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Development of porous medical implant scaffolds via laser additive manufacturing

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Abstract: The objective was to develop and evaluate the porous medical implant scaffolds designed via digital method and fabricated by laser additive manufacturing. A porous artificial femur model and several vessel scaffolds with customized design were created based on the widely used computed tomography (CT) technology and Pro/Engineer software, and then were obtained by selective laser melting of powdered titanium-alloy material. The fabricating results show that supports are not required with the improvement of the processability of lattice, and porous scaffolds with good interconnectivity can be fabricated. Some issues also appear, such as the low geometric accuracy of lattices. The exploited design freedom is an expected benefit in medical field due to the individual characteristic of each patient. It is expected that more scaffolds will be developed and applied in practical fields with further study on design, process and biocompatibility.

Key words: powdered materials; medical implant; porous structure; processability; rapid manufacturing

1 Introduction

For the past years, the laser additive manufacturing technologies have been applied to creating of physical prototypes from 3D digital models without the need for process planning. Recently, with the development of materials and the improvement of equipment, these technologies have been expected to directly fabricate metal components, which are used in practical fields [1]. The additive approach breaks up a complex 3D model into a series of 2D cross-sections with a nominal thickness so that it enables the direct fabrication of customized components which always have freeform surfaces and cannot be easily manufactured by conventional processes [2]. This observation promotes the expansion to the medical fields since the patients always have individual characteristics [3].

Scaffold, one type of implants in surgeries, has brought attention in recent years. One of the important reasons is that the scaffold cannot be easily obtained by using conventional processes due to the porous structure, for instance, the bone implant with pores for biocompatibility. To optimize the architecture of scaffolds for the direct fabrication, topology optimization is one of the new approaches which maximize scaffold stiffness and diffusive transport in the interconnected pores [4]. However, this optimization is only about the mechanical properties without consideration of the processability. It is reasonable that the processability should be considered when combining with materials and processes. As for materials, pure titanium or titanium alloy would be the most expected option, which has been widely used for various implants because of good biocompatibility and high mechanical strength. Many testing results show that the titanium-alloy components fabricated by laser additive manufacturing have higher tensile and compressive strengths but lower ductility in comparison with those of components manufactured by conventional processes [5,6]. Based on these progresses, the exploration of fabrication of porous scaffolds can be carried out. Among the limited reports, the biocompati-

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bility was preliminarily discussed, including the relationship between osteoindution and pore size, and the analogousness between porous structure and human bone, etc [7,8]. In addition, the post-processes, such as heat treatment, were investigated, mainly aiming to improve the mechanical behaviour [9]. Actually, the link of customized design with direct fabrication would be a challenging issue needed to be evaluated since the customized design should be assigned with good processability while the fabrication should be finished with customized feature. In other words, the development should be carried out in accordance with the patient's individual characteristics and the laser additive manufacturing process. This observation promotes a combination of additive manufacturing and computed tomography (CT), a widely used technology in medical, to facilitate the digital design of individual characteristics and the direct fabrication of unit cells, which will be evaluated in this work.

2 Development procedure and experimental conditions

Figure 1 shows the development procedure of customized porous implant scaffolds. It aims to obtain the customized scaffolds for surgical operation. The section information of pathological tissue is obtained by CT scan and the images are exported as Dicom file format. Then, the digital model can be restructured by processing of threshold segmentation, region growing or other operations in image processing software and is exported as STL file format. According to the digital model, doctors determine the repair solution and design the corresponding implants in CAD system since nearly every CAD system can input and output a STL file format. It is known that nearly every AM machine accepts the STL file format, which becomes a standard. Therefore, these two technologies, the CT and the additive manufacturing, are combined, and the customized implants can be directly fabricated after slicing and path manipulation. Compared with the conventional process, this digital method reduces the cycle time of design and fabrication. Furthermore, it builds the bridge for the cooperation between doctors and manufacturers.

In this work, the CT images were monitored by SOMATOM Emotion Spiral CT apparatus and imported into Mimics to restructure the original model. The design of customized porous structure was conducted in Pro/Engineer (version Wildfire 4.0) and the 3D model was imported into the additive manufacturing system. The employed system consisted of a ytterbium fiber laser with a continuous wavelength of 1090 nm, a galvanometer optical scanning system with dual axis mirror positioning scanners, and an F-theta lens with a focal distance of 163 mm. During the fabrication, a powder dispenser platform was raised up and a flexible brush spread powders to the built platform. Following the scanning paths programmed in the machine control data, the $X-Y$ scanner directed the laser beam to heat powders selectively to build a layer, and then the built platform descended a layer thickness. The machine repeated the above steps to fabricate a scaffold layer by layer.

The material used in the experiment was gas-atomized Ti6Al4V amorphous powder with granularity of 38 μm. The chemical compositions of the powdered material are listed in Table 1. During the experiment,

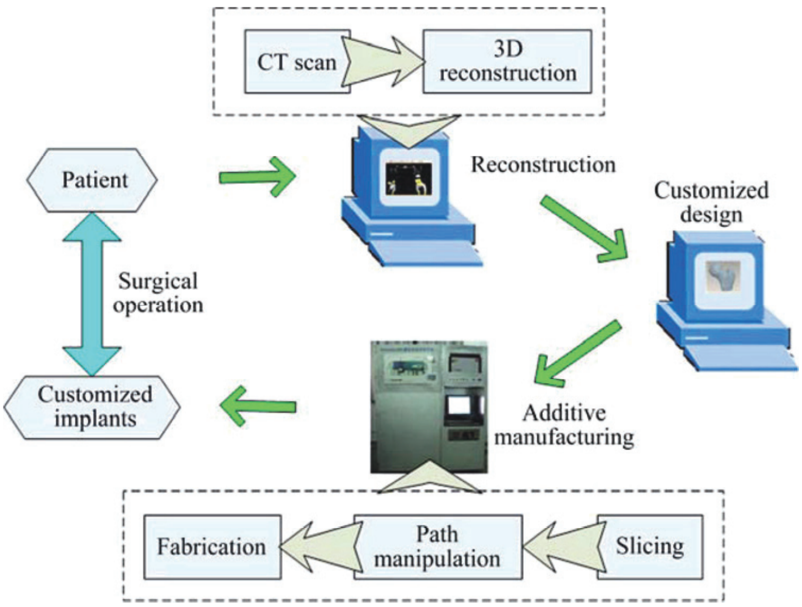

Fig. 1 Schematic of development procedure