3D PRINTING BODY PARTS: AN OVERVIEW OF HOW ADDITIVE MANUFACTURING IS SHAPING TISSUE ENGINEERING

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ABSTRACT

Additive manufacturing, commonly referred to as 3D printing, is a manufacturing technique that emerged in the 1980's mainly focused on engineering prototyping. Recent advances in the precision and cost of the techniques, as well as the widespread use of 3D modeling have increased 3D printing's scope of use from high-end engineering prototypes to a large variety of uses in manufacturing. 3D printing has been shown to improve the processing time, reduce waste, and increase the level of customization of certain products by eliminating the need for the specialty tooling and dies that are traditionally used in manufacturing. Additionally, the ability to physically print complex shapes based on a computer model has given rise to new products that would otherwise be simply impossible to create. The field of tissue engineering has taken advantage of this technology by printing organic cells and inorganic biomaterials with levels of control and precision that surpass previous production techniques. Furthermore, 3D printing allows for applications that can be customized on a case-by-case basis to fit the needs of individual patients. This review will overview the 3D printing-based techniques being used in tissue engineering, and discuss the current applications and challenges of this rapidly advancing field.

INTRODUCTION

Tissue engineering was conceptualized in 1987 at a National Science Foundation committee meeting[1]. The concept is defined as "an interdisciplinary field that applies the principle of engineering and the life sciences toward the development of biological substitutes that restore, maintain, or improve tissue function."[2]

Main components of tissue engineering

- **Cells** – The patient's own cells can be harvested and grown outside the body
- **Scaffold** – Made out of bio-compatible materials, the scaffold supports the tissue and allows for cell permeation.[3]

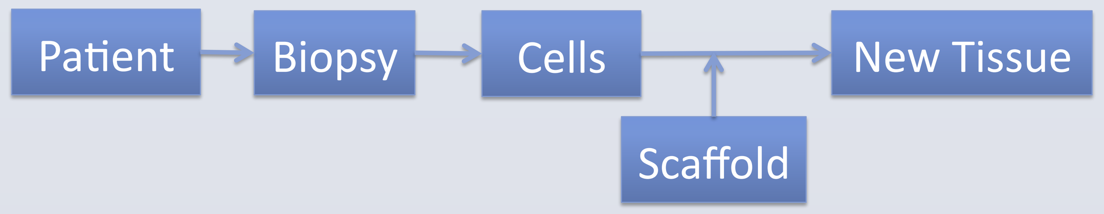

Figure 1. Flowchart representing the basic components used in tissue engineering.

Using the patient's own cells

- Eliminates the risk of disease transmission
- Eliminates the risk of immunogenic incompatibility
- Increases the availability of donor tissue[3]

CURRENT APPLICATIONS

ORGANS

- **The following structures have been successfully created using 3D printed bio-scaffolds[4]**
  - **Skin**
  - **Blood Vessels**
  - **Trachea**
  - **Esophagus**
  - **Bladder**

- 3D Printing and Tissue Engineering[5]
  - Automates the most tedious parts of the process, decreasing lead time
  - Increases precision and uniformity of the micro-scale structures of the bio-scaffolding
  - Allows for custom tailored treatments built directly from 3D MRI models of the patient's existing tissue structures

- When cells are removed from the host and assembled together on support structures, a few things happen naturally:
  - The tissues will fuse together[6]
  - The tissues actually adopt the form and the function of the original tissue structure[7]

- The biological mechanisms of cell permeation happen naturally, but it is up to the scientists to develop the bio-scaffold for the cells to grow on
  - The scaffold creates the form of the new tissue or organ
  - The scaffold ensures that the tissue or organ is structurally sound

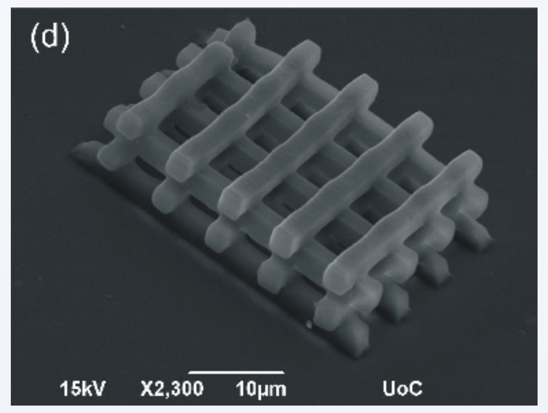

Figure 2[5]. PDMS bio-scaffold created using stereolithography techniques.

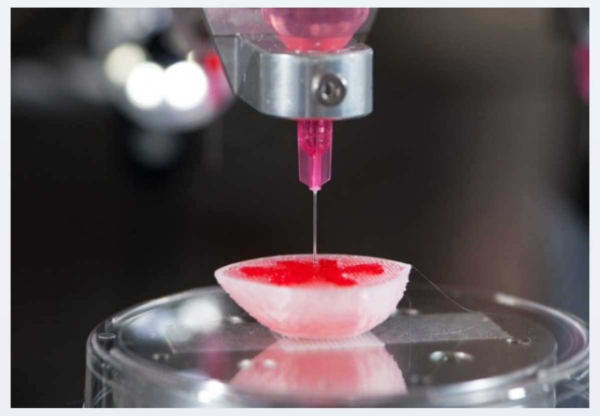

Figure 3[8]. Prototype kidney being created on a 3D printer.

Figure 4[4]. Functional bladder created using printed bio-scaffolds.

BONES

- Washington State University researchers are using 3D printed bio-scaffolds to grow bones[9]
  - Created 3D scaffolds made of bio-compatible material
  - Submerged the scaffold into immature human bone cells
  - A week later, the bone cells had attached to the scaffold and fused together
  - Can use this technique with a computed tomography scan to replicate a patient's own bone
- Oxford Performance Materials[10]
  - Received the first FDA approval to use 3D printed polymer implants to replace damaged bone structures in the human skull
  - Made out of PEKK, the implant acts as a very sturdy bio-scaffold that will allow the surrounding bone structure to grow into and fuse with the implant
- Other materials for bone implants are being researched including polyethylene, glass, and starch-based plastics like PLA
- Scaffolds for bones can also be designed for drug delivery – by implanting the necessary drugs inside the scaffold itself, the drug will be released as the regenerating tissue fuses with that section of the scaffold[11]

Figure 5[10]. Example of an FDA approved 3D printed PEKK cranial implant.

FUTURE TRENDS AND CHALLENGES

- The next step for 3D printing body parts is the creation of more complicated solid organs, specifically with large internal vascular networks. The following organs are currently in development:
  - **Sphincters** – 3D printed sphincters have been implanted into mice, and have developed their own native blood supply and function[12]
  - **Kidneys** – Artificial kidneys made with kidney cells have been shown to be functional in mice[13]
  - **Livers** – In late 2013, it was demonstrated that 3D printed liver tissue maintained key liver function for 40 days[14]

CONCLUSION

Tissue engineering and 3D printing are both emerging fields that are gaining a lot of attention in the scientific world. By incorporating 3D printing techniques, tissues engineering is reaching a point that therapies can be created quickly, precisely, and with a level of detailed customization that could never before have been imagined. The possibility of having replacement organs or bone created using tissue from the same patient, formed to the exact structure of the organ or bone being replaced sounds like the work of science fiction, but it is actually close to reality. There is still work to be done, but it is clear that these two relatively new fields have amazing potential together.

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