CHARACTERIZATION OF 3D PRINTED BIOACTIVE GLASS AND HYBRID SCAFFOLDS USING MICRO-CT IMAGE ANALYSIS

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DECLARATION

I declare that this is my own work and this Thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date: 01/05/2024

The supervisors should certify the Thesis with the following declaration.

The above candidate has carried out research for the Doctor of Philosophy Thesis under our supervision. We confirm that the declaration made above by the student is true and correct.

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Name of Supervisor: Dr. Thilina Lalitharatne

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Name of Supervisor: Prof. Julian Jones

Signature of the Supervisor: Date: 29/05/2024

DEDICATION

To Sri Lankans who honestly serve the country in the middle of an economic crisis.

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ABSTRACT

An ideal synthetic bone graft acts as a temporary template (scaffold) to regenerate bone. The scaffold should have an interconnected pore structure with similar mechanical properties to the bone. The scaffold should be fabricated with a biocompatible, biodegradable, and bioactive material. Bioactive glasses and hybrids have been identified as promising materials for synthetic bone grafts as they form a bond with the bone and stimulate new bone formation. Although the properties of bioactive glasses and the production processes of bioactive glass and hybrid scaffolds have been improved over the last five decades, producing patient-specific scaffolds with ideal properties is still a challenge. Optimizing the topology, production process, and chemical structure of bioactive glass and hybrid scaffolds is an iterative process with a comprehensive characterization of structural, bioactive, and biological properties. Micro-CT imaging can be used to characterize the production process, the structure of the scaffold, and the bone in-growth into the scaffold. Preparation of samples, selection of imaging parameters, the image reconstruction method, denoising, detection and tracking of Volumes of Interest, accurate image segmentation, and quantification of descriptors are vital in the characterization process conducted using micro-CT. This work presents a new multiscale and 4D (3D over time) micro-CT image analysis framework to characterize 3D-printed bioactive glass and hybrid scaffolds and demonstrate the effective use of micro-CT imaging in analyzing the production process of 3D printed bioactive glass and hybrid scaffolds. The Image analysis framework contains image processing components for denoising, tracking volumes of interest, and machine learning-based segmentation of micro-CT images to characterize bioactive and hybrid scaffolds from micro to macro scale. All the image processing components were evaluated using appropriate performance measures. Two studies were conducted to demonstrate the image analysis framework and effective use of micro-CT in the characterization process. The first study was a four-dimensional analysis of bioactive glass sintering within a 3D printed scaffold, conducted using synchrotron-sourced micro-CT. This study delivered new insights on the sintering of bioactive glass composition ICIE16. The second study was conducted to optimize the printing window of 3D-printed hybrid scaffolds using lab-based micro-CT. The results of this study identified the printing window that produces the best quality 3D printed hybrid scaffolds.

Keywords: Bioactive glass, 3D printing, Micro-CT, 3D image analysis

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LIST OF ABBREVIATIONS

Abbreviation	Description
AM	Additive manufacturing
CAD	computer-aided design
CCD	Charge Coupled Device
CCPi	Collaborative Computational Project in Tomographic Imaging
CGLS	Conjugate Gradient Least Squares
CIL	Core Imaging Library
DMA	Dynamic Mechanical Analysis
DSC	Dynamic Scanning Calorimetry
DSCD	Distance between Strut Centers Diagonally
DTA	Differential Thermal Analysis
ECM	Extracellular Matrix
FBP	Filtered Back-projection
FN	False negative
FP	Fales positive
GBT	Gradient Boosting Trees
GLCM	Gray Level Co-occurrence Matrix
HA	hydroxyapatite
HCA	hydroxycarbonate apatite
HSM	Hot Stage Microscope
IoU	Intersection over Union
Micro-CT	Micro Computed Tomography
PDD	Pore Diagonal Distance
RF	Random Forest
ROI	Region of Interest
SEM	Scanning Electron Microscopy
SVM	Support Vector Machine
TGA	Thermogravimetric Analysis
TN	True negative
TP	True positive
VOI	Volume of Interest
VOIs	Volumes of Interest