Journal of Orthopaedic Translation (2016) 6, 42—49

Available online at www.sciencedirect.com

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journal homepage: http://ees.elsevier.com/jot

REVIEW ARTICLE

From the printer: Potential of three-dimensional printing for orthopaedic applications

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Received 27 January 2016; received in revised form 14 April 2016; accepted 18 April 2016
Available online 10 May 2016

KEYWORDS
3D printing;
biofabrication;
orthopaedics;
regenerative medicine

Summary Three-dimensional (3D) printers can create complex structures based on digital models. The combination of medical diagnostic imaging with 3D printing has great potential in day-to-day clinics for patient-specific solutions and applications. In the musculoskeletal system, 3D printing is used to create custom-made implants, patient-specific instrumentation, and to regenerate tissues, in particular bone and cartilage. The major limiting factors for bioprinting include the lack of printing techniques with optimal printing resolution and materials with ideal mechanical strengths while maintaining cellular functionality. Before "tissues from the printer" can be widely applied, further research and development on improving and optimising printing techniques and biomaterials, and knowledge on the development of printed constructs into living tissues, is essential for future clinical application of this technology.

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http://dx.doi.org/10.1016/j.jot.2016.04.003

Introduction

Over the past 30 years, there has been great advancement in medical technologies. Three-dimensional (3D) printing, a technique based on topography and photosculpture, was originally developed in 1986 by Charles W. Hull to build objects layer by layer based on digital drawings [1,2]. This technique, also known as additive manufacturing, was designed to shorten the design cycle of new products by fabricating plastic prototypes (rapid prototyping). Different kinds of materials, such as metals and ceramics, can be used for the printing of 3D objects. By using digital blueprints and image data, 3D printing has been used in various applications, such as manufacturing, the food industry, education, and art. For example, using the front and side view photographs of a person, customised prescription glasses can be 3D printed to fit personal facial features [3]. In orthodontics, x-ray images and photographs of patient's teeth can be taken or scanned using a 3D scanner. These digital images are used for treatment plans and printing orthodontics braces to align teeth [4].

The ability to use medical image data for designing a model has opened up new possibilities in the field of medicine. Three-dimensional printing can be used for patient-specific therapy, as it allows for the fabrication of custom-made implants and medical devices. In parallel, with the concept of personalised medicine, which refers to patient-specific medication based on patients' genetic profile, 3D printing can be used for personalised treatment.

In the past few years, there has been an increase in the number of publications describing the use of 3D printing techniques in patient-specific treatments. Further research in tissue engineering and regenerative medicine focus on developing specific printers and materials to create 3D constructs with living cells, growth factors, and other biomaterials using 3D printing [5]. These constructs are envisioned to replace damaged or diseased tissues and can also be used as a disease or toxicity model to study the interaction between different cell types or for drug screening. This fabrication process, also known as biofabrication, which involves the printing of living cells and biomaterials, is defined as: "the automated generation of biologically functional products with structural organisation from living cells, bioactive molecules, biomaterials, cell aggregates such as microtissues, or hybrid cell-material constructs, through bioprinting or bioassembly and subsequent tissue maturation processes" [6]. It offers the possibility to build complex tissues by the deposition of various bio-inks, such that the form and content of a construct can be tailored to the tissue to be repaired. In this article, the current techniques and recent developments of 3D printing, for orthopaedic applications in particular, is presented.

Current technologies

The general workflow of creating a 3D printed product consists of a number of subsequent steps: (1) imaging and data processing; (2) selection of printing techniques; (3) selection of materials and bioactive components; and (4) printing/bioprinting of products (Figure 1).

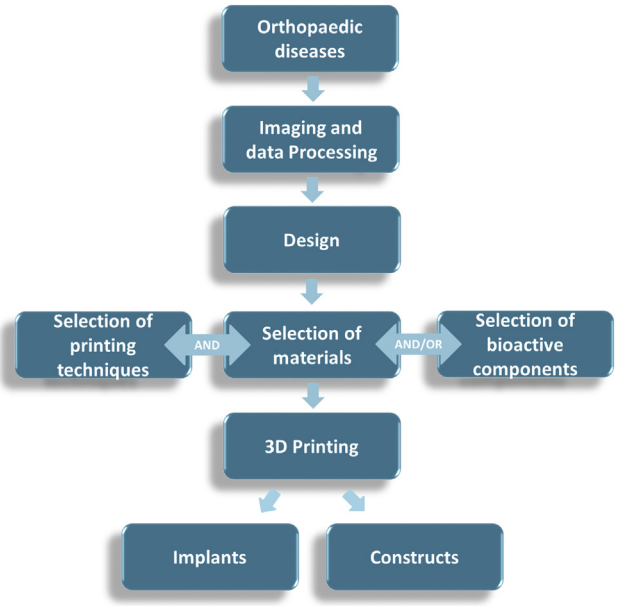

Figure 1 A schematic flow of creating three-dimensional (3D) printed products.

Imaging and data processing

Combining medical imaging and 3D printing opens up new possibilities for patient-specific therapy, as it allows for the customisation of prosthetics and implants and visualisation of complicated pathologies. The process of creating 3D models from imaging data involves image acquisition, data segmentation, and transformation into digital 3D models, followed by 3D printing and post processing [7]. The choice of imaging technique is based on the intended application and image resolution. The resolution of the resulting image is important, as images with poor resolution will result in an inaccurate and unfit model. In orthopaedics, imaging techniques such as x-ray imaging, computed tomography (CT), and magnetic resonance imaging (MRI) are commonly used. X-ray imaging and CT are often employed to diagnose bone fractures or muscle disorders, whereas MRI is used to detect soft tissue damage. Once the initial imaging data has been acquired, further processing, which includes selecting and isolating the region of interest using open or proprietary software, and transforming segmented data into volumetric data, will be carried out prior to printing.

Printing techniques

In order to meet the intended applications of a scaffold or implant, the architectural design of a construct at various levels, macro- (overall shape), micro- (tissue architecture) and nano-scales (surface modification) is important [8]. The selection of a 3D printer depends highly on the materials of interest and resolution of the products. Common printing techniques include fused deposition modelling (FDM), selective laser sintering (SLS), and inkjet printing. FDM printers generally extrude materials that are heated at the