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3D Printing in Healthcare

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Abstract : 3D printing is the means of producing three dimensional solid objects from a digital model. It has been regarded as one of the pillars of the third industrial revolution. No industry has embraced the 3DP technology more enthusiastically than healthcare, especially surgery. With healthcare industry under political and economic pressure to perform, 3D printing allows manufacturers to cost effectively produce customised medical devices. 3DP has the potential to change healthcare by making care affordable, accessible, and personalized. This paper provides a brief introduction on how 3DP is used in healthcare industry.

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Keywords: healthcare,_3D printing, 4D printing, additive manufacturing, rapid prototyping, modeling

I. Introduction

Three-dimensional printing (3DP) is a manufacturing procedure in which an object is fabricated by depositing materials—such as plastic, metal, ceramics, powders, liquids, or even living cells—in layers to produce a 3D object. Models can be multi-colored to highlight important features, such as tumors, cavities, and vascular tracks. 3DP technology can build a 3D object in almost any shape imaginable as defined in a computer-aided design (CAD) file. It is *additive* technology as distinct from traditional manufacturing techniques, which are s*ubtractive* processes in which material is removed by cutting or drilling.

3D printing (also known as additive manufacturing (AM) or rapid prototyping (RP)) was invented by Charles Hull in the early 1980s. Since then it has been used in manufacturing, automotive, electronics, aviation, aerospace, consumer products, education, entertainment, medicine, space missions, the military, and chemical and jewelry industries. It is a technology perfectly tailored for the healthcare industry. It offers a range of precision healthcare solutions, including tissue and organ fabrication; creation of customized prosthetics, implants, and anatomical models, drug delivery, and testing, as well as in clinical practice.

II. Applications

3D printing has found numerous applications in healthcare, automotive, aerospace, defense, military, engineering, libraries, food industry, dental, human medicine, and veterinary medicine. Perhaps the most exciting 3DP applications can be found in the world of healthcare. The applications of 3DP in healthcare are already in the mainstream. Here we present some typical 3DP applications in healthcare that are revolutionizing the industry [1,2]:

Manufacturing: 3DP has become a leading manufacturing method in healthcare for a wide range of applications including dentistry, tissue engineering and regenerative medicine, engineered tissue models, medical devices, anatomical models and drug formulation. It also allows on-demand fabrication with high productivity in a cost-effective manner. It allows more accurate personalized manufacturing of devices created to the patient's own specifications. Several medical products manufactured by 3D printing are currently available in the market.

Tissue Engineering: 3DP has emerged as a powerful tool for tissue engineering (or bioprinting) whether it is about blood, bones, heart or skin. Manufacturing a human tissue by 3D printing cells is an exciting, booming area. This allows the hospitals to print human tissue structures that could eliminate the need for some transplants. Flat tissues such as skin, tubular structures, and complex organs such as liver have been 3D bio printed. The main objective of 3D bioprinting is to reduce the shortage of supply in the organ donor market. The recent focus of tissue engineering has been to create functional tissues and organs for implantation and to develop tissue models. Bone tissue engineering is a promising approach to bone repair and reconstruction [3].

Pharmacology: 3DP is helping pharmaceutical companies to create more specific drugs. It opens a field of personalized pharmacology. It has enabled the fabrication of prototypes of patient-specific drug delivery devices (DDD) with varying complexity and shows that customization of drug products is possible. 3D printing of drugs could enable companies to create multi-drug capsules that release different compounds at different times. Imagine the possibility of printing your drugs at homes on your own 3D printers.

***Anatomical models*:** These are models of anatomy used in training, surgical planning, and reference during surgery. Imaging studies such as CT and MRI can be converted to blueprints of a patient's internal anatomy. 3DP anatomical models can help surgeons better prepared to perform surgery which will result in improved surgical outcome. Anatomical models are needed in bone construction and tumor treatments.

Prosthetics: Prosthetics provide improved quality of life to patients suffering from a loss of limb. Millions of people worldwide need mobility devices such as prosthetics. 3DP allows the creation of custom-fit prosthetics for a patient's specific anatomy and needs. 3D printed prostheses are fully customized to the wearer and are affordable.

***Dentistry*:** 3DP can create sophisticated components in mass production, which makes it an attractive technique for dentistry. By combining oral scanning, CAD/CAM design and 3DP, dental labs can accurately produce crowns, bridges, plaster/stone models, and a range of orthodontic appliances such as surgical guides and aligners [5]. Several dentists are enthusiastic in incorporating 3-D printing into their practice.

***Implants*:** The human body is complex and traditional implants often require fit-up and care during implantation. 3DP allows the complex shapes to be designed, optimized and fabricated to the exact dimensional requirements [4]. There are several manufacturers using 3D printing to produce commercial implant products. 3D printers can induce several desirable properties in such medical implants. 3D printed implants have been used across a variety of surgical specialties. For example, it is used in the treatment of such illnesses as diabetes.

Other areas of applications include radiology, breast phantom construction, medical imaging, and clinical care.

III. Advantages and Disadvantages

Benefits of 3DP in healthcare include the customization and personalization of medical products, drugs, and equipment; cost-effectiveness; increased productivity; the democratization of design and manufacturing; and enhanced collaboration. Hospitals could potentially create items on demand and this would significantly alter the healthcare supply chain. 3DP benefits patients, providers, and payers.

The advantages of 3DP include [6]:

1. *Customized products:* Perhaps the greatest advantage that 3D printers in healthcare applications is the freedom to produce custom-made medical products and equipment. Almost every 3DP application needs to be tailored to a specific patient and requires a high level of customization because no one body is the same. A customized 3DP model of each patient's heart enables a surgeon to adjust to the unique features of each patient's heart.
2. *Rapid prototyping:* Products can more quickly go from just a design to an actual prototype. It reduces time between design iterations.
3. *Reduced Costs:* Even though the initial setup costs are higher, 3D printing has become cheaper than cheap labor in third world countries. Additionally, the costs of 3D printing are still decreasing, with the potential of 3D printers in homes in the near future. Furthermore, the costs of customized products are the same for mass production products.
4. *Less inventory:* With traditional manufacturing technologies, it is much faster and cheaper to manufacture additional products that you probably know that you will eventually need. However, with 3D printing, only products that are sold need to be manufactured, thus warehousing of excess inventory is significantly less needed.
5. *Jobs opportunities:* 3DP technology creates jobs for highly-skilled designers who are adept at using 3D printers. More engineers are needed to design and build 3D printers, and more technicians are needed to maintain, use, and fix 3D printers.
6. *Medical:* While 3DP usages are still experimental, the potential advantages are huge. Imagine doctors quickly building and replacing critical organs, such as the heart, lungs, or liver that will have almost no chance of donor rejection, since the organs will be built using the patients' unique characters and DNA.

The disadvantages of 3DP should be understood and mitigated against. They include [6,7]:

1. *Fewer manufacturing Jobs:* As with all new technologies, manufacturing jobs will decrease. This disadvantage will have a large impact to the economies of third world countries, especially China, that depend on a large number of low skill jobs.
2. *Limited Materials:* Currently, 3D printers only manufacture products out of plastic, resin, certain metals, and ceramics. 3D printing of products in mixed materials and technology, such as circuit boards, are still under development.
3. *Copyright:* With 3D printing becoming more common, the printing of copyrighted products to create counterfeit items will become more common and nearly impossible to determine. This may require some regulations.
4. *Dangerous Items:* 3D printers can create useless or dangerous items, such as guns and knives, with very little or no oversight. 3D printers have already been employed for criminal purposes, such as printing illegal items like guns and master keys.
5. *Size limitations:* At present, 3D printers have limitations on size of the objects created.
6. *Speed:* The amount of time required to make 3D anatomical models limits the use of these models in time sensitive, emergent situations.

Although 3DP offers great benefits in healthcare, it also raises a number of ethical questions that will need to be addressed. The ethical issues include justice in access to health care since 3DP seems to increase disparities in health between rich and poor, testing for safety and efficacy, and whether or not we should use 3DP for human enhancement. There are also challenges with regard to regulatory issues and safety concerns. These challenges are slowing down the full implementation of 3DP in the healthcare industry.

IV. 4D Printing

The rapid advances in shape memory materials (or smart materials) and additive manufacturing have fueled the development of four-dimensional (4D) printing. The 3D printing of smart materials is known as 4D printing. 4D printing is a relatively new development. It is an additive manufacturing that integrates smart materials into the printing material for 3D printing. Smart materials have the ability to change their shape or properties (rigidity, color, texture, transparency, volume) under the influence of external stimuli. 3DP technology is able to alter the shape or properties of smart materials over time (the 4th dimension) as a response to the applied external stimuli. This gives rise to a new term "4D printing" [8].

4D printing promotes the use of 3D printers for creating final products instead of prototypes. Its objective is to simplify the

manufacturing process so that products can be created from just the base materials [9]

IV. Conclusion

3DP is an emerging, multidisciplinary field which includes engineering, biology, medicine, material science, and computer science. It is providing healthcare professionals with a powerful tool for rapid prototyping, surgical planning, enhancing students' education, promoting research, and improving patient communication. Although 3DP cannot beat the cost and scale advantage of traditional manufacturing, it is making impact in small scale manufacturing and prototyping. 3DP applications in healthcare industry are booming and may even disrupt many areas of traditional healthcare. It may become a part of mainstream healthcare practice to treat a wide range of people.

Several factors influence global adoption of 3D printing in the healthcare market. These include advances in technology, improvement in the healthcare infrastructure, and reduction in cost of 3DP technology. Healthcare technologies are often expensive when they first enter the market, becoming cheaper over time. As technology develops further, the 3D printing process will become faster and more cost-efficient. With improved technology and an increased range of engineering materials available, this technique is becoming more popular in R&D departments worldwide.

In some universities, 3DP medical models are deployed in the training of the surgeons of tomorrow. 3DP technology is here to stay. Its use in healthcare is growing every year. Current publications on 3DP are disparate. More information about 3DP can be found in *3D Printing in Medicine*, which is a peer reviewed open access journal on 3DP.

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