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Healthcare Applications of 3D Printing

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ABSTRACT: 3D printing is utilized for the development of novel surgical cutting and drill guides, prostheses as well as the fabrication of patient-specific copies of bones, organs, and blood arteries. Recent advancements in 3D printing in healthcare have resulted to lighter, stronger and safer goods, shorter lead times and cheaper prices. 3D printing has been utilized in the health industry to manufacture both basic and sophisticated prostheses as well as surgical implants. Apart from this, 3D printing may be utilized to create personalized prosthetic limbs that are appropriate to a particular patient. 3D printing is a relatively new, quickly growing technique of production that finds many uses in health- care, automotive, aerospace and military sectors and in many other fields. In this overview, applications in medicine that are changing the way operations are carried out, affecting prosthesis and implant industries as well as dentistry will be discussed. The relatively new subject of bio-printing that is printing with cells will also be briefly addressed.

KEYWORDS: 3D Printing, 3D Printer, CAD, Dentistry, Hearing Aids.

1. INTRODUCTION

A modification of an old inject printer led to the development of 3D printing (3DP). It is now quickly expanding: almost every week, new printers and printing materials with unique capabilities and interesting applications are introduced. 3DP applications are particularly prevalent in the healthcare, automotive, aerospace, and military sectors. This study will focus on medical applications that are changing the way procedures are performed, including affecting the prosthesis and implant industries, as well as dentistry, to mention a few. Bio-printing, or printing with cells, a relatively new subject, will also be briefly addressed. Numerous uses of 3DP in medicine fall under the category of customized medicine, as will be shown below. Implants or prostheses, for example, are 3D printed for a particular user's body, allowing the technology to be optimized for an individual rather than the typical user, as is the case with most mass-produced goods. Contrary to more well-known instances of personalized medicine that deal with medication molecules and their associated active sites, which are therefore on the nanoscale, 3DP applications created specifically for a patient's requirements are on the macroscale[1].

The use of 3DP in medicine is increasing. Customized implants and prostheses, medical models, and medical gadgets are among the innovations that are revolutionizing healthcare and potentially disrupting many aspects of conventional medicine. Several variables affect worldwide 3D printing in the healthcare industry, including technological advancements and improvements in healthcare infrastructure on the one hand, and a rise in both the proportion of the ageing population and expenditure in research and development on the other. The domain is quickly growing in popularity. Figure 1 shows a 3D printer from the Polish firm Zortrax.

Additive manufacturing, often known as 3D printing, is the technique of creating a three-dimensional physical item from a digital model. What's more, 3DP enables the production of things that would be difficult to acquire using any other manufacturing technique in a single run. Such capabilities may be seen in objects having holes, which are occasionally filled with a thick network, as in bone implants. Manufacturing things made up of multiple moving components or interpenetrating frameworks in one run is also difficult using any other technique[2].

Figure 1: A 3D printer of the Polish company Zortrax.

In a nutshell, 3DP entails putting down several layers of material in various forms, each one printed directly on top of the previous one using a computer software. Traditional manufacturing procedures, which are subtractive processes in which material is removed via methods such as cutting or drilling, are not compatible with 3DP as an additive technology.

The origins of 3DP may be traced back to the 1980s, although Mary Gehl went back much earlier, to the 1970s, without citing any sources. Surprisingly, in the early 1980s, the French General Electric Company and CILAS dropped their patent applications for stereolithography, one of the most significant techniques in 3DP, in which layers are added by curing with ultraviolet light laser. “Due to a lack of commercial potential,” the stated explanation was given. Chuck Hull, who established 3D Systems Corporation and developed a prototype method based on stereolithography, is one of the most significant founding fathers of 3DP. Hull's description of the method, which he described as a "system for producing three-dimensional things by constructing cross-sectional patterns of the item to be produced," was quite similar to Kodama's previous invention. Hull is most known for creating the STL file format, which is extensively used by 3D printing software, as well as the digital slicing and infill techniques that are now used in many procedures[3].

Prof. Ely Sachs of MIT developed the phrase "3D printing" in 1995 after working on a project to alter an inkjet printer such that a binding solution was extruded into a bed of powder instead of ink being applied to paper as in older inkjet printers. 3D printing (3DP) and additive manufacturing (AM) are now interchangeable terminology. This type of production is sometimes referred to as desktop manufacturing, fast manufacturing, or rapid prototyping.

Hull's STL files are created using a computer-aided design (CAD) programme, a 3D scanner, or a simple digital camera and photogrammetry software. They are produced in medicine by transforming X-ray or CT images into the STL format. The CAD method produces the least number of mistakes. They may be corrected before printing, enabling you to check the object's design before printing[4].

It is important to note that there are now at least 18 additive manufacturing techniques in use, some of which have undergone multiple revisions. Printing materials come in a wide variety of shapes and sizes. When plastic, acrylonitrile butadiene styrene, polyamide, nylon, and other materials are used, they are referred to as filaments. Metallic powders, rubber, glass, sand, carbon fibers and graphene, as well as biological materials may all be utilized to create 3DP. Post-processing is an essential step after an item has been printed using most techniques, since the prints have rough surfaces owing to the layering involved in the process. Playmakers has received a significant boost on the crowdsourcing platform Kickstarter for their idea to eliminate post-processing. They raised almost $433,500 for a totally new 3DP filament and desktop machine, which could significantly enhance the surface quality of 3D printed items and eliminate the need for post-processing[5].

Progress in 3DP will be made not just via the creation of new printers and filaments, but also through advancements in scanners and 3DP software. Commercial CAD packages nowadays are difficult to use and require specialized expertise. This has a negative impact on not just 3DP applications in healthcare, but also the 3DP consumer sector as a whole. The creation of high-quality specialized materials for 3D printed prostheses, implants, and other medical equipment is another area where 3DP may be used in healthcare.

Until a few years ago, 3DP was mostly utilized in so-called fast tooling and prototyping, which allowed engineers to develop and refine tools and prototypes during the design process. Today, however, this manufacturing technique is widely used in the automotive, aerospace, military, engineering, dentistry, and medical sectors. Fashion, footwear, jewelry, eyeglasses, cuisine, and a variety of other industries may all benefit from it. 3DP with cells, also known as bioprinting, is of particular interest since it is now delivering the initial applications and has a lot of potential. Jeremy Rifkin, an economist, social theorist, writer, and activist who has written 20 books on the effect of scientific and technology progress on the economy, labor, society, and the environment, believes that 3D printing is one of the foundations of the third industrial revolution[6].

1.1 3DP in Healthcare:

It is widely acknowledged that medical applications of 3D printing, both current and future, will usher in revolutionary advances. They can be divided into several broad categories, such as the creation of customized prosthetics, implants, and anatomical models, tissue and organ fabrication, specialty surgical instrument manufacturing, pharmaceutical research on drug fabrication, dosage forms, delivery, and discovery, and medical device manufacturing. Benefits of 3D printing in medicine include cost-effectiveness, greater productivity, democratization of design and production, and improved cooperation, in addition to customization and personalization of medical goods, medicines, and equipment[7].

Gartner, a market research company, says that 3DP uses in healthcare are now mainstream. It is undoubtedly true for hearing aids and to some extent for dental equipment, but advancement in areas like as implants and prostheses, as well as surgical planning, seems to be more difficult.

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Furthermore, many nontrivial applications mentioned below, such as fetal heart defect modelling and spectacles for the blind and visually handicapped, demonstrate how challenging it is to make predictions in this domain. The applications in healthcare appear to be divided into at least three categories: mainstream or near-mainstream (hearing aids and dental devices), widely used but not mainstream (including the majority of the prosthesis market or manufacturing medical devices such as stethoscopes or blind books), and those in the early stages of development but capable (including the majority of the prosthesis market or manufacturing medical devices such as stethoscopes or blind books). Another topic to consider is the 3DP of medicines. In general, the uses of 3DP in medicine are varied, and in certain sectors, it has disrupted the whole industry (as in the hearing aids business) or may disrupt the entire market (as in the prosthetics market).

1.2 3DP in Hearing Aids:

There have been many media stories about amazing 3DP uses on Earth and in space, but a modest yet astounding breakthrough in hearing aid production has gone almost undetected. It's "The 3D Printing Revolution You Haven't Heard About," as Forbes' Rakesh Sharma puts it. According to Phil Reeves, author of a report on the 3D printing business, more than 10 million 3D printed hearing aids were in use globally in 2013. Today, there are a lot more. 3DP turned a manual, labor-intensive business into a quick, patient-focused automated one. Prior to the introduction of 3DP into this area, hearing aid manufacture seemed to be akin to artisanal production, taking more than a week. The 3DP process, which includes scanning, modelling, and printing, may now be completed in less than a day[8].

Materialize, a Belgian firm, spearheaded the change in this field in conjunction with a Swiss hearing aids manufacturer. Rapid Shell Modeling, or RSM, was the first 3DP programme in this area, developed in 2000. EnvisionTec, on the other hand, created its own method in 2005, while Widex, headquartered in Denmark, produced the world's tiniest aid with CAMISHA (Computer Aided Manufacturing of Individual Shells for Hearing Aids). The Starkey Innovation Expo was recently held in Las Vegas. According to Starkey's Faukes, the firm manufactures 98 percent of hearing aids using stereolithography (SLA) printers, with the remaining 2% not utilizing 3DP due to medical considerations and complex form factors. Surprisingly, the adoption of 3DP has not reduced the cost of hearing aids, owing to the fact that just a few firms dominate the market. It should be noted that the use of 3DP in the production of hearing aids was examined as an example of its disruptive impact on existing businesses. The Institute of Physiology and Pathology of Hearing in Kajetany, Poland, utilizes 3DP for modelling and teaching reasons rather than implant production.

1.3 3D Printing in Dentistry:

Fast tooling and rapid prototyping were among the earliest industrial uses of 3DP. As a result, it was a logical next step to utilize it in dentistry, where unique, customized items were produced. Dental laboratories can now create crowns, bridges, plaster/stone models, and a variety of orthodontic equipment such as surgical guides and aligners correctly and quickly by integrating oral scanning, CAD/CAM design, and 3D printing. A 3D scan is obtained instead of unpleasant impressions, which is then converted into a 3D model and sent to be 3D printed. A complete variety of orthodontic equipment, delivery and positioning trays, clear aligners, and retainers may be made using the printed model. Furthermore, the models may be easily saved as 3D CAD (Computer

Assisted Design) files on a computer. 3DP enables for the digitization of the whole process, substantially reducing production times and boosting capacity. Furthermore, they remove the need for physical imprints and model storage[9].

"Changes came quick and furious in 2015, especially since it was the year of the International Dental Show, which showcased some of the most cutting-edge technologies coming to the dental lab world," says the author.

1. New denture workflows have appeared all over the place. "While the entire impact of digital technologies on the denture process has yet to be realized, 2015 provided some intriguing peeks into the possibilities. Full dentures made completely from digital data now don't seem that far away."
2. CAD is changing due to more user-friendly modules.
3. In 2015, "printing completely completed dental prostheses and restorations with the press of a but- tone appeared to become closer to reality for the first time." "3D printing flirts with the future" with a dental printer that can print layers of various materials over one another and FDA-approved denture material for 3DP.
4. 3DP's disruptive nature for the industry: Dentists are incorporating laboratories into their clinics using 3DP, and both printers and materials are bringing revolutionary improvements to labs, dentists, and dental technicians. This necessitates ongoing education for dental technicians on the one hand, as well as some new and interesting possibilities on the other.
5. The number of dental laboratories in the United States is declining: There are a slew of new 3D printers for dentistry and orthodontic labs on the market, including models from Startasys, Zenith 3D Printing Systems, Envision, AXSYS, Valplast, and others. As previously stated, the new, first FDA-approved printing substance as well as a new bacteria-killing ingredient must be highlighted.

Surgical guides, which are also 3D printed, are an intriguing and little-known kind of surgical 3D printed equipment utilized in dental treatment. To conclude, new low-cost printers for small, medium, and big dental laboratories and clinics, as well as new materials, have ensured widespread usage of 3DP in dentistry in the United States. Other nations will very certainly follow suit. Surprisingly, the first liability lawsuit using 3DP (dental aligners) has been filed in California, according to our understanding[10].

1.4 Surgical Planning in Virtual Reality:

In medical practice, imaging methods are critical. The addition of 3DP improves surgical planning significantly. Internal organs and anatomical components are seen in depth using computed tomography (CT) and/or magnetic resonance imaging (MRI). Their 3D printed copies are accurate in terms of size, weight, and texture, enabling surgeons to practice complex operations using 3D models. Fasotec, a Japanese firm acquired by Stratasys, created a Biotexture Wet Model that accurately mimics organs like the lungs, allowing surgeons and trainees to perform procedures. Surgery planning with the use of 3D printed models is becoming a common practice. It has aided complete face transplants, the first adult-to-child kidney transplant, hospital-based excision of a kidney or liver tumor, and acetabular reconstructive surgery, to mention a few.

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2. DISCUSSION

Manufacturing human tissue using 3D printing cells is an interesting and rapidly growing field of potential 3DP applications. The primary goal of 3D bioprinting in the future is to alleviate the organ donor shortage. However, current accomplishments are more modest: the significant application of lab-on-the-chip has been suggested, which is a high-throughput 3D-bioprinted tissue model exVive3D Liver for research, drug development, and toxicity. Bioprinting using stem cells, which was just reported, offers up new possibilities in this field. Cellink, a Swedish firm, and RoosterBio, an American stem cell company, are offering the world's first ever "thaw and use" human mesenchymal stem cells bioink.

3D bioprinting applications need feasible and standardized materials, such as cell-friendly biomaterials. Until far, 3D bioprinting has only been done on flat tissues like skin, tubular structures, and hollow and complicated solid organs like the liver. Chinese researchers have reported 3D bioprinting of kidney, ear, and liver tissues, but they do not seem to be implantation-ready. Bioprinting of bones, cartilage, muscles, and other tissues is currently being researched.

There's also a new substance called self-healing bio-glass that can be used for 3D printed cartilage re-placing. Dr. Anthony Attala of the Wake Forest Institute for Regenerative Medicine pioneered 3D bioprinting by using it to manufacture heart and kidney organ tissues, and Gabriel Villard of Oxford University developed a bioprinter and, later, by printing two layers of different cells, for the first time observed changes in specimens after printing, which became known as 4D printing. Dr. A. Atala's team recently reported the completion of an integrated tissue–organ printer (ITOP) capable of fabricating stable, human-scale tissue constructions of any form. The ITOP's capabilities were shown by the researchers producing mandible and calvarial bone, cartilage, and skeletal muscle.

Organovo is one of the most active businesses in the field of 3D bioprinting. Although no implantable human organ can yet be 3D bioprinted, Organovo has printed liver and kidney tissues. They developed their amazing lab-on-chip, called the ex- Vive3D Liver Model, based on primary human hepatocytes, stellate, and endothelial cell types found in native human liver, with the goal of drug testing that is stable for at least 42 days and much more effective than standard 2D liver cell culture systems offered by industry. Instead of utilizing people or animals, L'Oréal has partnered with Organovo to develop 3DP skin models for cosmetic research.

Among the many 3D bioprinters revealed, the Swedish company CEL- LINK has developed INKREDIBLE, a low-cost bioprinter that costs $5000 for the basic model and $9000 for the more advanced model and uses their own bioink and cells. When utilizing their proprietary bioink on their 3D printer, CELLINK was able to produce an astonishing outcome in which up to 98 percent of cells were alive. A gadget called Biopen, which isn't quite a bioprinter, enables surgeons to mend broken bone and cartilage by "drawing" new cells directly onto bone during a surgical operation. Organs manufactured in 3D for transplantation are still a long way off. Xu Mingen, the inventor of the “Regenovo” bioprinter, a Chinese researcher at Hangzhou Dianzi University, projected that completely functioning printed organs may be feasible within the next 10 to 20 years.

Lee Cronin's group used their 3D printed reactionware to print the chemical ibuprofen, extending their concept on the possibilities of 3D printing in chemistry. On the one hand, many medication printing uses have been suggested, such as printing nonstandard dosages for youngsters or the elderly. On the other hand, harsh words of condemnation have been spoken in light of the potential of drug misuse. The ability to 3D print medicines using downloaded pharmaceutical formulas piped straight into an appropriate 3D printer, similar to how music downloads have disrupted the music business, will have significant consequences for the pharmaceutical sector. This case demonstrates the kinds of severe legal issues that 3D printing may cause. Sprintam, Aprecia Pharmaceuticals' first 3D printed medicine, has been approved by the United States Food and Drug Administration (FDA). 3DP allows the production of extremely porous pills, allowing for large medication dosages in a single tablet. This kind of tablet dissolves rapidly and is easy to swallow.

3. CONCLUSIONS

In the medical field, 3DP is extensively utilized. Hearing aids are the first industrial branch to be completely taken over by 3DP, and dentistry seems to be following suit. Traditional and innovative medical equipment, 3DP of medicines, and the use of models in virtual surgical planning and education in healthcare are all fast expanding fields of 3DP applications in medicine. In most areas, they provide much less costly alternatives to traditional equipment and procedures, assist with diagnostics and medical treatments, and unleash creativity via the simplicity of prototyping new gadgets. Consider the impact of virtual surgical planning or the above-mentioned in-expensive limb prosthesis. 3DP's contribution to customized medicine is one of its most notable features. According to Wikipedia, "the phrase has gained popularity in recent years as a result of the development of novel diagnostic and informatics techniques that offer knowledge of the molecular basis of illness, especially genomics." On the nanoscale, it's referred to as customized medicine. Because implants, prostheses, and a variety of medical equipment are patient-specific, 3DP provides customized treatment on a large scale. Apart from Organovo's exVive3D Liver tissue model, 3D bioprinting is still in its early stages, since 3D bioprinted organs are still out of reach. However, it will undoubtedly result in medical revolutions. Medical uses of 3DP will be accelerated by the introduction of new (bio) printers and (bio)compatible materials.

The American National Institutes of Health (NIH) created the NIH 3D Print Exchange Internet website to speed up research and development in this area. It provides open, comprehensive, and interactive access for searching, browsing, downloading, and sharing biomedical 3D print files, modelling tutorials, and educational material. Several websites provide free downloads of limb prosthetics, for example. The future of 3DP applications in medicine seems promising. We will see existing apps being extended and refined, as well as the creation of new outstanding applications. Sometimes, like with the hearing aids industry, the advancement will upset the whole field without delivering price savings, but in general, 3DP will change a large portion of healthcare.

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