INVESTIGATING THE TOOLPATH DESIGN OF 3D-PRINTED PVA CRYOGELS

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Introduction

It is widely reported that connective tissues, such as articular cartilage, have poor self-repair properties, and damage to such tissues has a significant negative impact on patient quality of life[1]. Soft tissues have complex structures and anisotropic mechanical properties that vary greatly depending on physiological function[2]. Owing to challenges with replicating natural tissues, soft tissue damage treatments are currently limited. Hence, there is great interest in researching soft tissue-mimicking materials. Polyvinyl alcohol (PVA) hydrogels have gained significant interest due to their biocompatibility and mechanical properties analogous to those of soft tissues. The mechanical properties of PVA hydrogels can be tailored for different applications[3]. However, challenges exist with constructing 3D tissue-like structures using hydrogels due to their soft and porous structure, and low viscosity[4]. Advances in additive manufacturing (AM) technologies have led to the development of printers with beds that can be chilled to sub-zero (°C) temperatures. These platforms enable the physical cross-linking of PVA hydrogels upon deposition, creating PVA cryogels (PVA-C). Research into toolpath variation and the effect of this on the mechanical properties is limited. In this study, the toolpath design and fabrication of PVA-C, and the subsequent impact on the mechanical properties, will be investigated.

Methods

The digital samples were designed (Autodesk Fusion 360, California, USA), sliced and converted into G-code (REGEMAT 3D designer, Granada, Spain), then customised by differing the toolpaths, created using MATLAB (MathWorks Inc., Massachusetts, USA). A 11% w/w PVA solution was prepared by dissolving powdered PVA, with a hydrolysis of 99+% and molecular weight of 146-186 kDa, (Sigma Aldrich) in deionised water through autoclaving (one hour at 121°C), and continuously mechanically stirring the solution for two hours – one hour on a hotplate at 50°C, then one hour with the hotplate removed, allowing the solution to gradually return to room temperature). To fabricate the samples, a REGEMAT Bio V1 bioprinter (REGEMAT, Granada, Spain) fitted with a 0.58 mm nozzle was used. The bioprinter bed temperature was maintained at -8°C (+/- 0.5°C) during printing, to enable physical cross-linking of the PVA-C to occur upon deposition. By directly modifying the G-code, different toolpaths were used to fabricate the samples. After the completion of the printing, the samples were subjected to three 24 hour freeze-thaw cycles, undertaken at -20°C and room temperature. To assess the mechanical impact of the change in toolpath design, the samples were mechanically tested using a Bose Electroforce 3200 (TA Instruments, Delaware, USA).

Results

Preliminary results from this study are presented here. Figure 1 shows a CAM digital representation of a tool-path design, based on a sine-wave function. Figure 2 demonstrates a fabricated sample of PVA-C based on an alternating 0° to 90° toolpath.

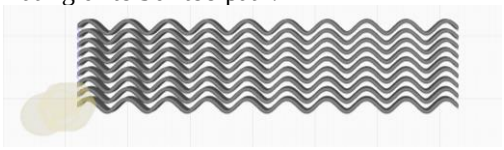

Figure 1: CAM toolpath design, based on a sine-wave.

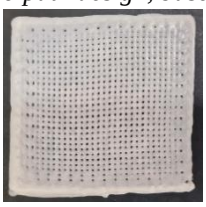

Figure 2: Fabricated PVA-C sample with an alternating 0-90° toolpath.

Discussion

Toolpath design is an integral process parameter in AM. This study has investigated how different toolpaths can be designed and utilized for 3D printing PVA-C. The preliminary results show a sine-wave-based toolpath design, and a fabricated sample based on an alternating 0°-90° toolpath. The potential design options of the proposed technique present huge flexibility in terms of toolpath, material structure and hence the mechanical properties. The capability to add anisotropy into PVA structures, through toolpath variation, will enable the future fabrication of materials which more accurately mimic the mechanical behavior of natural tissue.

References

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