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APPLICATION OF 3D PRINTING IN THE HEALTHCARE SYSTEM

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ABSTRACT

3D printing is having various applications in healthcare, aerospace industry, building, electricity, architecture, medicine, food, textile, automotive industry, and many other areas. 3D printing technology is a relatively new, rapidly growing method involved in producing healthcare products. The first instance of the coronavirus illness (COVID-19) was discovered in Wuhan, China, in December 2019. On March 12, 2020, the World Health Organization proclaimed COVID-19 as a pandemic. The new coronavirus triggered a pandemic with high mortality and morbidity, posing problems for both patients and healthcare staff. The healthcare system is waging a struggle to boost bed capacity, supplies, and skilled staff. To alleviate the lack of critically needed medical supplies, crisis-response initiatives are underway. The need, particularly for personal protective equipment (PPE) and medical supplies has been tremendous during the COVID-19 epidemic. The traditional manufacturing of medical equipment has been contested by rising aggregate demand, and the necessity for low-cost, easy, and quick production is greater than ever. Producers have turned to 3D printing to close the gap and increase the production of medical devices. To accommodate 3D printing, several previously produced designs have been modified and redesigned. It is pointed out in this review that three-dimensional printing might help the entire world deal with current and upcoming issues.

Index Term - 3D printing, healthcare, COVID–19, personal protective equipment, Medical devices

1. INTRODUCTION

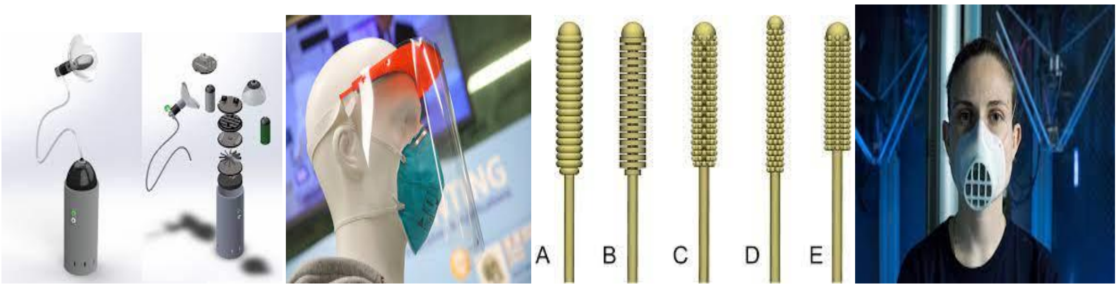
A manufacturing process known as 3D printing involves materials such as metallic or plastic for layering to generate 3D stuff. [(1)]Rapid prototyping or additive manufacturing (AM) are other terms for it. [(2)] The origin of 3D printing may be traced back to the 1960s. Even until the 1980s, when it was given the name additive manufacturing, it remained mostly unknown. In 1988, Chuck Hull unveiled the stereolithography device, the first industrial AM device. [(3)] As manufacturers became interested in this technology, it marked the beginning of "the revolution." Professor Cima coined the phrase "3D printing" in 1993 to describe a printer that could create a model utilizing a variety of printing materials such as plastic, metal, and ceramics. In the past 25 years, 3D printing technology has improved significantly, earning the title of "fourth industrial revolution."[(4)]

The COVID-19 pandemic is a viral infection caused by a new coronavirus. It is a sickness that is extremely infectious. Because there is no effective therapy for COVID-19, it is attempted to reduce the number of people who get the condition. Personal protection equipment (PPE) is utilized for the prevention of infection. The virus has also affected global supply networks, making urgent transit of physical products an extra problem. Digital files are unaffected, and locally manufactured things might be a suitable answer to these issues, allowing 3D printers to make masks, ventilation devices, and portions of the material used in testing. The fast prototyping community stepped up to assist with the personal protective equipment shortage. To find a speedy fix for the PPE kit, large manufacturers, tiny maker communities, academic institutions, and laypeople all collaborated. Makers have worked with government authorities all around the world to lower regulatory requirements and liability concerns to mobilize 3D printing. In addition, 3D printing holds promise for treating organ damage brought on by the disease. (5)

In recent years, 3D printing technology has captured the interest of many societal segments and has shown to have a wide range of applications in different fields of human participation. It has a lot of promise in medicine and health science for creating prosthetics, bone grafts, implants, and machine parts. Biotissues and cell printing material were used to print artificial body parts and organs, as well as synthetic heart tissue and bionic ears. By layering a printing substance on top of a computer design, 3D printing allows a real item to be created from a digital design as mentioned in Figure 1. 3D modeling software such as SolidWorks or Tinkercad may be used to create digital designs in open source software. Depending on the 3D printing technology, material waste can include support materials, base layers, and exposed powder beds. Traditional production processes frequently waste 80–90% of the raw resources. (5-6)

CAD Designing

3D Printer



Ventilator **Face shield** **Nasal Swabs** **Facemask**

Figure 1. Computer-aided design modelling and production of various items using 3D printing in the healthcare system [7]

2. Application of Additive Manufacturing in the Healthcare system

2.1 Respiratory Support System in Hospital

COVID-19's influence in Italy has resulted in a regional scarcity of critical equipment like masks and hoods for non-invasive ventilation. The fundamental component of such respiratory support equipment, the venturi valve, was difficult to replicate. [8] Due to the high demand, a community of doctors and engineers using 3D printing at a local Italian company called Isinnora has successfully developed a way for producing these valves to supplement the local supply. [9]

Using a ventilator splitter that was 3D printed allows using one ventilator for numerous patients, which is another way to enhance the local supply of ventilators. The USFDA does not object to the creation and implementation of specific devices, such as the T-connector, that meet the requirements outlined in the guidance given to the FDA for use in placing multiple patients on mechanical ventilation when the number of patients who need invasive mechanical ventilation goes over the availability of the accessible ventilators and typical healthcare has been switched to crisis care in the interest of preserving life. The FDA has stated that it has "no objection" to this method in the COVID-19 emergency. The use of 3D printing is still quite limited for a large portion of the local population, so strong partnerships between businesses and hospitals are necessary to ensure adequate production methods for pertinent clinical applications. Isinnova's engineers are always working to provide novel modifications to currently on-the-market respiratory products. [10] Most recently, GrabCAD user FilpKober enhanced and made public non-adjustable venturi valve designs. At rates of supplemental oxygen supply valve design attain a certain level of inspired oxygen as in figure 2. [11]

Figure 2 - free to-use non-adjustable venturi valve for a fio2 of 33% and 101 per min of supplemental oxygen flow. [11]

Respiratory support is required for patients who are suffering from breathing problems because their lungs are not working properly. In such cases, an abundant amount of oxygen is required, and removing carbon dioxide from that ventilator is needed. A “Lifesaving” supportive measure is a ventilator. During the time of the pandemic, the number of patients suffering from COVID-19 has risen. However, that amount of ventilators is not available in the hospital. Their high-cost un-obtainability is a challenge. [12]

There are two different types of ventilators – 1. Invasive ventilator
2. Non-invasive ventilator.

The bulk of 3D-printed designs are used to treat patients' respiratory needs. Scuba diving masks were revealed to be ventilators employing a conversion that can be attached to the oxygen tanks in terms of safety equipment. [13, 14]In a very short period of time, part of the ventilation was manufactured with the help of 3D printing. In Spain, the first ventilator was created by 3D printing. 3D printing machines fulfil the gap between the availability and requirement of ventilators which is the main objective of 3D printing. To design and develop the 3D-printed ventilator Leitat-1 technology was used. In 2008, G. Neyman and Charlene Babcock created and unveiled a straightforward splitter mechanism allowing the simultaneous use of one ventilator for several patients in emergency scenarios. [15] This concept served as the inspiration for the tube spilsplitterst Form labs and other businesses created. The simultaneous usage of a single mask is acceptable while using tubing spillers. [13, 16]

3. 3D Printed Devices in Healthcare Systems

Personal Protective Equipment (PPE)

In the context of quarantine safety precautions, the pandemic has caused concern and anxiety among the general population. Many reusable PPE devices with insertable filters have been created by members of the global 3D printing community. These devices are typically produced at a lower cost using desktop filament extrusion printers. Because there are many difficult issues to overcome while designing 3D printed PPE, 3D printed PPE takes many hours to manufacture on typical desktop printers. To manufacture dozen of masks per printer, this process can be paralyzed with many 3D printing laboratories with multiple printers. [17]

Facemask –

Facemasks are worn to shield the user's face from liquid pollutants and airborne toxins. A few solutions are 3D printed. To create a prototype N95 mask, the FDA, NIH 3D print exchange, and the United States vetethe rans Association are collaborating. [18]

Masks have been in limited availability worldwide, thus designers must concentrate on other strategies to meet public demand. Scuba and snorkel masks have been converted to serve a variety of purposes and can be worn as facemasks. [19-21]This converter can attach and hold a filter to a mask, which can be quickly and afforda3D-produced used in a small size. To fit inside the holder, the users must have access to the mask and filter paper. This mask has multiple uses. Every time after usage of this mask there is a need for disinfection. The only way to protect against the COVID-19 pandemic is by the daily production of PPE like scuba diving masks, and such creative innovation can advance global science. [22, 23]

Polylactic acid filament serves as a flat piece in the printing of Copper 3D NanoHack but this design has several demerits. In the desktop printer, just one mask solely can be printed at a time due to the flat design. After being heated to a temperature of roughly 55-60 degrees Celsius using forced air or by immersing it in hot air, it is then physically finally put together to form its three-dimensional form. [24]

Figure 3 -copper 3D Nano hack mask [24]

Thingiverse user Kvatthro designed the HEPA (High-Efficacy Particulate Absorbing Filter) mask which can be produced with desktop printers. Due to the possibility of customizing the mask to each user after heat exposure and achieving the best possible air seal in field settings, PLA filament is utilized. As seen in Figure 4, several variations of masks for males and females have ports at the front that can accommodate an interchangeable HEPA filter insert. [25, 26]

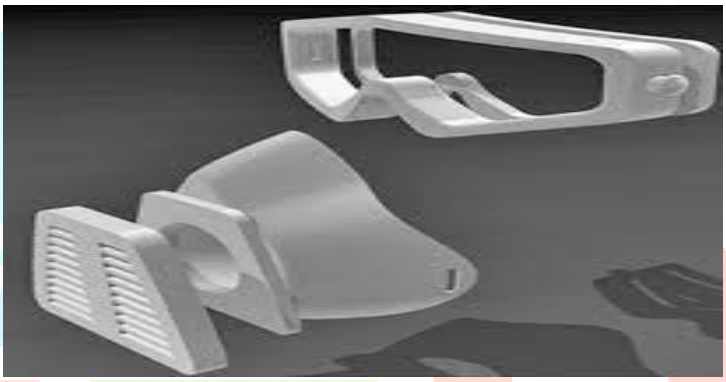


Figure 4 - design of a HEPA mask with a box for inserting a HEPA filter[26]

Face shield

One of the most often used preventative measures, face shields put a physical partition separating the user's face from the environment. Face shields are equipment that is recommended by WHO as a part of PPE for the prevention of airborne infection so that the global propagation of COVID-19 and another some infectious disease can be avoided. [27, 28] It is a simple device in which the headpiece is covered with a face shield which is made from a transparent plastic sheet that is connected. Many companies such as Form labs, Prusa, and Stratasys, three distinct 3D printing businesses, offer standards for the design and manufacturing of the face shield and these designs are shared online. [29, 30, 31, 32] Most of the current face shield design has been constructed of a user-specific headband that was 3D printed and is designed to support a front plate that could be created using any clear material which could be laser cut. [31] Despite being reusable, face shields are disinfected after each use and there are established processes for doing so. [33] WHO still recommends the wearing of glasses along with the face shield for the protection of the eyes some designers also suggested for designing a large face shithathich allows enough space for wearing personal goggles [34,35]

figure – 5 prusa research's initial reusable 3d printed face shield [33]

Hand-free Tools

For the period of 72 hours, the variant of COVID-19 could stay on different materials so it requires conscientious precaution. [36] Avoiding direct contact with surfaces during the pandemic, especially in public and medical facilities, is crucial to lowering contamination. [37] COVID-19 virus spreaders are objects like doors, door handles, buttons, etc. having potential because of interactions with different people often. [38] For that, there is a need for modification of a range of handles to allow another mechanism for opening doors without skin coming into contact with the surface directly have been created, materialized, and produced on the majority of 3D printing platforms. Various types of hands-free tools were designed and produced by Francois et al. and used in Greater Paris University Hospitals and other sites. The door handles devices for hands-free opening doors are installed in such a way that it is possible to open and shut the door using the elbow or forearms. [38] Different kinds of hands-free door openers have been designed and materialized by the company in a cylindrical, rectangular, spherical &circular shape handler they can be produced using 3D printing techniques such as multi jet fusion, selective laser sintering, or fused filament fabrication as in figure 6. [39] Furthermore many designers provide hands-free devices for turning on or off switches, releasing water faucets, catching handles, and other common tasks for personal usage. [40]

Figure – 6 Hands-free models [39]

Nasopharyngeal swabs

Massive screening is an essential measure for battling the COVID-19 outbreak. Reverse transcription polymerase chain reaction (RT-PCR) is used to examine the sample, which is taken from the upper part of the respiratory system. **[41]** For virus detection nasopharyngeal swabs provide the highest sensitivity. **[42]** It is a medical device in the form of a rod shape, with short synthetic filaments covering the head. It is utilized to gather a patient's upper respiratory tract secretions. For the head storage in a vial with viral transport media, there is a swab having a breakpoint on the shaft. Then vial is sealed and sent for testing. The swab must be flexible and sterilizable so that a safe and reliable test can be done. **[37, 43]** For COVID-19, cotton swabs are not allowed. **[41, 42]** FFF printable and sterilizable PETG nasopharyngeal swabs are created by Cox and Kopsell. **[44]** By using commercial swabs clinical test performed as a control and a 3D printed model is more effective than a control group. Up to 4 million, test swabs which are FDA registered created per week via vat photo polymerization with medical grade design by Carbon, Form Labs, Envisiontec, Origin, and Abiogenix companies. **[45]** Some of the nasal cavity swab designs, such as the exchange respiration model created by Marianne (Johns Hopkins University Applied Physics Laboratory). **[46]**

Figure – 7 Nasopharyngeal swabs

Isolation Chamber and Wards –

For patients who are infected with COVID-19, any suspicions can be verified as ed infection, isolation rooms or wards are required to prevent the spreading of that infection. Patients in the hospital may transmit the illness through droplets and aerosols. Therefore there is a need for the development of an isolation chamber. **[47, 48]** For COVID-19 patient's negative airflow isolation chamber was designed by Cubillos et al.**[49]**in this device, For constant negatiairflow low, a clear plastic bag is wrapped over a rigid cubic frame chamber. In that way, air from the inside chamber is prevented from contaminating the external environment. To achieve this, 3D-printed ports are used, allowing for nebulization, oxygen administration, and suction. A headbox with negative pressure isolation called a "badger box" was developed in a partnership between Sector 67 and the University of Wisconsin-Madison Department of Surgery, Dr Hau Le, and UW Madison College of Engineering**[50]**. This headbox is made using additive manufacturing to create glove grommets. Chinese companies can be highlighted in the large-scale project, or the f creation of 3D-printed isolation chambers or wards. **[51, 52]** For patients these wards can be used as a cozy setting for solitude and treatment. For healthcare professionals like doctors, and nurses who are in direct contact with the patient, it is also serving as a maintained properly and secure resting place. The typical ward is 2.8 meters tall and 10 meters square. Construction of 3D-printed wards happens quickly and automatically. The 3D printing process calls for little labour expense. These wards can be relocated, and they can be wired into a network for power. [53, 54] The material utilized in newly constructed 3D printed structures can be recycled, such as industrial or solid construction debris. [51]

4. 3D Printed Medicines

Tablets and capsules are solid oral dosage forms. Manufacturing of these involves multiple processes like blending, mixing, milling, and finally compression into tablets. This manufacturing process's main drawbacks are that it takes a long time, is expensive, and requires specialized labor. [55, 56] 3D printing is different from traditional mass production. It required less time for the manufacturing of tablets and due to this rapid release of drug products in the market can be possible. In a customized way, there is the possibility of the 3D print oral solid dosage form (OSDF) with different drugs. According to the patient's characteristics, these medicines can be manufactured in a decentralized manner, with controlled dosage, controlled release, and most crucially in a pandemic situation. Due to stability concerns throughout the production process, computer-aided design (CAD) enables the quick manufacture of medications as well as speedy production. [57] Therefore, 3D healthcare goods should follow GMPs and fulfil the requirements and quality of traditional dosage forms. [58, 59]

5. Other applications of 3D printing

Today, 3D printing is widely employed in a variety of industries, including the building and construction, electrical, architectural, medical, food, textile, automotive, pharmaceutical, and fashion industries. The challenges presented by COVID-19 are numerous, and the only solution for these issues, from personal protective equipment (PPE) to emergency homes to isolate patients, is 3D printing. [60]

- 3D printing technology can be used to replicate the skin's natural structure.
- Drugs may be generated with remarkable efficiency using 3D printing; size reduction, necessary dosage, and precise drug control are all made possible.
- Organs and tissues can be replaced, enhanced, or kept functional through 3D printing.
- The goal of 3D printing technology is to recreate, enhance, or maintain the functionalities of bone or cartilage that have been damaged by trauma or disease.
- The failure of an organ caused by an illness, an accident, or a birth defect can also be printed using 3D printing.
- Since 3D printing allows for the creation of manipulable models of cancer tissues, it has the potential to accelerate cancer research.

6. Conclusion –

The pandemic hugely affected our lifestyle due to COVID-19, and medical and preventive supplies demand is increasing there is a shortage of that so one of the main essential concerns is to control and avoid the further spread of this virus. Most governments and businesses at the time were unable to supply the necessities. Through the online community, designers from around the world receive knowledge about potential designs and consumer needs. With the use of recent developments in additive manufacturing for quick emergency prevention, diagnosis, and treatment, a proposed design was produced using 3D printers. Numerous significant 3D printer manufacturers and university partnerships made it possible for new products to be prototyped and tested for quality before being released online for general usage. Nasal swabs being 3D printed in the early stages of the pandemic is one of the key benefits of this partnership. Lack of safety rules and achieving the criteria of proposed devices are two major obstacles facing 3D printing. Because of this, authorities and governments can set up a uniform procedure for regulatory inspection of the designs and clinical uses of 3D-printed medical devices. Although these efforts fall short of meeting all needs for quality and quantity, it was a big step in demonstrating the production capabilities and potential of 3D printing. It is anticipated that patient care settings will improve in the future thanks to technological advancements and increased engineering utilization in the medical sector.

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