PhD PROJECT PROPOSAL

PhD PROJECT TITLE:

Origami based design of ingestible medical instrumentation

PhD SUPERVISORY TEAM

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PhD PROJECT DETAILS

Project abstract

The gut is an important part of the body due to its role in absorbing nutrients and medicines. However, our understanding of it is limited. This project will design, build and test an ingestible device that resides in the intestines for an extended period, enabling longitudinal analysis of the gut. The ingestible device will utilise origami design principles to design and make a device that is both small enough to be swallowed but can expand at a desired point along the gut, as well as withstand the intestinal mechanical forces and then shrink down again to safely excrete the device.

Applications of Topology

To be swallowed, the device must be no bigger than 11 mm diameter. To reside in the small intestine the diameter must increase to at least 20 mm, to reside in the large intestine it must increase in diameter to at least 75mm, before dropping back to an 11 mm diameter for excretion. This may be achieved through the use of origami structures that can be deployed in the body. Design of such structures require topological design techniques due to the changing shape, structure and size of the device.

DETAILED PROJECT DESCRIPTION

Orally ingestible devices have the potential to improve our understanding of the origins of gastrointestinal disease. Several pill-sized, swallowable diagnostic devices have been produced in recent years. These devices, while helpful, are mostly passively propelled through the gastrointestinal tract (GI tract) by peristaltic forces, thereby providing a snapshot of the state of the GI tract at a single moment in time[1]. These devices must have the ability to stop and analyse changes in the GI tract over an extended period if they are to shed light on the metabolic and physiological conditions that contribute to GI disease.

Modifying ingestible devices to incorporate some form of structure to enable them to reside at a fixed point along the GI tract for a period is challenging. The ingestible device must still be swallowable and be able to pass through the entire length of the GI tract when desired, limiting its diameter to 11mm. However, to be fixed in position at a specific point along the GI tract, the residence structure must be able to extend the size of the ingestible device to a diameter of 20mm in the small intestine and 75mm in the large intestine when triggered, before also returning to its initial size to ensure safe removal. In addition to changing shape or size, the ingestible device, when fixed in place, must withstand mechanical forces in the GI tract due to peristalsis, the passage of chyme (digesting food) or the low friction due to mucus [2]. Finally, deployment of the residence structure must be controlled so that there is little risk of excessive tissue distension or perforation, which can lead to patient discomfort or the need for surgical intervention, respectively.

One way of creating a resident structure that can be deployed to increase the diameter of the device to keep it in place is through the use of design techniques based on origami, the ancient Japanese art of folding paper. Origami based techniques are widely used to create deployable structures for satellites and other volume-constrained applications[3]. In vivo deployment of the structure could be achieved by utilising the natural elasticity of the structure, the use of swellable or pH-responsive polymers, or some other means. Collapsing the structure may be achieved by the same or dissimilar methods, such as the use of biodegradable polymers timed to dissolve after a known length of time. This project will allow the student to gain experience in mathematics that will be used to describe and analyse the changing shape and size of the structure and materials science and medical device prototyping used to build the devices. The device concepts will be assessed to measure their performance under conditions similar to that in the GI tract using either pneumatic silicone tissue phantoms of the GI tract or the use of ex vivo porcine tissue. Hands-on training will be provided to support these activities in various microengineering and manufacturing techniques that may be needed to make device prototypes as well as basic electronics and LabVIEW skills for testing the device. Additional training will develop mathematical modelling skills in continuum mechanics and geometry.

The student will be hosted in the School of Engineering as a member of the Biomedical Engineering group, which are active in research areas such as biomaterials, orthopaedics, surface engineering, microsystems and medical device design. They will be jointly supervised by Dr Gerard Cummins and Dr Rosemary Dyson. This research project builds upon Dr Cummins expertise in the development of diagnostic and therapeutic technologies for gastrointestinal disease by applying electronics, mechanics and microengineering with the aim of clinical translation. The project also complements the research of Dr Rosemary

Dyson in the utilisation of mathematical modelling to solve mechanical, clinical and industrial problems.

This project would ideally suit a student with a background in mechanical engineering, applied mathematics, physics or biomedical engineering. An interest in medical device development and healthcare technology would also be beneficial.

Healthcare technology is recognised by the Engineering and Physical Sciences Research Council as a critical theme of research across the UK. Healthcare technology is also a strategic area of research within the University of Birmingham, with efforts conducted across all Schools in the College of Engineering and Physical Sciences. The University of Birmingham recognises the importance of healthcare technology and the need to maximise the impact of this research through translation into clinical practice through organisations such as the Institute of Translational Medicine and the Healthcare Technologies Institute (HTI). The HTI brings together researchers from across campus to facilitate the fast and effective translation of new discoveries to health applications, and there will be opportunities to engage with this organisation as part of the doctoral studies.

[1] G. Cummins, B.F. Cox, G. Ciuti, T. Anbarasan, M.P.Y. Desmulliez, S. Cochran, R. Steele, J.N. Plevris, A. Koulaouzidis, Gastrointestinal diagnosis using non-white light imaging capsule endoscopy, Nat. Rev. Gastroenterol. Hepatol. 16 (2019) 429–447. https://doi.org/10.1038/s41575-019-0140-z.

[2] L. Barducci, J.C. Norton, S. Sarker, S. Mohammed, R. Jones, P. Valdastri, B.S. Terry, Fundamentals of the gut for capsule engineers, Prog. Biomed. Eng. 2 (2020) 042002. https://doi.org/10.1088/2516-1091/abab4c.

[3] J.J. Park, P. Won, S.H. Ko, A Review on Hierarchical Origami and Kirigami Structure for Engineering Applications, Int. J. Precis. Eng. Manuf. - Green Technol. 6 (2019) 147–161. https://doi.org/10.1007/s40684-019-00027-2.