PhD PROJECT PROPOSAL

## **PhD Project Title**

Knee joint arthroplasty: *is topology and topological design industry’s answer for*

## personalised healthcare?

## **PhD Supervisory Team**

Principal Supervisor: Daniel Espino ([d.m.espino@bham.ac.uk](mailto:d.m.espino@bham.ac.uk)), Biomedical Engineering Research Group, School of Engineering

Co-Supervisor/s: Sophie Cox ([s.c.cox@bham.ac.uk](mailto:s.c.cox@bham.ac.uk)), School of Chemical Engineering, Healthcare Technologies Institute & Centre for Custom Medical Devices

## **Project Abstract**

The aim of this study is to develop a prosthetic medical device, for the tibia, for a revision knee arthroplasty. The process of surgical planning for additive manufacture requires development of a computational framework that enables morphing of equation-sets to a diseased structure. This healthcare application will ideally exploit 3D printing; where a medical device is manufactured to match the individual. Surgical planning is not trivial as the optimal result is unknown and must be approximated from the individual’s diseased knee. This process requires a form of geometric (not elastic), yet continuous, deformation of the joint contour.

## **Detailed Project Description**

**BACKGROUND**

Knee joint arthroplasty is a procedure used clinically either when there is injury to the knee joint or when disease is present. Injury would typically result from trauma, while the main disease leading to surgery is osteoarthritis. The main risk factor for osteoarthritis is obesity1,2, which is on the rise in the UK and USA. Treatment for osteoarthritis is palliative, focused on ameliorating pain, until joint surgery can no longer be avoided.

There is a current push towards developing healthcare technologies which are personalised and fully exploit computational power for precision and objectivity. For example, the Medical Device Innovation Consortium and the Food and Drug Administration have identified a need to use computational techniques for timely delivery of medical devices3. In combination with the advent of additive manufacture there is great potential to generate innovative medical devices customised for optimal health benefits.

Computational techniques are available to characterise the shape of joints, and numerical methods can be used on subject specific CAD models generated from medical scans. However, the ability to fully map the workflow from medical device custom to a patient, surgical planning, and manufacture of bespoke surgical tools and prosthesis, requires development. A central limitation is the ability to have an anatomically accurate description of geometry, which can be morphed from diseased to healthy and across a range of individuals. Could topology and topological design be the solution?

AIM

The aim of this study is to develop a prosthetic medical device, for the tibia, for a revision knee arthroplasty. This will be achieved by:

* Completion of a topological analysis of the knee structure, specifically linked to the tibia and tibial plateau;
* Numerical analysis of the medical device, optimised for placement;
* Evaluating the surgical procedure and the instruments custom for the subject undergoing
* surgery;
* definition of a sizing system which fully exploit techniques such as additive manufacture;
* definition of a standard to approach the pre-surgical plan.

REJOINT will manufacture a finalised, suitable medical device and commission mechanical testing to the appropriate quality standards by a certified laboratory.

METHODOLOGY

1. Topology and morphometry: The shape of the tibial plateau will be characterised in terms of its morphometry. From this a scalable geometry will be developed. The use of topology should then employed to reverse match a diseased/damaged joint to the idealised joint shape.
2. Medical device design, surgical tools & planning: The idealised joint shape will form the basis for the development of the prosthetic device. It will require the evaluation of instruments for surgery, a sizing system linked to topology and morphometry, and should result in a standard approach for pre-surgical planning.
3. Finite Element Analysis (FEA): A numerical model will be developed, which incorporates geometry, material properties of tissues, and is based on the scans for the individual undergoing surgery. This analysis predicts the concentration of stress across the medical device and tibia. Ansys, Abaqus of FEBio are potential software to be used for the numerical analysis.
4. Optimisation: artificial intelligence methods (e.g. evolutionary algorithms) will be used to optimise the geometric shape which best enables a knee revision. This will be constrained by specific parameters (e.g. as related to quality standards, surgical needs, etc) and will require the use of weighting functions. The methodological process from 2.-4. will be iterative, and ideally automated using HPC facilities.
5. Additive manufacture and prototyping: once a design has been developed, it will be 3D printed for assessment with potential for visual inspection and mechanical testing. Additionally, once REJOINT are satisfied that the prototype meets their needs, it will be analysed via their standard testing platforms.

TRAINING

This is an interdisciplinary project, and as such the depth and breadth of training will be tailored to the researcher. In brief, key areas where training is expected include:

* Computing (optimisation algorithms) and computational modelling (e.g. FEA);
* Anatomy, morphometric measurements and anatomical variability;
* Design and manufacture (specifically 3D printing);
* Materials science theory, and relation to material properties;
* Commercialisation and clinical uptake of healthcare technology.

TOPOLOGY CDT

The intention is to exploit topological principles, so that healthcare technology can be developed to ensure that surgical planning is completed with greater objectivity and more rapidly. The shape of a knee joint will need to be parametrised, and then a computational framework developed which maps an individual’s geometric variables to this with an end result of an optimised medical device made via additive manufacture.

RESEARCH-GROUPS

This project will be supervised across two school, School of Chemical Engineering and the School of Engineering. The student will have access to the Biomedical Engineering Research Group laboratory, the Institute for Translational Medicine, and the Centre for Custom Medical Devices. In addition, techniques for optimisation will likely require access to HPC facilities at the University (Bluebear). External to the University, the researcher will be expected to liaise extensively with the R&D group at REJOINT.

RESEARCH-STRATEGIES (UoB/EPSRC)

This project integrates biomedicine, physical science, and computer science with computational modelling. Both EPSRC and UoB have invested heavily in healthcare technology and manufacturing, both of which will be a focus of this proposed PhD. Specifically, the computational technologies which enable greater exploitation of additive manufacture for personalised medicine are being developed; there is scope to use techniques associated with topology and topological design to do this.

BACKGROUND

The project is interdisciplinary, and as such any from a range of backgrounds would suit. What is vital is the flexibility and adaptability to work at the interface between subject areas, and the drive to identify skills requiring development & enthusiasm/determination to work to develop these new skills.

Computing, Mathematics, Engineering, and Physical sciences are all appropriate, as are affiliated backgrounds. Ideally the researcher would have some previous exposure to Matlab and a working understanding of mechanics-of-materials.

REFERENCES

[1] Aspden RM. Obesity punches above its weight in osteoarthritis. Nat Rev Rheumatol. 2011;7(1):65-68.

[2] Lee, R. & Kean, W. F. Obesity and knee osteoarthritis. Inflammopharmacology 2012;20:53–58.

[3] Faris O, Shuren J.An FDA viewpoint on unique considerations for medical-device clinical trials. N. Engl. J. Med. 2017;376:1350–1357.