DESIGN OPTIMISATION OF NEXT-GENERATION SCAFFOLD-BASED BONE RECONSTRUCTION IMPLANTS: PHD THESIS PRESENTATION

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Introduction

This doctoral research demonstrates the latest advances in patient-specific design, biomechanical modelling, and optimisation of next-generation scaffold-based devices for reconstructing large jawbone defects. One outcome of this research is an innovative clinical planning tool used to inform and guide the decision-making process of a maxillofacial surgeon prior to undertaking a mandibular reconstruction procedure. This innovative research underpins the design and production of next-generation tissue scaffold implants. These new medical devices will be additively manufactured to be patient specific and, for the first time, enable the reconstruction of large segmental bone defects with the complete volume of the gap being filled with a porous 3D-printed tissue-engineered scaffold.

Research Project 1

Using computed tomographic (CT)-based finite element (FE) modelling combined with multiobjective optimisation, determine the optimal height (h) and angle (α) to place a titanium fixation plate on a scaffold-based reconstructed human mandible (Fig. 1) so as to enhance tissue ingrowth, structural strength and structural stiffness of the scaffold-host bone construct [1].

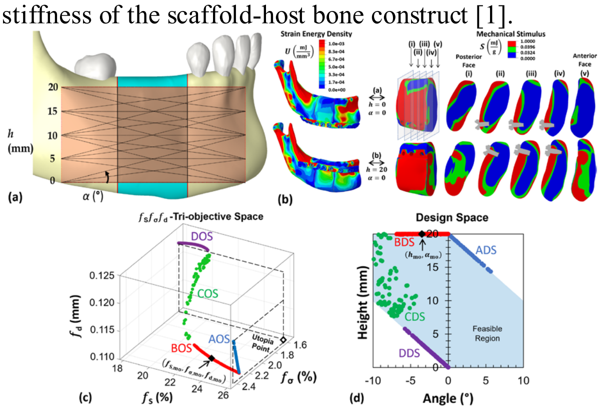

Fig.1: CT-based FE modelling and multiobjective optimisation for optimal fixation plate placement

Research Project 2

Develop a state-of-the-art CT-based FE sheep mandible reconstruction model by: (i) characterising the elastic mechanical properties of selective laser sintered (SLS) polyetheretherketone (PEEK) with a universal testing machine (Fig. 2a), (ii), inversely characterising the Young's modulus of the intact sheep mandible cortical bone by *in vitro* mechanical testing with digital image correlation (DIC) and a digital twin CT-based FE model of the *intact* sheep mandible (Fig. 2b,c), and (iii) validating a digital twin CT-based FE model of the *reconstructed* sheep mandible with an additively manufactured SLS PEEK scaffold-based implant using *in vitro* mechanical testing with DIC.

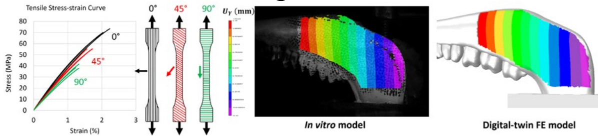

Fig.2:(a) SLS PEEK stress-strain curve (b) DIC (c) FEA

Research Project 3

Using the CT-based FE model of the reconstructed sheep mandible and multiobjective optimisation, determine the optimal design of the scaffold microstructure (Schwarz P-surface unit cell) for a sheep mandible implant so as to promote tissue ingrowth through (i) enhancing mechanical stimulus of the scaffold, and (ii) enhancing permeability.

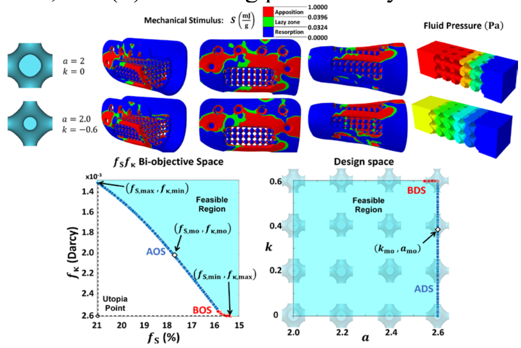

Fig.3: Multiobjective optimisation of unit cell microstructure

Research Project 4

Evaluate bone ingrowth conditions of a one-body tissue scaffold implant for reconstructing a segmental defect in a sheep mandible after 12 weeks *in vivo* (Fig. 4).

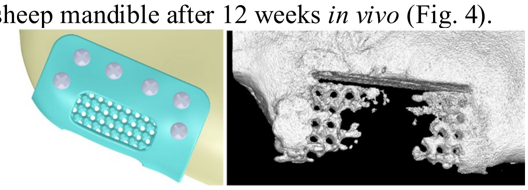

Fig.4: Neo-tissue formation in porous scaffold after 12 weeks in vivo.

Conclusions

The impact of this research overcomes the limitation of current surgical practice of using grafted bone to bridge the defect. In addition, this research and methodology can be readily extended to include other orthopaedic surgical procedures such as spinal fusions or hip and knee reconstructions.

References

1. Ferguson BM et al., J. Mech. Behavior Biomed. Mater.; 126:104855(2021); https://doi.org/jkqj.