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Innovative application of Additive Manufacturing in Biomedical Healthcare Technologies

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Abstract: 3D printing or additive manufacturing is the process of producing three-dimensional solid objects from a computerized record. The printer utilizes a sort of layering process, by which one layer is added after the other until a fully formed object is obtained. It enables creators and architects to make complex parts for automobiles, machines or planes a lot less expensive and significantly less time than some other manufacture techniques. It does not require the use of fixtures, cutting tools, coolants, and other auxiliary resources. It allows design optimization and the production of customized parts on-demand. Its advantages over conventional manufacturing have captivated the imagination of the public, reflected in recent mainstream publications that call additive manufacturing “the third industrial revolution.”

COVID-19 has led to extraordinary demand for medical equipment and supplies. Global supply chain interruptions mean the need for certain medical devices, including personal protective equipment (PPE), outpaces the available supply. To respond to this demand, organizations are using 3D printing and other innovative manufacturing processes to produce urgently required medical devices, including PPE and ventilator parts.

3D printing has shown extraordinary potential in the field of medicine in recent years, and with its unparalleled improvement, the eventual future of medical technique looks brilliant. The domain of hearing aids is the first manufacturing branch fully overtaken by 3D printing, and dentistry seems to be following suit. Implants and prostheses, the application of models in virtual surgical planning and teaching in healthcare, traditional and novel medical devices, 3D printing of drugs – all these are rapidly developing areas of the 3D printing applications in medicine. In this review, applications in medicine that are revolutionizing the way surgeries are carried out, disrupting prosthesis and implant markets as well as our research in the customized casts is included.

Keywords: 3D printing, applications in healthcare, hearing devices dentistry, surgery, medical devices

I. Introduction

There are different kinds of traditional machining techniques that have existed for many years and have helped human beings to build things. Although the technology for traditional machining has evolved in recent years, it has several limitations. While the introduction of non-traditional machinings such as electric discharge machining or electric chemical machining within the manufacturing world has generated a revolution, but all these industrial processes require computers and robot technology for these processes to be implemented such as removing material from a larger mass of block to get the required shape of the final product which could increase the manufacturing expense for these traditional designs and their production processes.

3D printing is a process of creating objects by stacking layers of material on each other such that the intended product is produced by stacking up the product within different layers in a variety of ways depending on the technology being used to reduce complexity concerning the design prospects of these complex components, thereby avoiding assembly requirements in whole. This with an added advantage of being a tool-less process significantly reduces the prohibitive costs and lead times within the design and manufacturing ecosystems. The printing process usually starts with the making of a 3D digital model that is created using any 3D software program or by scanning the

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product using a 3D scanner and then layered into slices and converted into a file that could be understood by the 3D printer. The material processed by the 3D printer is layered according to the design specified.[3]

II. Current 3D Printing Technologies

All 3D printers do not use the same technology as there are numerous means to print the layers to form the finished product. Some techniques such as liquefying the material or simply softening it to make the layers whereas others use high powered UV laser to cure photoreactive resin and "print" the object.

Some of the 3D printing technologies that are utilized these days are:

1) Stereolithography (SLA)
2) Fused deposition modeling (FDM)
3) Selective Laser Sintering (SLS)
4) Laminated object manufacturing (LOM)
5) Digital Light Processing (DLP)

The kind of model which we want to design gives us the 3D printing methodology that needs to be used for its design. The below sections give us a detailed approach regarding the different processes and the products used within the 3D printing methodologies.

Fig 1. 3D printing process

III. New Future for The Medical Industry

Within the Medical Industry, 3D printing has a wide range of possibilities to usher in a new era of cost-effectiveness and convenience within it. It helps to develop a sustainable framework to tackle the storage of organs donated and if needed print them without facing any difficulties which could lead to a cheap organ replacement while reducing the waiting timeframe or a mismatch of the organ [1].

The prosthetics printed on the Modular 3D printing have served as an alternative for the traditional models while reducing the costs for their manufacturing. This could prove how effective these 3D printed models are compared to the traditional models as they are effective while providing a vast number of opportunities. These consist of manufacturing difficult drug models, organ transplants that couldn't find viable donors or during emergencies. It also has the advantage of reducing the manufacturing cost to more than half of what they expected, in turn, providing alternatives that could pave way for a futuristic medicine with a vast set of alternatives such as creating tissues and organoids, surgical tools, patient-specific surgical models and custom-made prosthetics. [1]

This is a technique vastly applied by the medical world within a vast of several fields such as X-rays, Computed Tomography (CT) Scans, Magnetic Resonance Imaging (MRI) scans where the data obtained from them has been fed to the 3D printer which had increased the dependency by the Medical industry on 3D printing from $713.3m in 2016 to $3.5bn in 2017 with an expected growth rate of 17.7% within 2017 to 2025.

1. Cheap medical equipment quickly made way

A future where medical treatment has developed highly customized, with patient-specific treatments, not 'one size fits all', is now being realized where applications that could provide high performance and are compatible with biosensor feedback devices and advanced diagnostics. Such functionality will require technology with increased sensitivity, specificity, tenability, and customizable. While this technology has yet to be fully realized, recent advances in bio fabrication and bioprinting may enable anywhere on-demand medical treatment. [2]

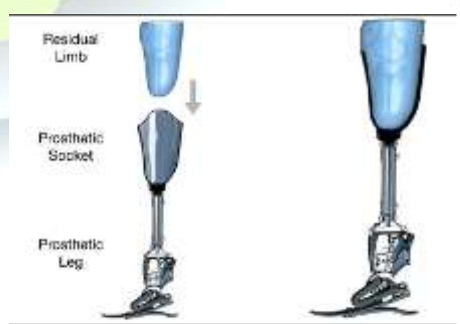

Fig 2. Prosthetic Limb socket design

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2. 3D Printed Personal Protective Equipment PPE

PPE is one of the most valuable protective layers for healthcare workers around the world in a crisis like COVID-19. The typical N95 respirator can block at least 95% of both bacterial and viral particles in the sub-micron length scale, making it necessary for healthcare workers to deal with patients who are infected with SARS-CoV-2. However, most of these N95 respirators were designed as quick disposables, which means they are not fit to be used or retained for an extended period. However, the quickly depleting supplies have caused many facilities to urge their healthcare workers to repeatedly use their disposable N95 respirators, which would put them at great risk of being infected. The industrial supply chain is unable to scale up to meet current demands so we need alternative PPE strategies (at the N95 performance level or better) that can immediately and effectively protect healthcare workers from being infected.[7]

3D-printed PPE can be used to provide a physical barrier to the environment. However, 3D-printed PPE are unlikely to provide the same fluid barrier and air filtration protection as FDA-cleared surgical masks and N95 respirators

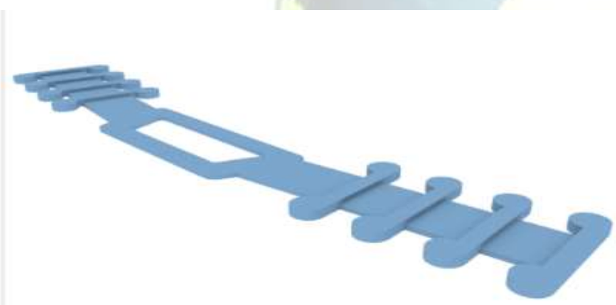

Fig 3. 3D printed surgical mask tension straps

3. Bio-printing

Introduction of Bioprinting within 3D printing is one of its vast applications within the Medical Industry within the 21st century which is why it has become a boon for people whose immune system doesn't accept the donated organs or when there is a shortage during an emergency. It also has its advantages where Realtime research is possible which could cause an indefinite shutdown of lab testing on humans and animals. We are getting closer to print living tissues such as blood vessels, bones, skins [3]. It was in the early 20th century when researchers discovered that the nozzle of the inkjet printers could spray out living cells without damaging them but their main disadvantage is that they need to be provided a nurturing environment to stay alive. Nowadays, microgels enriched with vitamins, proteins and other life-sustaining compounds provide these conditions. In 2014 itself many companies announced the first successful printing of liver tissues and it functioned as a real liver for weeks.

Then functional human kidney tissues were generated with a 3D bioprinter. Bioprinting could also be an effective way to test pharmaceuticals. Clinical trials today are lengthy and expensive. But with bio-printed tissues new products can be assessed and brought to market more quickly, all without harming test subjects. The surgical challenges with using bio-printed tissues are technological ones. If we can overcome those hurdles then the engineered tissue can function just as well as the original one.[4][5]

It's possible that one day, your surgeon will ship your tissue sample (or stem cells or just DNA data) to a bio-printing company, and a few days later, the organ tissue you need will arrive in a sterile container via FedEx, ready for implantation. But it will take many years of research till we get there. So the current state of bioprinting is about being able to accurately and safely print out tissues not entire organs.

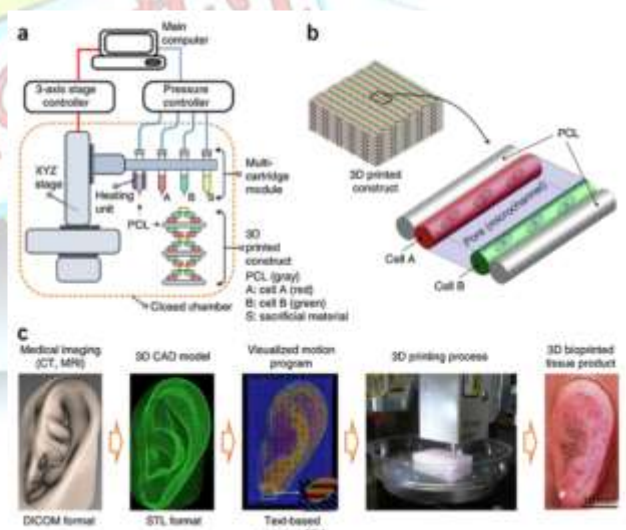

Fig 4. 3D Bio-printing process

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IV. Our Work

1. 3D Printed Personal Protective Equipment PPE

One of the challenges in many hospitals around the globe is facing during the COVID-19 pandemic is the shortage of masks, face shields and other forms of personal protective equipment (PPE). Currently, our lab is manufacturing 100+ face shields per day, but manufacturers of PPE equipment are currently unable to meet the demand. 3D printing and other additive manufacturing technologies are being used to fill the gaps in the PPE supply chain.

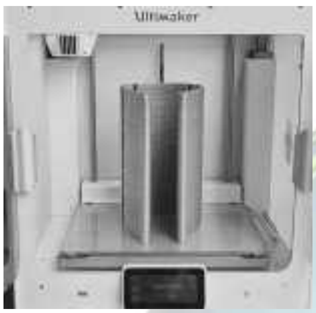

Fig 5. 3D printing face shield

A coordinated effort is needed to supply the necessary equipment and ensure that equipment is approved for use in the healthcare environment. In the first week of March 2020, our lab reached out to the EMI Additive Lab to start manufacturing face shields for the nearby hospitals in Bangalore. After creating a model, workflow, and receiving approval from the company, the EMI Additive Lab is now being used to 3D print, wash, and assemble more than 100 face shields a day.

Fig. 6. 3D Printed Face Mask

Evaluating needs was the first and foremost goal of the project, rather than directing efforts towards manufacturing equipment that may not be compatible for use in the nearby hospital setting. Based on a conversation with the health officials, it was determined that face shields were in high demand and the most feasible PPE items for production using 3D printing.

Fig 7. Fracture Cast model

2. 3D Printed Plaster Cast

Traditional orthopedic casts are typically made from plaster or fiberglass. They often require orthopedic technicians to assist with applying the cast material. These casts are bulky they're not water-resistant and they have poor breathability. So, the skin can become irritated and in worst-case scenarios, cutaneous complications can occur. Traditional casts can also make daily tasks very difficult like taking a shower.

So, in our work, we introduce 3D printable plastic casts that are waterproof ventilated and lightweight making them more practical for daily use and they introduced a novel design objective of post immobilization treatments like cryotherapy and acupuncture. So the healing time can be reduced by this technique [1].

Fig 8. 3D scanned image

We first studied the Zhang's work of thermal comfort of the cast. Team study the thermal sensitivity distributions of different people and they customize the cast design for the patient's thermal comfort. Work proposes a new computational approach to design a cast customized in terms of the shape, the mechanical stiffness, and the thermal comfort.

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Firstly, 3D scanning the fractured region of the human body and once we have that 3d scan shape, then capture thermal images using an infrared camera and these are two-dimensional images that are then mapped on to the 3D model to generate those temperature distributions in 3D. Then the Thermal Comfort Sensitivity is computed to govern the pattern generation where the human thermal comfort is maximized [6].

So considering factors of structural strength, they introduce a Hollowed Voronoi Tessellation (HVT) pattern that's employed for designing a web-like pattern. After optimizing the pattern for air exposure, a structural enhancement scheme is performed to convert the surface into a non-uniform thickened solid model that ensures mechanical stiffness on caste. Finally, we 3d print the result to create [7].

We haven't achieved the thermal comfort and Hollowed Voronoi tessellation due to the lack of infrastructure in our lab. We did print and analyze it in Ansys 6.0.

V. Conclusion

3D printing has become a useful and potentially life-changing tool in several different fields, including medicine, healthcare, advanced manufacturing fields. Researchers continue to ameliorate existing medical applications that use 3D printing technology and to investigate new ones. The medical advances that have been made using 3D printing are already extraordinary and exciting, but some of the more revolutionary applications, such as organ printing, will need time to evolve.

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