all3dp.com/1/best-pla-filament/
9.	Punch (FP-20 Kangaro® No. 376224)	Amazon	https://www.amazon.in/Kangaro-FP-20-Paper-Punch/dp/B00OBAEKSI
10.	Elastic fabric band	Amazon	https://www.amazon.com/Elastic-Sewing-Springy-Stretch-Knitting/dp/B07LFXVR8H
11.	P-20 Super glue	Jumia	https://www.jumia.com.ng/super-glue-quality-p-20-industrial-shoe-multi-purpose-strong-super-glue-68040441.html
12.	Ultraviolet bactericidal lamp	Cell Bazar	https://cellbazaar.com/furniture-home-appliances/others_536w-uvc-ultraviolet-t8-tube-light-length-48-sitong-china_i128483

2.2. Print temperatures and timings

After fixing PLA filament of the desired colour into the extruder and some optimisation trials were run, the default parameters to execute the best print job was set to include 211^{0}C nozzle temperature and 70^{0}C print bed temperature. It took an average of 1 hour 5 minutes to print the 3D Verkstan face shield frame (at 15g/piece and approximately 50 pieces/1kg spool) and 3 hours for the face mask (at 56g/piece and approximately 50 pieces/1kg spool).

2.3. Structural Design and Components

The face shield comprised of a visor, a frame and a suspension component (Fig. 6). The visor is the reusable and replaceable transparent shield easily obtainable from local stores. Visor materials are manufactured from any of several types of materials including polyvinyl chloride (PVC), polycarbonate, acetate, propionate, and polyethylene terephthalate glycol (PETG) (17, 26). The visor bore most of the shield's aesthetics which included the marginal ribbon tapings of varying colours as well as the brand stickers for the shield (not shown). The frame is the 3D printed part (as illustrated in Fig. 7), which is typically a lightweight plastic, mostly responsible for the architectural foundation, framework and support of the face shield. It is adjustable and almost (but not totally) encircles the circumference of the head. While some frame models possess temple bars that make them wearable like standard eyewear/eyeglass, they fit smartly to the head without being fastened with a suspension system (Fig. 9); other types may avail the suspension system to keep firm to the head (Fig. 6). The suspension system employed was an elastic band cut to be partially circumferential around the head as it complements the frame (Fig. 6). It assists in maintaining the position and stability of the face shield on the face.

2.4. Post-Printing; Packaging with accessories and Sterilisation

2.4.1. Print Detachment

Upon completing each print job, the print bed temperature was allowed to fall to 50^0C or less to allow for cooling and to further solidify the printed object. More importantly, the bed cooling facilitates easier detachment of the print from the glass bed. This became an important routine/protocol to prevent denaturing of the print in a forceful removal attempt, especially in circumstances where many copies of the object were printed simultaneously. While the use of alcohol spray could facilitate the detachment of stuck prints (27, 28), self-cooling – especially to 50^0C or less - proved a better outcome.From time to time (eg when prints would end in the middle of the night), the printer was allowed to cool down completely despite our tight printing schedule. This proved beneficial, as we could perform checks on the printer itself and make sure wear and tear would not compromise subsequential prints.

2.4.2. Finishing and accessorial fittings

Following detachment from the printbed, leftover material would be cut away from the print using pliers and the printed parts would be sanded where necessary. For the face shield, the taped visors and (optional) band constituted its accessories (see Fig. 6 and Fig. 9), while for the 3D-printed face masks, its accessories (Fig. 8) included the elastic bands, cushioning pads (carefully tailored into clothed foams), and filters which were cut carefully from a hygienic anti-microbial tissue paper (Paloma classic super soft tissues; Fig. 10), since tissue papers have also been proven to give some protection to both adults and children against airborne particles (29). A few inches away from the visor's superior margins, the four holes needed to secure it to the four pins of the frame were created with a punch (FP-20 Kangaro® No. 376224). As the length of the visor measured 30cm, its centre was spotted at the 15cm mark of a ruler with a soft pin. From that centre, two other spots were marked 3.9cm away to the right and left of this centre point. These cater for the two anterior pins. From these pins, another 8cm spots were bilaterally marked on the side, to accommodate the two lateral pins. All the 4 pins were thereafter perforated with the punch (Fig. 12). The visors were then snuggly fixed through these complementary pins and holes. To support the shield's circumferential stability around the head, an elastic fabric band of 15-18cm was similarly punched with two holes each on the right and left ends to accommodate the arms of the shield frame where such is deemed useful by the user. Such accessory was however required only in the case of a weak print which could be due to under-extrusion challenges from the printer.

Bands measuring 20cm each were inserted on both sides of the 3D-printed face masks through holes pre-designed for such along with the prints. Edges of the bands were thereafter fastened together with a sewing machine. Pads made of clothed foams with colours matching the print's filaments were fixed to the face masks using an adhesive (P-20 Super glue; manufacturer Zhejiang Jiuerjiu Chemicals Co., Ltd, China shown in Fig. 11) (30).

2.4.3. Sterilisation and packing

Sterilisation was accomplished by spraying a solution of rubbing alcohol (methylated spirit - C_2H_6O), hydrogen peroxide (H_2O_2) and distilled water (H_2O) (at 800 ml, 45 ml and 155 ml volumes respectively to make a 1000 ml solution) (31), following which items were allowed to dry. Adequate sized transparent nylons were used in packing the assembled face shields and face masks respectively and sealed up with a sealing machine. Packaged items were again sterilizsed under an ultraviolet bactericidal lamp (STONC ZWSZ 15W manufactured by GaoPeng SiTong).

2.5. Quality Assurance

End-users including medical personnel from within and outside the Teaching Hospital of the Olabisi Onabanjo University, journalists and workers at various media firms, staff members of various universities, and other individuals from the general public within and outside Ogun State, Nigeria, participated in trial runs of the first 20 products to determine the fitness of the products, clarity of vision through the visor, and breathbility through the face mask and shield when worn either separately or together.

Results

3.1. Print Quantity & Distribution

In different colours, over four hundred face shields were printed and assembled in total during the project. With one operator of the 3D printer and another assembler, each face shield and each face mask took the average production time of 1 hour 30 minutes and 3 hours 30 minutes respectively; each costing 1,200 naira (2.92 USD) and 2,000 naira (4.86 USD) respectively to produce. As at the time of this project, face shields and reusable face masks were very scarce within the locality and would thus cost at least 5,000 naira (12.16 USD) and 10,000 (24.32 USD) respectively.

Discussion

4.1. Feedbacks

The use of face shields over the years has been characterised with more advantages than disadvantages. While the noted challenges/disadvantages include glaring, fogging, optical imperfection, being relatively bulkier than goggles and safety glasses, and relatively poorer peripheral fit than protective facemasks(8); its outweighing advantages include its being more comfortable than many face masks, larger protection of the face, ease of donning and doffing, relative inexpensiveness, non/less retention of facial dermal heat, lesser fogging compared to goggles, non-impact on vocalisation, and concurrent compatibility with other PPEs (8).

In this project, feedback from end users commended the innovativeness in the usefulness of the 3D printer in contributing directly to communal needs for PPEs during the pandemic and the aesthetics of the face shields and face masks. At the initial production and distribution stages, the feedback helped to improve the shield smoothening for further skin-friendliness, band sizing variations to accommodate more head circumferences, and general finishing of the face shields. The products were thus found useful, not only by health workers within the confines of hospitals but also by pre-hospital emergency medical providers, other first responders like police officers and firefighters, dentists, laboratory workers, and veterinary care personnel. They also benefitted custodial staff dealing with spills and contaminated waste, grocery store staff, as well as people with need to provide essential services to or be in contact with many people during the pandemic, as the curve gradually flattens out and ultimately slopes downward in Nigeria.

4.2. Manufacturing using 3D printers

The manufacture of goods using 3D printers is a part of what has been called the fourth industrial revolution (32), where digital designs can be seamlessly shared over the internet, allowing anyone to replicate an object using a locally available 3D printer. This new technological development bypasses the need for shipping finished products, and therefore is more robust to problems that can occur in traditional supply chains, as the raw materials needed for 3D printing can be stored in bulk and over extended periods of time. Taking advantage of this, we were able to manufacture a large number of PPE, even if the 3D printer model used in this project was not built for massive serial manufacturing, as seen in the time it took to print each item. However, if we had more machines available, we could have them running in parallel, reducing the relative time needed to produce PPE. This has been demonstrated by Prusa Research, a Czech company that has turned several printers from their printer farm into PPE producing devices, and had more than 150000 face shields printed, CE certified and shipped (Fig. 6) (18). This establishment (Prusa) together with the eye-opening publication of Chagas et al. (17) thus contributed most significantly to the motivations behind this project. With only one printer however, we could not aim to supply the entire local market demand, but we worked as a bridge, supplying as many PPE as we could until traditional manufacturers sorted out their stocks and made more PPE commercially available.

In practical terms, 3D printing is not without issues, and issues that slow down production do appear. Familiarity with such issues and the general machine operation are paramount for consistency.

Fortunately, kind and willing experts from across the globe are ready (in many cases) to make the exercise bearable for newcomers when necessary, through diverse online platforms. As experienced in this project, such issues included under-extrusion, nozzle clogging which necessitated clearing, filament breakages during insertion, and the need to replace filaments with new ones either due to exhaustion of a spool or for colour change (more details on these issues can be found here (33)). Power cuts from the main grid occurred as common in this part of the world, making it likely that a print would be stopped in the middle, rendering the part that was printed up to that point useless. However, with acquired expertise, truncated prints were maneuvered to build further from exactly where they stopped to prevent the futility of the uncompleted print. Under-extrusion turned out to be a complication of a cracked plastic extruder block. The fallout from this was a weak face shield frame print, which would usually require the headband to support the shield's circumferential stability around the head. However, this problem was corrected with complete substitution of the extruder gears with alloy equivalents as procured from Creality 3D (the printer's manufacturers).

More awareness is required in the global south on 3D printing potentials, particularly in universities and research institutions where innovative alternatives to expensive equipment remain vital. With bigger and many more printers, much more could have been accomplished. Certainly, a lot more possibilities lie ahead, only if institutions invest more in this technology like the Neurophytotherapy Research Unit lab did to acquire this printer ahead of the pandemic for the development of research tools.

4.3. Beyond the COVID days

We aim for more than PPE replication and building. By leveraging other FOSH projects and initiatives, we want to work on scientific equipment and test-kits used for medical diagnostics, following the steps of what other local groups have done, such as locally developed medical ventilators (as achieved by the Yunusa Garba-led team of inventors (34) and others in the country). Beyond medical applications we also want to develop tools relevant for scientific experiments. Already, micropipettes and micro-centrifuge in line with protocols of Brennan et al. (35) and the Thingiverse community (36, 37) have been printed and optimised in the lab. This was practically possible in the parlance of “the €100 lab”, where 3D-printable open-source platform is deployable for state-of-the-art techniques like optogenetics, fluorescence microscopy, and temperature control as usually necessary in *Drosophila*, zebrafish and Caenorhabditis elegans behavioural assays (38, 39).

Conclusion

African research remains dependent on foreign aid for most advancements (40), which makes it impossible to sustainably build and maintain state-of-the-art facilities, as it is impossible to antecipate when the next round of funds will be available to keep and run these facilities (41). In fact, foreign aid enjoyed by African countries over the time since their respective years of independence has been blamed for the developed culture of dependency in Africa, which has consequently fostered paternalism rather than partnership with the global north (40–42).

So, indeed the statement of Ernest Rutherford that “we haven't got the money, (and) so we'll have to think” summarises what African scientists need to do. They need to think innovatively if they are to bring local research/medical infrastructure to the same levels experienced in the global north. One possible innovative thinking is investing on FOSH for local knowledge and capacity building development, as leveraging open source technologies allows for 1) acquisition of locally sourceable components (17), 2) local production of tools, bypassing long waits and bureaucracy with customs, 3) local repair and calibration, 4) reduced costs, 5) easier customization of existing tools (a summary of these ideas has been documented by Chagas (43)).

As the world looks forward to the flattening and ultimate nosedive of the COVID-19 curve (even though the second wave is already here (44–47)), our mission is to corroborate the campaign for FOSH while we do our bit to stem the tides of doing nothing as is conventional in an economic system that relies mostly on international grants. As we demonstrate, our project recorded successes in the local fabrication of 3D-printed face shields and face masks as subsets of PPEs, saving the day especially at the initial stages of the viral transmission, while the larger-scale manufacturers tried to gain their commercial footing amidst the lockdowns.

Our project's success was founded on the practical premise that every complicated equipment is only an assembly of multiple different simple components and that open labware designs show everyone how these components go together. Furthermore, the low cost and price points of the required materials such as the filament and others, allowed us to pool money together. And as "members of the public" we could start designing solutions for problems which were up to now only addressable with funds from government/research institutions.

Declarations

7.1. Ethics approval and consent to participate

Not applicable

7.2. Consent for publication

Not applicable

7.3. Availability of data and materials

Not applicable

7.4. Competing interests

Not applicable

7.5. Funding

Not applicable

7.6. Authors' contributions

The project was developed and led by RF in the Neurophytotherapy research laboratory (NPTRL) where all the 3D printing and assembly was executed using the lab's printer. Logistic guidance and mentorship through the 3D printing were provided by AMC and MM. The large scale production was conceived and funded by personal contributions from members of the Future of Medicine for science, technology and innovations group (FoMSTIG), headed by AA (Ahmed Adedeji), and members of which are RF, TRA and OO. AA (Abisola Akinbo - a student member of NPTRL) managed the shipment modalities and optimistion of the 3D printer. The fisrt manuscript was written by RF with initial technical reviews made by AMC and MM while final reviews were made by AA (Adedeji), OO, TRA and AA (Akinbo).

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Figures

Figure 1

Prusa Face shield (A) & Nose mask (B)

Figure 2

Map of Nigerian states showing Ogun to the north of Lagos

Figure 3

Assembly of the 3D printer by NPTRL members

Figure 4

Creality Ender-3 pro High Precision 3D Printer

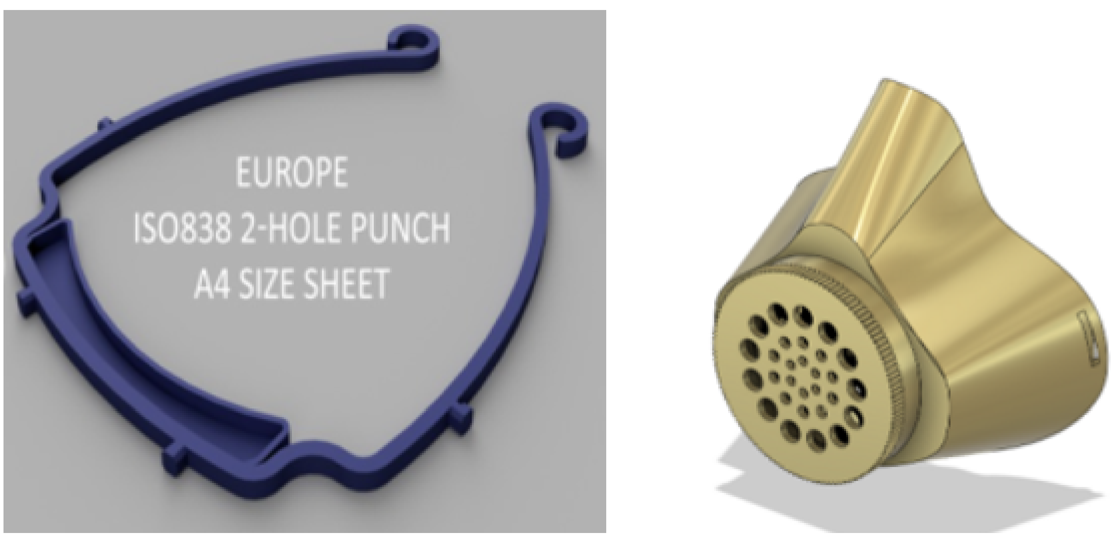

Figure 5

Models of 3D-Printable Face shield frame (3DVerkstan) and face mask (Prusa)

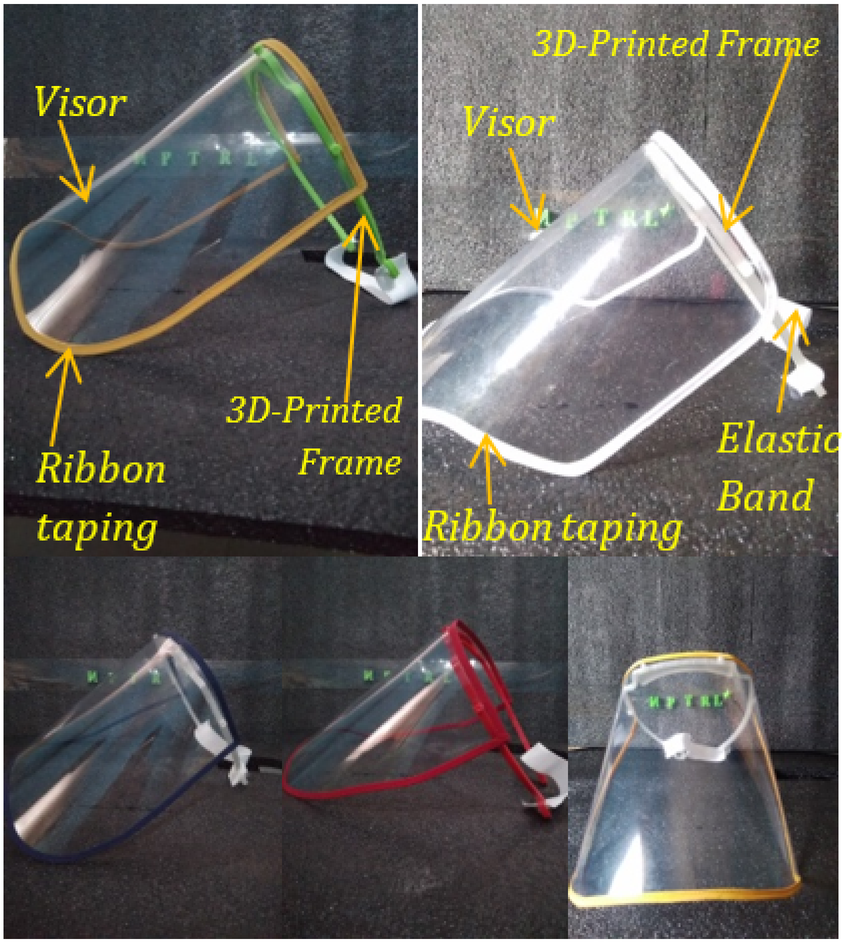

Figure 6

Two 3D-Printed NPTRL Face shields

Figure 7

3D Printing of NPTRL Face shields in progress

Figure 8

3D-Printed Nose masks (Inset shows packaged & sealed nose masks with filters)

Figure 9

A 3D-printed face shield model with frames wearable like eyeglass

Figure 10

Tissue Filter

Figure 11

Super Glue

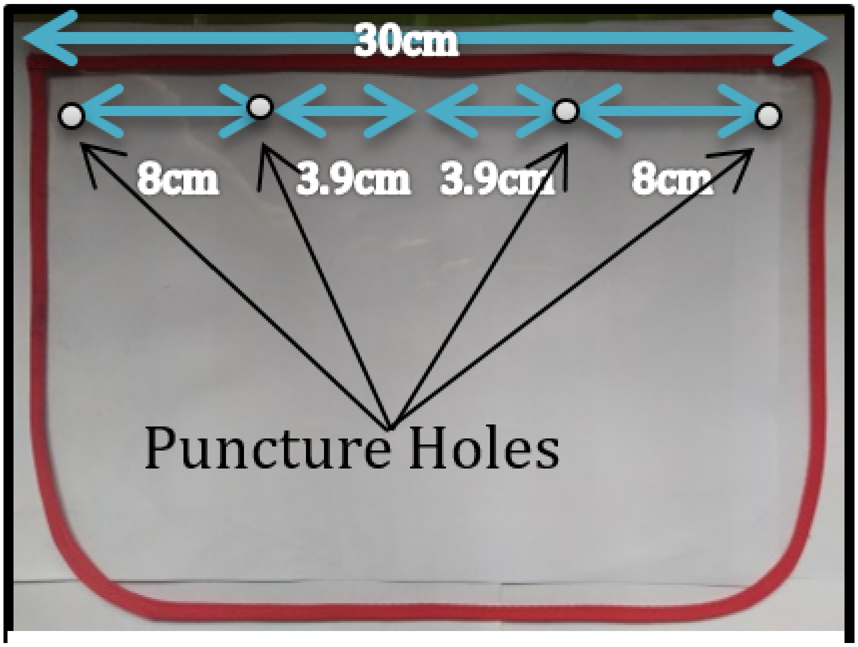

Figure 12

Face shield visor showing the puncture holes