



DESIGN AND EVALUATION OF A LOW-COST 3D-PRINTED POWERED AIR-PURIFYING RESPIRATOR FOR HEALTHCARE APPLICATIONS

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Abstract: The present device is indigenously prepared for all healthcare practitioners to support manufacturing in India. Additionally, it can be used in other sectors where there is a danger that contaminated air may cause respiratory disorders. Healthcare workers (HCWs) are at particular risk during pandemics and epidemics of highly virulent diseases with significant morbidity and a case fatality rate. These diseases include severe acute respiratory syndrome coronaviruses, SARS-CoV-1 and SARS-CoV-2, Middle Eastern Respiratory Syndrome (MERS), and Ebola. With the current (SARS-CoV-2) global pandemic, it is critical to delineate appropriate contextual respiratory protection for HCWs. All locally available components can easily be serviced and replaced, making it a cheaper device than all other Powered air-purifying respirators (PAPRs) available. The major components are the helmet and filter casing. There is moderate quality evidence for PAPR. Its use is associated with higher thermotolerance but lower mobility and communication ability scores. There has been a trend toward improved self-reported comfort with PAPR technology in low-quality observational simulation studies. Due to its two-layer filtering layers, it can be used in adversely contaminated environments. Field observational studies have shown no difference in infections among healthcare workers using the PAPR device compared to other matched ventilators. The PAPR was confirmed to have low mobility and high thermostability with audibility. However, more practical research is needed to explain the effectiveness of PAPR technology and provider satisfaction.

Keywords: Covid-19, PAPR, Respiratory Protection, Healthcare worker

I. INTRODUCTION

Coronavirus disease (COVID-19) has had a profound global impact due to its rapid transmission and severe health consequences (1). In recent decades, several outbreaks of highly infectious diseases have emerged, including the Ebola crisis (2014–2016), Middle East respiratory syndrome coronavirus (MERS-CoV), and severe acute respiratory syndrome (SARS caused by SARS-CoV-1) (2). COVID-19 primarily affects the respiratory system and spreads through fine droplets expelled from the mouth, nose, or saliva of infected individuals (3–6). The disease has affected millions of people worldwide, leading the World Health Organization (WHO) to declare it a global pandemic (7,8). Infection control guidelines recommended by the WHO emphasize the use of personal protective equipment (PPE) based on the assumption that the primary transmission mechanisms of SARS-CoV-2 involve direct and indirect droplet transmission as well as fomite contamination (9,10). The unprecedented scale of the pandemic severely strained global healthcare resources, resulting in widespread fear and uncertainty (11). In response to the rapidly escalating situation, precautionary measures were implemented worldwide. International and domestic travel were restricted, and disruptions in transportation significantly affected

the supply chains of essential goods (12,13). Powered air-purifying respirators (PAPRs) provide a higher level of protection compared with conventional non-powered respirators because the blower generates positive pressure within the facepiece under most working conditions, thereby reducing the inward leakage of contaminated air (14). Despite such protective measures, frontline healthcare workers continued to remain at high risk during the pandemic (8,15). In most healthcare settings, workers were provided with traditional PPE kits comprising N95 masks, gloves, goggles, face shields, and impermeable gowns that covered the body from head to toe (16,17). Experimental studies also demonstrated that SARS-CoV-2 and SARS-CoV-1 could remain viable in aerosolized form for up to three hours, although with a reduction in infectious titer over time (18–21).

The prolonged use of PPE under demanding clinical conditions created significant discomfort for healthcare workers, and in some cases led to fatigue, unconsciousness, and even fatalities (22). Nevertheless, the clinical relevance of certain experimental transmission models has been questioned (11). Furthermore, establishing definitive evidence for airborne transmission of SARS-CoV-2 presents considerable methodological challenges (8,9, 23–25). These uncertainties emphasized the urgent need to enhance the protection of frontline healthcare workers and reduce the risk of transmission from asymptomatic carriers. During the early stages of the pandemic, a severe shortage of essential protective equipment further complicated the situation. Consequently, governments, private organizations, and individuals worldwide began exploring innovative solutions to address shortages and develop alternative protective devices (26–29).

During this unprecedented global crisis, when many conventional manufacturing industries were either restricted or focused on producing essential medical supplies, three-dimensional (3D) printing technology emerged as a critical tool for rapid and cost-effective production of medical components (10–12). Additive manufacturing enabled decentralized and on-demand fabrication, thereby helping mitigate disruptions in conventional supply chains. Several components of PPE kits, including goggles, face shields, and protective helmets, were manufactured using 3D printing technologies. Additionally, various medical devices and accessories such as ventilator casings, oxygen concentrator components, and diagnostic swabs were developed through collaborative efforts involving hobbyists, industry experts, and government agencies. In some instances, scuba diving masks were modified for use as ventilator interfaces, and ventilator splitters were developed to allow a single ventilator to support multiple patients. Beyond these applications, a wide range of supplementary devices such as mask connectors, strap adjusters, and casings for continuous positive airway pressure (CPAP) and bilevel positive airway pressure (BiPAP) systems were also produced through additive manufacturing. Numerous designs and open-source solutions for diagnostic and protective equipment were shared and distributed globally (30–37). Although the supply of PPE gradually improved, repeated waves of the pandemic required governments to adopt rapid and scalable solutions to ensure the safety of healthcare workers. Commercially available PAPR systems manufactured by international companies such as 3M and Zimmer were reported to be effective; however, their high cost limited widespread accessibility (38). These devices are typically worn around the waist beneath PPE kits and provide filtered air through a blower mechanism, generating positive pressure within a connected helmet or facepiece. This configuration reduces breathing resistance, heat buildup, and discomfort while offering protection against airborne respiratory infections.

Consequently, several independent research groups and organizations developed alternative PAPR designs of varying shapes and configurations, many of which incorporated 3D-printed components and were supported by government or private funding initiatives (39–43). Various additive manufacturing technologies were employed for these developments; however, fused deposition modeling (FDM), an extrusion-based printing technique, was the most frequently utilized approach (44,45). FDM was preferred because it enables rapid prototyping, low-cost manufacturing, and localized production, thereby supporting on-demand fabrication and minimizing disruptions caused by global supply chain limitations (46).

Several innovative adaptations of PAPR systems were also reported. For instance, PAPRs were developed for firefighters to provide respiratory protection during COVID-19 without relying on disposable masks (Michigan Tech). In another approach, a conventional surgical helmet was modified into a PAPR device by integrating a filter and blower directly onto the helmet assembly (47). Similarly, snorkel masks were converted into PAPR devices using 3D-printed adapters and commercially available components (48). Other researchers developed low-cost deployable respirators powered by portable power banks to provide affordable protection for frontline workers (49). In addition, filters for PAPR devices were produced through reverse engineering and 3D printing techniques to ensure airtight sealing and controlled airflow through high-efficiency particulate air (HEPA) filtration materials (50).

II. Identification of Research Gaps

- i. The major challenge in the use of PAPRs is their high cost. A single PAPR unit can cost approximately \$1,800, placing a significant burden on departmental equipment budgets (OSF Saint Francis Medical Centers).
- ii. PAPRs also involve additional expenses. A typical PAPR costs around \$900, while the battery costs approximately \$130, and a charger for 10 PAPRs may range between \$1,700 and \$2,000 (Johns Hopkins University School of Medicine).
- iii. At approximately \$1,000 per PAPR, cost becomes a major factor influencing decisions related to upgrading or adopting respiratory protective equipment (North Shore–Long Island Jewish Health System).
- iv. Such products are often expensive for many workers in developing countries like India, including healthcare professionals and individuals working in hazardous environments such as waste management or mining.
- v. Individual components are also costly; for instance, helmets range between \$271.74 and \$351.74, batteries cost about \$130, and chargers for 10 PAPRs can cost \$1,700–\$2,000.

III. Research Motivation

The COVID-19 pandemic led to widespread lockdowns that disrupted industries, educational institutions, and healthcare systems worldwide. During this period, many professionals were required to work remotely while healthcare workers continued to operate under challenging and high-risk conditions. Motivated by the urgent need for accessible protective solutions, our team sought to contribute by developing devices that were not readily available across the country. Beginning with the production of face shields during the early stages of the pandemic, the work later progressed toward the design and development of a cost-effective powered air-purifying respirator (PAPR) using easily available components, thereby minimizing the impact of shipping limitations and cross-border supply restrictions.

IV. Objectives

This novel study has been designed to accomplish the following objectives:

- i. To develop an indigenously designed powered air-purifying respirator (PAPR) device.
- ii. To ensure the system is cost-effective and composed of easily available components, even during pandemics.
- iii. To enable its use in both medical and industrial environments.
- iv. To provide clear vision for the user during operation.
- v. To facilitate effective communication while wearing the device.
- vi. To enhance user comfort and overall sense of well-being.

V. Design Methodology

The objective of this study was to design and develop an indigenously engineered powered air-purifying respirator (PAPR) that is cost-effective and readily accessible for healthcare workers. To achieve this, concurrent design and engineering principles were applied during the development process. The device was designed and assembled using SolidWorks (Dassault Systèmes), and the components were subsequently fabricated using 3D printing technology. The conceptual workflow and development stages followed in the creation of the device are illustrated in Figure 1.

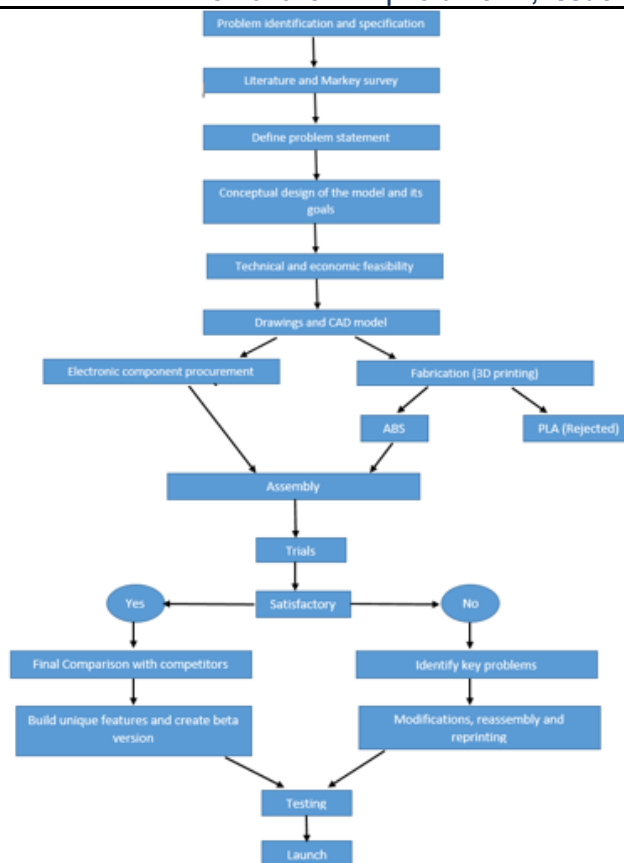


Figure 1. Conceptual flowchart of the product design process.

- i. **Problem Identification and Specification** – Defining a problem requires careful consideration of the socio-technical system, including the stakeholders who may be affected by or influence the design decision. A clearly defined problem helps structure and guide the process of developing an effective solution. Therefore, the problem was identified by analysing the needs of healthcare workers and the limitations of existing respiratory protection systems.
- ii. **Literature and Market Survey** – A comprehensive review of relevant literature was conducted to understand previous work related to the design and development of PAPR devices. This review included scholarly publications, case studies, and available reports. In addition, a market survey was carried out to identify commercially available PAPR systems and alternative components that could be used in their design. Particular attention was given to the cost, availability, and accessibility of the devices and their components.
- iii. **Definition of the Problem Statement** – The study identified the need for an additional and reliable protective device that could remain accessible despite shortages and supply restrictions. Reports of fatigue, unconsciousness, and fatalities among healthcare professionals working long hours in critical care environments highlighted the necessity for a device that could provide improved respiratory support and protection.
- iv. **Conceptual Design of the Model** – Once the decision was made to develop a PAPR device, a conceptual model was created by analysing existing commercial designs and their components. The process involved extensive brainstorming with medical professionals and engineering experts. Initial sketches and virtual models were prepared, followed by the development of free-body diagrams to visualize the arrangement and interaction of the device components.
- v. **Technical and Economic Feasibility** – A key design objective was to develop a device that could be assembled using components readily available from standard electrical or electronic stores. However, due to COVID-19 related restrictions and supply chain disruptions, several components were either unavailable or significantly overpriced. Therefore, the final components were selected based on their low cost, availability, and ease of replacement, ensuring minimal maintenance requirements.
- vi. **Component procurement, expenses, and comparison with existing devices** – Each component of the

device was carefully selected with an emphasis on cost efficiency and availability. Table 1 presents the cost details of the various components used in the device. Figure 2 provides a comparative analysis of different PAPR designs reported in research studies during the COVID-19 pandemic by academic institutions and independent researchers. However, most of these studies did not report the actual cost of the developed devices. Therefore, commercially available PAPR systems from major global manufacturers were considered for cost comparison. The price differences between the proposed device and commercially manufactured systems are summarized in Table 2.

Table 1. PAPR components and the respective cost

S. No	Component	Procurement	Price
1	Blower Fan	Amazon	499INR (6.53 \$)
2	Battery	Vendor	500 INR (6.54)
3	Helmet	(3D Printed)	650 INR (\$8.51)
4	Helmet Harness	Commercially available	100 INR (\$1.31)
5	Hose	Commercially available	350 INR (\$4.58)
6	Helmet Harness	(3D Printed)	150 INR (\$1.96)
7	Box or housing	(3D Printed)	400 INR (\$5.23)
8	Filter	Amazon	399 INR (\$5.22)
9	Banana plugs	Commercially available	10 INR (\$0.13)
9	Wires	Commercially available	25 INR (\$0.33)
10	Switch	Commercially available	10 INR (\$0.13)
11	Belt	Commercially available	30 INR (\$0.39)
Total:			3023 INR (\$39.55)




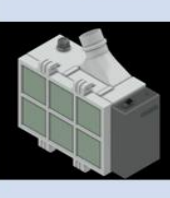


https://www.berkeley.edu/news/2020/04/ready-to-deployable-respirator-conditions-help-frontline-healthcare-workers (UC Berkeley engineers)	https://today.duke.edu/2020/04/covid-19-papr	https://talk.lansingmakersnetwork.org/t/3d-printing-time-help-needed-for-papr-respirator-project/2188	https://www.indiamart.com/proddetail/aura-papr-23142866830.html	Present Design	
					
Bulky design with separate battery chamber	Elongated towards back. This could create discomfort while head movement	Multiple segments attached to the head gear thereby making uncomfortable situation for the user	Compact yet contains multiple 3D printed connection that can loose or wear out with time thereby becoming an inlet source for the contaminants	Huge size at the back will cause discomfort while standing and sitting. Also a wide diameter house can cause weight elevated at one side.	All components closely packed with their respective chambers. Only on side opening with an adjustable belt to easily move the box according to the direction.
Commercial medical viral filter with no specifications to stop covid particulates	HMEF filter alone is incapable of stopping covid virus	No specific detail of the filters used	No specific detail of the filters used	Single layer heap filter with an efficiency to stop covid particulates	Twin layer (activated charcoal and H13 grade heap) filter. An additional HMEF filter at the outlet of the box to prevent any further contamination being entered.

Figure 2. Comparison between different PAPR developed by universities and freelancers

Table 2. Cost comparison between different manufacturers according to e-commerce website Indiamart.com

3M (PAPR) Versaflo Powered Air Purifying	1.50 lakh
Honeywell PA700 Powered Air Purifying	2.10 lakh
Jupiter Ready to Use Pack A2P3 Dealer	85000
Drager X- Plore 8000 Powered Air Purifying	1.12 lakh
RPB PX5 PAPR Powered Air Purifying Respirator, Particulate	97,000
MARK AURA (PAPR), Infectious diseases, Model Name/Number: AURA-1	45,000
Duraflow Air Respirator	74,000
PAPR - Powered Air Purifying Respirator, Model Name/Number: Ultrahood	60,000

5.1. Blower Fan: This is a brushless turbine air blower of the axial variety. The DC blower fan operates at 4500 RPM with a current of 2.70 A and a power output of 32.4 at 12 V (working voltage 6.0-13.2 V). The unit produces 1.95 psi of static pressure, 1.08 m³/minute of airflow, and 60 decibels of noise. This blower's features made it a good fit for the heap filters, which benefit from a high airflow rate with minimal noise. These are commonly used in BBQ stoves and can be purchased at any local electronics store. The air and pressure settings were determined with the help of a Philips BIPAP machine. Before the waist gear was ready, this was the only way to get oxygen into your system. According to the user's observations and evaluations, the ambient air quality and noise levels were adequate. As a result, the decision was made to use the fan.

5.2. HEPA Filter: The two-way filter as shown in figure 3 (a) is positioned at the top of the box/housing. As a result of its total openness, it is able to take in a full and healthy supply of air. Activated charcoal, embedded in a honeycomb structure, improves airflow and gets rid of odours and other potentially harmful substances like total volatile organic compounds (TVOC). In contrast, the H13 Grade HEPA filter behind it is 99.97% effective at removing PM 2.5, which includes allergens as small as 0.2 microns in size, such as bacteria, viruses, and dust mites. Better air and filtration are provided by the vertical slots of the HEPA layer and the honeycomb structure of the activated charcoal layer, which also acts as a silencer for the airflow. The manufacturer states that its lifespan is one year, but that this is significantly dependent on the number of hours it is used. However, as this is for COVID wards, the filter should be changed every two months. Additionally, it is suggested that an HMEF filter as shown in figure 3 (b) be installed in the box's exhaust system. These filters are designed for single-person use for a maximum of 24 hours. Lightweight and effective against 99.9% of germs and viruses, they are a great addition to ventilators. The fact that it is an exchange medium for healing and moisture means that it has a low potential for water loss. Using both filters aids in preventing recontamination and the spread of disease by making it impossible for any contamination to pass through the box.

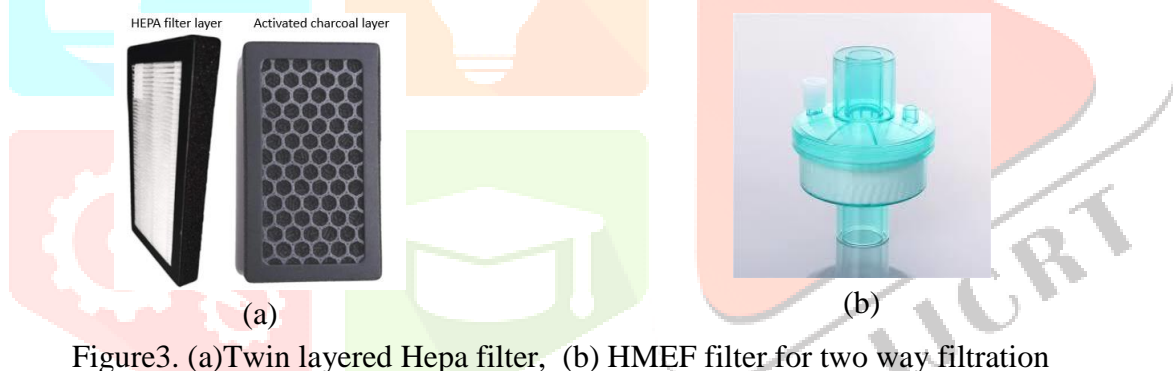


Figure3. (a)Twin layered Hepa filter, (b) HMEF filter for two way filtration

5.3. Circuit.: The circuit consists of 12 V each red and black electric wires, 2 sets set of high quality 4mm banana plugs. The set consists of a plug and socket (Male and Female) and can connect with 2mm to 5mm wires. The electronic line connection is quick, easy, secure, and dependable. These are readily available in any electrical and electronic shop at the lowest prices. The male part was connected to the battery and the female with the blower.

5.4. Battery: As illustrated in figure 4 the battery is a 11.1 V lithium-ion prismatic customized battery consisting of 3 cells of 3.7 v 9000 mAh single cell each. We can manage upper and lower cut off and short circuit-off its battery management system. Once fully charged, it can run for 10 hours with the provided blower.



Figure 4. Customized battery

5.5. Box/Housing: The whole case or housing is 3D printed, with just the back cover being created separately. It is where the battery, circuit, and fan/blower are stored. Like what's illustrated in Figure 5, they all include separate, hermetically sealed compartments. Closing the back cover is a lot more difficult than opening the front because of the secure clamps. Only the filter housing serves as an intake. It's always been left wide open at the top so the fan can draw in as much air as possible. Given that the filter's effectiveness for 0.3 m NaCl aerosols, PF, and flow rate in the box has not yet been tested, an extra HMEF filter is employed at the exit (diffuser) to offer additional purification. This is done to further eliminate the potential for contamination by keeping harmful microorganisms from entering the container. A better airflow and lower pressure drop are two goals of the diffuser's design. The circuit consists of just two 220 V volt wires (red and blue), with the blower's male end connected to the battery. A 5V on/off toggle switch and an analogue battery voltage display are built in. The user will be reminded to swap the battery out when necessary.

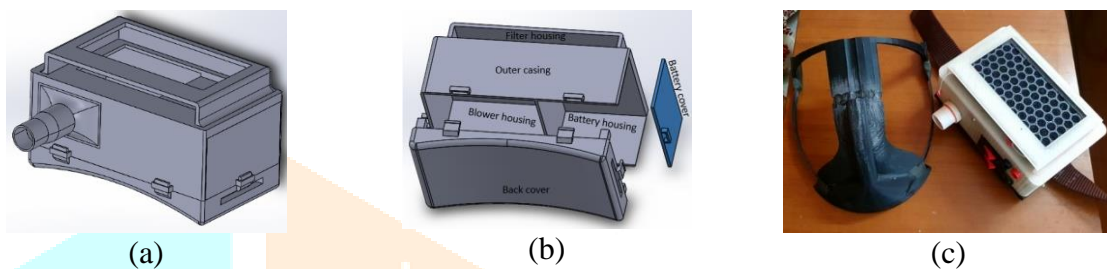


Figure 5. (A) CAD model of the assembled box (B) Exploded view of the box with all independent housings for the filter, blower and circuit, and battery, back cover with clamps, (C) 3D printed model of the box containing the blower, filter, and battery.

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5.6. Head Gear: All components of the headgear (helmet and strip) are 3D printed with ABS material using an elevated 3D hobby printer. PLA and ABS are compared in Table 3, as the helmet and box were predominantly printed with PLA. However, due to the tremendous heat, both models were warped, with no prospect of recovering their previous form. Therefore, the complete assembly was 3D printed in ABS material, which is more functional than PLA. All available printing methods were thereafter evaluated to determine which was the most efficient and cost-effective. Table 4 covers the available technologies and printers, as well as their estimated costs and materials. The most expensive printer was Stratasys' Fortus 4,000 MC, while the least expensive was Reality. Additionally, the availability of Fortus materials was not fast, as the parent business sold it and its logistics required authorization from the local government. Due to the biocompatibility of the material, it was extensively used for ventilator components and other surgical instruments. Creality, on the other hand, was rejected due to its small print bed size and poor printing at high speeds, even with 100% infill density. So, the elevated 3D printer was chosen for the build because it could make a prototype quickly and with high quality.

The helmet conforms to the head harness and may thus accommodate a wide range of head circumferences. For maximum support and durability, the infill density is set at 100%. The diffuser on this device directs air away from the user's face, preventing dryness and fogging of the visor or face shield. The visor, or face shield, is built into the hood that covers the headpiece. The visor can be kept at a safe distance from the face and improved visibility can be achieved thanks to an adjustable 3D printed

strip on the inside of the helmet. To provide a secure connection, the breathing hose's attachment is maintained at the same diameter as the hose, within a tolerance of +1 mm. The surgeons didn't use any unnecessary clamps since they could get caught up in the hood or snap off under the weight of a sudden pull, both of which could have had disastrous consequences. There are four velcro attachment points on the helmet and strips for a secure fit of the hood.

Table 3. Material selection based on scoring

Properties	Material	
	ABS	PLA
Strength	4	3
HeatResistance	5	2
Durability	4	3
Printability	3	4
Post Processing	4	3
Cost	3	4

Table 4. Type of technology and printer available with the estimated cost and material

Technology	Printer	Material Used	Cost per spool/canister	Availability	Biocompatibility
FDM	Raise 3D	PLA/ABS	2000(INR)	Easy	No
	Fortus	ABS/PC		Difficult	Yes
	Creality	PLA/ABS	1500(INR)	Easy	No
Polyjet	Eden	MED 610		Difficult	Yes
SALE				Difficult	No

Figure 6 depicts the prototype after it was built and ready for usage by medical professionals in covid and surgical wards (a). Wearable over the waist and under the PPE equipment, it offers healthcare personnel further protection and comfort during covid testing, postmortems, and other procedures that generate aerosols (see Figure 3). (b).



Figure 6. (A) Assembled PAPR system, (B) Helmet gear and waist gear donned by the healthcare worker, (C) device covered under the PPE kit hood.

Despite the fact that it has not yet been validated, it was utilised by adhering to all of the other covid precautions. by the state or the government. Because the container was meant to be a single piece that was 3D printed and had only two openings (an air inlet and an air exhaust), it did not have any open sources through which the virus or bacteria could enter. However, in order to take further safety measures, a HWEF filter was installed in the box diffuser so that the virus could not spread. During the procedures and the hour-long covid ward service, this device helped provide a sense of comfort for the user by supplying them with clean and filtered air while they were wearing unbreathable PPE kits.

Last but not least, the present prototype can be designed in two versions. Version 1.0 is for healthcare workers, and version 2 is for industrial users, Table 5.

Table 5. Two versions for different areas of applications

Version 1 (Healthcare workers)	Version 2 (Industrial workers)
<ul style="list-style-type: none"> Effectively used by the surgeons and other healthcare workers. Worn under PPE kit hood. 	<ul style="list-style-type: none"> Welders, gas chambers, and coal miners can use snorkel masks, while the firefighters can use helmets
<ul style="list-style-type: none"> We will inbuild a Bluetooth microphone for good coordination between doctors and other present medical teams. 	<ul style="list-style-type: none"> Walkie-talkie arrangement for coordination among fellow workers. This system can be incorporated into regular industrial helmets with slight modifications.

5.7. Below mentioned points can be considered when designing and developing a cost-effective and efficient PAPR.

- Infill density should be 100 % for the helmet. If clamps are added, they should be in the downward position so that it does not get entangled with the hood.
- Filter opening should be wide or of the same dimension as the filter for unrestricted air intake. Any covering would limit the air supply, and two blowers or a more powerful blower would be required, increasing the weight and cost.
- A filter life indicator can be incorporated, which would turn the device off and doesn't function if the filter is not changed.

VI. Discussion

The purpose of this study was to demonstrate the design and development of a low-cost powered air-purifying respirator (PAPR) device using locally available components while minimizing dependence on complex supply chains. During the COVID-19 pandemic, strict restrictions and disruptions in transportation delayed or prevented the delivery of essential equipment, thereby compromising the safety of many individuals, particularly healthcare workers (HCWs). Although HCWs strictly followed COVID-19 safety protocols, the risk of cross-contamination remained high. Therefore, the development of an additional protective device was considered necessary to enhance worker safety while simultaneously addressing supply chain limitations associated with protective equipment. The proposed device was designed using a simple and accessible fabrication process that can be easily replicated, open-sourced, and shared for further development.

Several reports have documented the successful use of improvised or home-made alternatives to expensive commercially available protective equipment. However, only a limited number of studies provide detailed descriptions of the design and development processes. The device presented in this study was fabricated using a low-cost desktop 3D printer and readily available materials. Among additive manufacturing technologies, fused deposition modeling (FDM) was selected due to its affordability, accessibility, and ease of use. During the pandemic, numerous hobbyists and enthusiasts contributed to the production of protective equipment using such desktop printing technologies. Desktop printers can typically utilize materials such as ABS or PLA. However, industrial-grade printers such as PolyJet or Fortus 400mc involve significantly higher printing and material costs. In this work, a Raised3D printer was used due to its balance between cost, build quality, and surface finish. Furthermore, ABS material was preferred over PLA, particularly for regions with higher ambient temperatures such as India, as PLA is prone to deformation under elevated temperature conditions.

An industrial safety helmet could potentially serve as an alternative headgear component. However, such an approach would require significant modifications to the diffuser design and breathing hose connection. Due to the urgency of the pandemic situation, there was limited time available for extensive redesign and testing. Therefore, a lightweight helmet design was developed that provided sufficient internal space for the head harness and other components. Preliminary testing and user observations suggested that the design was suitable for practical use. Alternative designs reported in the literature include modified snorkel masks and surgical helmets; however, these configurations often required additional attachments that increased complexity and reduced comfort for the user.

During later phases of the pandemic, the supply of PPE kits and N95 masks improved significantly. Therefore, disposable hoods from existing PPE kits were incorporated into the design. In addition, HMEF

filters available within hospital environments were used alongside HEPA/activated charcoal layered filters to enhance filtration performance. At the time of writing, the device is undergoing further evaluation through virology testing, UV-C viricidal testing, UV-C intensity analysis, airflow rate measurement, and filtration efficiency assessment.

The prototypes developed in this study were tested on a limited basis through user feedback and observational analysis. Particular attention was given to user comfort, including prevention of visor fogging and avoidance of dryness in the eyes and nasal passages during prolonged operation. The selected blower was chosen after comparison with airflow characteristics observed in BiPAP machines, primarily in terms of airflow sensation and delivery rate. For safety purposes, two filtration stages were incorporated: one at the air intake and another at the outlet of the housing unit. The blower and battery were integrated within a single housing structure fabricated using 3D printing. Nevertheless, as with any protective equipment, the device must undergo long-term testing to validate its efficiency, durability, and safety under real clinical conditions.

During the pandemic, 3D printing emerged as a critical technology for the rapid development of essential devices, particularly when conventional manufacturing systems were disrupted. The ability to quickly design and produce components locally demonstrated the significant potential of additive manufacturing in emergency situations.

Prior to the pandemic, PAPRs were not widely available in many markets, and their high cost limited accessibility, particularly in middle-income countries. Both institutional procurement and individual purchase of such devices remain expensive. In the early stages of the pandemic, limited availability further increased market prices. The proposed design addresses this limitation by providing a cost-effective and easily manufacturable alternative using locally available materials and 3D printing technology. Furthermore, the open and collaborative nature of such developments has encouraged the participation of hobbyists, engineers, and researchers in producing protective equipment during emergencies.

Although the device is currently undergoing further evaluation, comprehensive analysis of its long-term benefits, safety, and potential impact on infection rates among healthcare workers is necessary. However, such clinical evaluations require significant time and resources. Facilitating access to such innovations and ensuring their timely deployment during emergencies remain essential for improving preparedness for future healthcare crises. Ultimately, collaborative efforts among researchers, healthcare professionals, and technologists can play a vital role in developing effective and accessible protective solutions.

VII. Conclusions: In conclusion, this research presents a straightforward and economical design for the PAPR. It was created in response to the limited availability of safety equipment, with the intention of boosting the level of user safety and protection while simultaneously supporting local manufacturers. It is manufactured utilizing technology that allows for the printing of three-dimensional objects at a low cost, which is encouraging for locally developed components. Because of the low cost, both the medical personnel and the administration of the hospital will be encouraged to use respirators. The employees will have an easier time training in case there is an outbreak, and they will also be able to replace any damaged components more quickly. Because of the way that it was designed, there is no reduction in the amount of airflow, and the noise level at the outlet provided by the helmet equipment is lower than it normally would be. Because the gadget was created after going through a number of iterations, it does not require significant testing before it can be examined for its application in the medical field. There are two different iterations of it altogether. Version 1.0 was utilized by the HCW, whereas version 2.0 was utilized by workers in industries such as petrol stations, landfills, foundries, and mines. The architecture of this concept is geared mostly for individuals who provide medical services as their target audience.

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