1. Bioactive Glass Development (industry linked)
Supervisors: Dr Philip Boughton, Prof Andrew Ruys

Bioactive glasses are used in tissue engineering, bone putty, dental root therapy, implant coatings and bioabsorbable devices. This industry linked project aims to develop new applications and improve existing glass manufacturing processes. Opportunity to investigate and develop novel glass compositions and post-forming methods (microspheres/fibers/coatings) to address clinical needs will be provided. Bioglass science, process design, and analytical testing within a commercial context will provide invaluable device design and manufacturing experience.

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2. Soft Tissue Scaffold Development (industry linked)
Supervisors: Dr Philip Boughton, A Prof Andrew Ruys, Prof Sue McLennan

Variotis™ is a versatile bioactive soft tissue scaffold that can be used with a range of cells and tissues. New methods, modifications and applications will be investigated. Photo-activated capabilities and bioactive glass facilitated tissue adhesion are important areas for investigation. The project will also include refinement objectives for existing production and post-process routes for various scaffold forms. The final phase of the project will involve design customization of the scaffold form and type for a tissue engineering collaborator.

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3. Tissue Engineering Bioreactor Systems (industry linked)
Supervisors: Dr Philip Boughton, Dr Giang Tran, Prof Andrew Ruys

In vitro tissue engineering benefits from biomechanical stimulus. The novel iaxsys™ system has been designed to complement existing cell biology experimental methods and equipment constraints. This project aims to further develop and refine systems: actuation, sensors, feedback, interface, mechanical couplings, perfusion, plate-bank and in-situ microscopy. User requirement analysis, design and development, manufacturing and verification/validation aspects will be addressed. Ability and experience with design (CAD), cell testing, and software programming will be helpful.

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4. Working with the biomedical industry to develop 3D printed medical devices

**Supervisors:** Prof Julie Cairney, Dr Philip Boughton

Working with the biomedical industry to develop 3D printed medical devices

3D Medical are an exciting new start up based in Melbourne. They recently listed with the ASX and are already Australia’s leading medical and healthcare specific technology provider. In an Australian first, they recently developed a 3D printed and customised titanium jaw joint which was used to correct a rare jaw deformity in a 32-year-old male (x-ray shown below).

In this project, you will work closely with the 3D Medical to develop new 3D printed products for orthopaedics. By undertaking a thorough review of the current orthopaedic consumables, you will be expected to identify the top 5 applications in which 3D printing could ‘disrupt’ the market for existing technologies. From there, you will be design and print a prototype product.

The student undertaking this honours project will have the opportunity to undertake an industry placement in Melbourne over summer with 3D Medical.

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5. Valve Biomaterials Optimization (Industry Linked)

**Supervisors:** Dr Philip Boughton, Dr Giang Tran, Prof Andrew Ruys

Bovine pericardium is the outer membrane of the heart that is widely used in bioengineering of variety of cardiovascular applications including heart valve leaflets, patches for pericardial for cardiovascular reconstructive procedure as well as in general surgery. Calcification of these tissues can lead to structural dysfunction, tissue degeneration and catastrophic implant failure. The onset of calcification and its effects will be studied by a range of techniques. Existing and novel methods to prevent calcification will be investigated. Other opportunities to further enhance heart valve materials and valve configurations are also available.

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  Supervisors: Dr Philip Boughton, Dr Giang Tran, Prof Andrew Ruys

Collagenous tissue such as bovine pericardium and porcine aortic wall have been used successfully in bioprosthetics for the past 40 years. The established route for collagenous tissue production utilizes glutaraldehyde crosslinking agent. A variety of processing conditions are employed by manufacturers. Concentration of glutaraldehyde, thickness of tissues, and strain conditions during crosslinking can be varied to enhance the mechanical performance of the bioprosthetic materials. This industry-sponsored study will provide opportunities to improve manufacturing processes, develop new approaches, engage in mechanical verification and analytical methods. This project is focussed on delivering process design, manufacturing and test recommendations.

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7. 3D Printed Titanium Biomaterials Characterization
  
  Supervisors: Dr Philip Boughton, Prof Julie Cairney

3DMedical are an exciting new start up based in Melbourne. They recently listed with the ASX and are already Australia’s leading medical and healthcare specific technology provider. In an Australian first, they recently developed a 3D printed and customised titanium jaw joint which was used to correct a rare jaw deformity in a 32-year-old male (x-ray shown below).

In this project, you will work closely with the 3D Medical to characterize SLM printed Titanium for mechanical properties, microstructural and fibroblast cell response. Titanium samples from a conventional manufacturing route will be compared against. Anisotropic printed structures will also be investigated. Recommendations for optimal 3d printing parameters for orthopaedic relevant outcomes will be established.

The student undertaking this honours project will have the opportunity to undertake an industry placement in Melbourne over summer with 3DMedical.

Contact: philip.boughton@sydney.edu.au | 0402890150 | Rm 242 J13
8. Skin Tissue Engineering (RPA & Industry Linked).
Supervisors: Prof Sue McLennan, A Prof Karen Vickery, Dr Philip Boughton, Prof Andrew Ruys

Diabetes and diabetic ulcers is a growing problem in aging populations and among remote indigenous communities. A novel resorbable scaffold for treating serious diabetic ulcers is currently being developed. Dermal chronic wounds are typically necrotic, apoxic, compromised by entrenched infection, and poor in mechanical integrity. An elastic highly interconnective porous scaffold laden with antibiotics and antibacterial agents is being developed. This project will focus on further biologic verification testing and design improvement of this scaffold with particular focus on resorption rate optimization. Exposure to production methods, invitro cell testing, analytical methods, mechanical testing will be provided.

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9. Development of an App for Clinical Research, Rehabilitation Engineering, and Bioinformatics (industry linked)
Supervisors: Dr Philip Boughton, Dr Simon Poon, Tamer Sabet, Prof Andrew Ruys

Popular mobile devices contain a variety of sensors and integrated systems that can be applied to rehabilitation engineering, clinical research and bioinformatics. A thorough review of published and patented methods will be conducted. Broad design opportunities will be mapped out. A new app for use in conjunction with a treatment for frozen shoulder will be developed for mainstream mobile device platforms. The app will track patient joint biomechanics, have capacity to detect treatment abnormalities to allow immediate intervention if necessary, while remotely transponding data for centralized bioinformatic analysis. The prototype app will be verified and validated to ensure mitigation of risks identified in a design risk analysis and safety risk matrix. Candidates will need good software and hardware engineering experience.

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Supervisors: Specialist Physio Tamer Sabet, Dr Philip Boughton

The project will involve development of a pillow-augmenting system to provide cervical spine near-neutral zone positioning in varied positions. In addition to biomechanical design – materials selection, fabrication, user-friendliness, aesthetics, life-cycle, and business case summary will be important aspects to be addressed by this project.

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11. Supine Spine Manipulator (The Sydney Spine Institute)
Supervisors: Specialist Physio Tamer Sabet, Dr Philip Boughton

The aim is to develop a system to induce controlled amounts of displacement to select portions of the spine while supine. The system will incorporate a pressure sensor array and act via a pressure transducer system. The system will effectively provide manipulation therapy similar to that provided by a musculoskeletal physiotherapist, but in a quantified, repeatable, accessible manner. This system will also provide another method by which to track back pain foci with time.

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12. Minimally-Invasive Trans-segmental Device for Treating Spondylolisthesis (The Sydney Spine Institute)
Supervisors: Dr James Van Gelder, Dr Philip Boughton

“Slipped disk” is a major cause of serious low back pain. Surgical approaches to treating this condition. A minimally invasive trans-segmental device design for treating spondylolisthesis is under development. Design process, prototype fabrication, specimen testing, biomechanical validation will be the mainstay of this project. Experience with CAD, FEA, mechanical testing, is preferred.

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13. Intracranial Pressure Monitoring System (Concord Hospital, Iosys Pty Ltd)
Supervisors: Dr Philip Boughton, Dr Simon Poon, Dr James Van Gelder

Like ECG, Intracranial Pressure (ICP) is an important vital sign used in intensive care. It is often too costly to be employed outside of ICU. Intracranial pressure monitoring systems provide a lower cost possibility to obtain important relative measurements (RAP) to assist with clinical planning, particularly in geriatric medicine. A compact mobile intracranial pressure monitoring system concept is under development and if transferable to a smartphone APP would also become an important M-health resource.

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The development of electrospun nerve conduits for peripheral repair is a relatively new area. Prototype conduit specimens (of a variety of conductivities) will be fabricated and cell tested. Cell culture will be conducted with and without electrical stimulation. Verification and validation testing will be undertaken to confirm specification requirements. Medical science background and/or cell culture experience is preferred.

Contact: philip.boughton@sydney.edu.au | 0402890150 | Rm 242 J13
15. Cancer Treatment Review & Innovation Recommendations (with Medicine)

Supervisors: Head of Discipline (Med. Imaging) Clin A/Prof Noel Young, Dr Philip Boughton

Current cancer treatments are a vital part of healthcare provision but place a substantive economic burden on society. Patient survivability across major forms of cancer have improved over the past decades but new techniques provide marginal increments of improvement with large increments in cost. In this study a range of strategies will be employed to assess the state of cancer treatment in use. Detail on current technology and methodologies will be captured, in addition to clinical expert opinion on opportunities for future innovation directions and technical support needs.

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Accessible Foot Injury Mitigating Solutions (Project ACESO, Royal Prince Alfred, Medicine)

Supervisors: Prof Stephen Twigg, Prof Sue McLennan, Dr Philip Boughton

Elderly commonly suffer from some peripheral neuropathy and metabolic dysfunction (diabetes). Toe and foot injuries can go unnoticed and lead to chronic infections that may result in loss of limb and even loss of life. Custom footwear is available to mitigate against injuries but they are costly and inaccessible to most. The project will focus on conception, design iteration and delivery of one or more prototype solutions in consultation with cross-disciplinary experts.

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ROAM Portable Pediatric Oxygen Supply System (Industry Linked)

Supervisors: Marco Tallarida & Dr Philip Boughton

The global market for oxygen therapy, estimated at US$1.8b inclusive of oxygen concentrators and regulators, is experiencing growth largely from the ageing population and demand for easy to use mobile/home systems. Pediatrics also constitutes an important sector of the market.

ROAM is a light weight portable ‘humanised’ oxygen cylinder with an intuitive control interface designed initially for the paediatric market. Key attributes include (i) extended oxygen supply time compared to incumbent technology; (ii) 40% lighter than existing
metal tanks; (iii) nasal mask specifically designed for paediatric use; and (iv) a design aesthetic of appeal to young patients. This medical device is being developed in line with ISO13485/IEC60601.

Design & development projects on offer include:
1. Regulator control and safety systems
2. Hardware – software systems integration with smartphone control
3. Chassis and composite storage system verification and validation

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**Intraocular Lens Implant System (Sydney Eye Hospital & Save Sight Institute)**
Supervisors: Prof John Griff, Dr Philip Boughton, Prof Stepanie Watson

Prototype intraocular lens prototype with ciliary tethered haptics.

The World Health Organisation estimates there were 161 million visually impaired people worldwide in 2002, cataract accounting for 47.8%. Over the next 20 years, there will be a doubling in the incidence of cataract, visual morbidity, and need for cataract surgery. The Global Intraocular Lens (IOL) Market is forecast to reach $3.1 Billion by 2017; compounded annual growth rate of 4%; due to: increase of cataracts in the aging global population; increase of risk factors such as diabetes and increase of new and available technologies.

Current IOL designs are not appropriate for pediatrics, require a significant surgical portal for delivery, can migrate and misalign due to lack of appropriate fixation methods, and have significant chance of post capsule opacification. There may be opportunities to address some of these issues and develop a biomimetic compliant IOL that can be coupled to the ciliary for improved restoration of sight.

In conjunction with ophthalmology specialists, this project seeks to identify priority IOL requirements and design risks to then lead to development of an IOL prototype proof of concept.

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Dr Elizabeth Clarke
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http://sydney.edu.au/medicine/ibjr/research/mm.php

Dynamic MRI of spinal disc deformation under motion

Available to 1 honours student. Most suited to a Mechanical-Biomedical student but would consider other students with mechanical aptitude who would be happy to work with cadaveric tissue.

Certain motions place the spinal disc under higher risk of injury. In vitro studies have tracked cadaveric spinal disc strains using radiographic tracers (e.g. a grid of wires or beads) and stereo-radiography (Fig. 1), however this is invasive and to measure disc strains in living humans, non-invasive methods are required. Imaging techniques have been used in humans to measure disc deformation under static loading conditions (i.e. the spinal segment is loaded and held stationary while images are captured) however this does not capture the internal strains during dynamic loading.

This project develops and validates methods to measure internal strains in spinal discs and surrogate materials under dynamic conditions using dynamic MRI methods (e.g. Fig. 2). The student will be involved in design and manufacture of MRI-compatible equipment to apply controlled dynamic loading to spinal discs. Fiducial markers will be used to validate the dynamic scan measurements and differences between dynamic and quasi-static spinal disc strains will be quantified.

Figure 1. Tracking of cadaveric spinal disc strains using stereo-radiography (Costi et al., Journal of Biomechanics, 2007, 40: 2457-2466)

Figure 2. MRI tagging (SPAMM) tracking silicone block deformation under compression (left, Clarke et al., Journal of Biomechanics, 2011, 44:2461-2465) and using velocity measurements from cine phase contrast MRIs to reconstruct 3D block displacements (right, Sheehan et al., Journal of Biomechanics, 1998, 31: 21-26).
Knee Instability and Injury Mechanisms

Available to 1 honours student. Most suited to a Mechanical-Biomedical student but would consider other students with mechanical aptitude who would be happy to work with cadaveric tissue.

Approximately 50% of patients who suffer severe joint trauma (e.g. ACL or meniscus tears) will develop osteoarthritis within approximately 15 years. Unfortunately the majority of these joint injuries occur in active adolescents and young adults, and many of these will develop post-traumatic osteoarthritis (pt-OA) in their thirties and forties (10-15 years younger than those with other forms of OA). Joint replacement is undesirable in these young patients due to expected implant lifetime, and there are currently no therapies approved to structurally modify or halt osteoarthritis. There is therefore a critical need to improve our understanding of the links between joint trauma and pt-OA. Better understanding of joint injury mechanisms and the instability that develops after joint injury, may lead to prevention of some of these injuries or prevention of pt-OA after joint injury.

This project uses animal joints to replicate clinically relevant injury mechanisms (such as meniscus tears and ACL rupture) (e.g. Fig. 1) and then performs biomechanical testing (Fig. 2) of the joint to measure changes such as instability, stiffness and strength. The project could also investigate histological osteoarthritis progression in these joints (Fig. 3) and relate this to the injury conditions and joint biomechanics.

![Fig. 1 Apparatus to produce knee trauma](image1)

![Fig. 2 Assessment of mouse knee instability following ACL transection](image2)

![Fig. 3 Severe pt-OA develops in the mouse knee 4 weeks after ACL rupture](image3)
Risks and mechanisms of childhood injuries from indoor trampoline centres

Available to 1 honours or project student.

Children’s hospitals in Sydney have experienced an increase in the number of childhood injuries sustained from indoor trampoline centres. Many of these injuries are soft tissue injuries, but they also include many fractures and lacerations requiring operative treatment, and even spinal injuries. With two new centres opening nationally each month, there is a critical need to investigate the causes of these injuries and ways to reduce and prevent them.

This project would involve identifying risks and mechanisms of injuries sustained at these parks using a combination of CCTV recordings supplied by trampoline parks and medical records review. Ultimately, this data could be used to inform the Industry Australian Standard to improve the design, layout and procedures of these parks, which is in development at the moment.
Honours thesis topics:

**Evaluating implanted ceramic scaffolds in bone** (2-3 possible in this area)

Evaluating cell responses to implanted ceramic scaffolds and polymer materials. Ceramic scaffolds of standard or novel materials have been inserted into defects in the bone of rat or rabbit tibiae. For this project the student will develop techniques to fully evaluate the bone inductive and conductive tissue responses to these scaffolds using microcomputerised tomography and plastic embedded and quantitative histologic measurements. Surface treatment of polymers will also be assessed for their ability to improve biocompatibility and bioactivity. Outcomes to be assessed will be extent of cell invasion, numbers of osteoblasts and osteoclasts and measurement of bone formation rates. Assessments will be histological using histomorphometry to determine the static and dynamic parameters of bone regeneration. Cell culture techniques will also be applied to evaluate the way cells interact with the materials in a defined environment.

**Cancer in bone** (1-2 possible in this area)

Mice will be treated with novel anti-cancer agents. Bones of these mice containing breast and prostate cancer tumours will be assessed by micro-computerized tomography and histological methods to determine the amount of bone destruction and new bone formation, and the growth rates and invasiveness of the tumours cells. Results will be analysed to determine the possible benefit of these compounds in reducing cancer metastasis to bone. And on the incidence and progression rates of breast and prostate cancers. The student will be trained in the measurement of bone lesions using microCT, and histological techniques including hard tissue histology, histomorphometry, immunostaining and TUNEL staining for assessing cancer cell apoptosis (programmed cell death). These projects may also involve cell culture studies growing cancer cells in the lab and evaluating responses to various treatments.
Each year an estimated millions of patients suffer from bone fracture, while hundreds of thousands of patients have conditions where large segments of bone are destroyed or must be removed. As such new clinical treatment schemes are necessary to augment the body’s natural healing process. As a fast emerging interdisciplinary technology, tissue engineering provides alternative therapeutic strategies for repair of damaged tissue and organs, which shows enormous potential to generate host-grown tissue in sufficient quantity and quality.

A milestone in the load-bearing tissue (e.g. bone/cartilage) engineering has been the development of 3D scaffold technique that guides cells to generate desirable functional tissue under appropriate mechanical and biological conditions. The success of tissue regeneration lies heavily on the architecture design of the scaffold and its bio-reaction with the seeding cells. Permeability has been recognised as one critical criterion for scaffold design in ensuring cell migration and nutrient delivery. This project aims to (1) characterise the effective permeability of different scaffold architecture; (2) develop finite element based homogenisation technique for permeable problem; (3) design optimisation for tailored effective permeability. The student is expected to closely work with the Research Fellow in the group and redevelop Matlab code for finite element analysis and homogenisation for the permeable problem. The results will be prototyped in commercial free-form solid fabrication facility.

**Opportunity:** Masters or Honours theses

**Reference**


Design of Safety Systems for Crashworthiness Criteria

**Supervisors:** Professor Qing Li (AMME) and Dr Guangyong Sun (AMME)

Rm S509, Bldg J07 Mechanical Engineering, ph: 9352 8607

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Crashworthiness is one of the most important criteria in vehicle design, which often requires large-scale design analysis for a full vehicle model consisting of many structural parts and special safety elements. This project develops a two-stage procedure to cope with crashworthiness design of structural frame and occupant restraint system.

In the first stage, a multiobjective optimization is carried out for structural parameters in the frontal parts without considering the details of the occupant restraint device. The foam filled thin-walled tube will be used as new energy absorber and a design optimisation will also be performed in this stage.

In the second stage, the parameters of the occupant restraint system are optimized based on an optimized structural system. Human dummy and restraint system will be modelled and optimised in details.

In these two stages, explicit finite element program (Dyna3D) and multi-body dynamics methods will be employed to respectively construct response surface and Kriging model with various design of experiment (DOE) techniques. A full-scale vehicle model will be developed to demonstrate the capability of the present two-stage design method.

**Opportunity:** Masters or Honours theses

![Images showing crashworthiness at different times](image)

**References**


Design Optimisation for Road Safety System

Supervisors: Professor Qing Li (AMME) and Dr Guangyong Sun (AMME)

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As the main safety facility on the highway, a guardrail system is essential for the vehicle safety. In this study, the 3D Finite Element (FE) models of the vehicle and the corrugated beam guardrail system will be created. Two types of widely used corrugated beam semi-rigid guardrails will be considered, which are the W-beam guardrail and the Thrie-beam guardrail. The collision between the corrugated beam guardrail systems and the vehicle body will be analyzed. In the collision process, the snagging effect of the post to the vehicle body is also taken into account. The multiobjective optimization problem will be used to determine dimensional sizes of guardrails. Response surface method (RSM) is applied to construct the surrogate models for the objective and constraint functions. The Pareto set and the optimal solution will be obtained.

The student is expected to have background in finite element method and will be trained for highly nonlinear finite element analysis in LS-Dyna. Surrogate models based design will be applied for seeking multiobjective optimisation.

Opportunity: Masters or Honours theses

Reference
S Hou, W Tan, Y Zheng, X Han, Q Li (2014) Optimization design of corrugated beam guardrail based on RBF-MQ surrogate model and collision safety consideration, Advances in Engineering Software 78, 28-40.
Crashworthiness is one of the most important criteria in vehicle design, which often requires large-scale design analysis for a full vehicle model consisting of many structural parts and special safety elements. The major challenge facing to engineering community is how to design multicomponent system for a range of crashworthiness criteria. Previous researches had found that different connection patterns will have different crashworthiness performances during the crush.

In the past, evolutionary structural optimization (ESO) had been applied to find out the locations with the highest stress concentration at the overlap area of connection and therefore to determine the proper locations for placing the connection elements. However, it has not proven that applying the connections on the highest stress concentration area will give the best performance on energy absorption under crashing scenarios and the connection patterns where connections are not in stress concentration area are not being concerned.

The genetic algorithm (GA) will be used in this study for determining optimal pattern of connection elements so that the highest energy absorption capacity can be obtained. This thesis study will tackle topology optimization problems for connection pattern in multicomponent system. The nonlinear FEA will be used as a solution engine for modelling, data collection, and optimisation.

The student is expected to have background in finite element method and will be trained for highly nonlinear finite element analysis in LS-Dyna. Surrogate models based design will be applied for seeking multiobjective optimisation.

References
Sydney Concord Hospital

Design Analysis and Optimization for Novel Arterial Stents

Supervisors: Professors Qing Li (AMME) and Harry Lowe (Sydney Concord Hospital and Faculty of Medicine)

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Cardiovascular diseases (CVD) are one of the leading causes of death in western countries due to lifestyle and an increasingly ageing population. In Australia, more than 176,000 patients are hospitalised and 180,000 cardiovascular procedures are performed each year. Open-heart bypass surgery is one of the most widely used procedures for CVD, and carries with it the major problem of long waiting lists due to the large number of hospitalised patient-days (>1.64 million totally in 2004–05) in the country. As a fast emerging interdisciplinary technology in interventional cardiology, stenting treatment provides an alternative therapeutic strategy, which uses a mechanical device (called a stent) to compress the plaque against the artery wall opening the lumen of the obstructed artery for restoring blood flow. This technology demonstrates the enormous potential to minimise surgical invasion/risk and shorten the hospital days.

This research aims at developing a computational framework for stent design analysis and optimization. In this study, a newly designed cardiovascular stent with adapting the aorta stent geometry will be modelled and evaluated by three-dimensional finite element analysis. Compared with the existing conventional stents in the market, a series of novel designs will be assessed to characterise the stiffness, damage to the arterial wall, fatigue life, and other biomechanical behaviours. The geometry sharpness and increase the manufacturability.

Opportunity: Masters or Honours theses
The ratio of patients who request orthodontic therapy to the total population is surprisingly high. Unofficial data reports that every year 60% of all adolescents in Australia undergo orthodontic treatment to improve their healthy start to life. Orthodontic tooth movement (OTM) within the dentoalveolar bone is based on the ability of surrounding bone and periodontal ligament (PDL) to react to a mechanical stimulus (e.g. stress/damage/strain energy) with remodelling processes. Orthodontic forces generate a complex set of mechanical stimuli triggering biological reactions in dentoalveolar and PDL, thereby causing teeth to move to ideal positions in the jaw. Although it is recognised that the change in biomechanical environment leads to OTM, it is unclear which of the mechanical signals are dominating the initiation of the bone remodelling and how to quantify a dynamic tooth movement process in response to the orthodontic force.

This project aims to (1) develop a precise model of the orthodontic treatment based on CT images (NewTom – Sydney Dental Hospital in USyd Faculty of Dentistry), which may involve uses of Rhinoceros/ScanFE – Solidworks – Ansys or Strand7); (2) quantify the biomechanical responses in several different stages of OTM; (3) correlate the mechanical stimuli to the OTM rate measured in clinic. In this project, the student will use his/her CAD/FEA skills to an interdisciplinary topic, and he/she is expected to closely work with USyd dental specialists (Prof Darendeliler) at Department of Orthodontics.

References
Sydney Dental Hospital

Biomechanical Investigation into Orthodontic Root Resorption

Supervisors: Professor Qing Li (AMME) and Professor A. Darendeliler (Sydney Dental Hospital and Faculty of Dentistry)

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Orthodontic root resorption (ORR) is described as the loss of hard tissue especially of cementum and dentine of tooth tissue which can be an irreversible sequel of orthodontic treatment. It has been documented that the phenomenon of root resorption is a very common disorder, affecting up to 100% of all treated cases, and after treatment, 41% of adult patients had increased root resorption of over 2.5mm in one or more teeth. Under severe circumstances root resorption may potentially jeopardise the longevity and functional capacity of the treated teeth; and may result in ending the treatment and greatly compromising the outcome of a successful orthodontic therapy.

This project aims to (1) elucidate the biomechanical pattern of orthodontic force distribution along the tooth root and its surrounding tissues by creating 3D finite element model and to develop a numerical prediction of ORR (by using micro-CT scanner SkyScan 1172 at Electronic Microscopic Unit and uses of Rhinoceros/ScanFE – Solidworks – Ansys or Strand7); (2) correlate the root stress/strain to the change in cementum properties; (3) To validate the numerical prediction through a clinical trial where the occurrence of orthodontic root resorption (ORR) is predicted and therefore may be prevented. In this project, the student will is expected to closely work with USyd dental specialists (Prof Darendeliler) at Department of Orthodontics.

Opportunity: Masters or Honours theses
Sydney Dental Hospital

Modelling of Cracking in Dental Ceramic Restorations.

Supervisors: Professor Qing Li (AMME) and Prof Michael Swain (Sydney Dental Hospital and Faculty of Dentistry)

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Ceramics become more and more popular as dental restorative materials. However sintering and curing of such materials induces considerable residual stress of layered structure, resulting in tensile stresses at the margin that may induce fracture. The aim of this project is to utilise ABAQUS software to quantify the residual stresses and predict the conditions for the onset of failure and follow the extent of fracture.

The student is expected to (1) create 3D FE model of a tooth with caries and in-lay ceramic filling; (2) model shrinkage of materials in different temperature; (3) simulate the crack initiation and propagation around the filling region; and (4) optimise the filling shape to minimize potential fracture failure. The student is also expected to work with PhD students in dental clinical and experimental studies.

Opportunity: Masters or Honours theses

References:
Hip replacement surgery enables patients who once suffered from osteoarthritis to walk pain-free. However, there is a high incidence of failure due to bone fracture, resulting in huge additional public and private health costs, and a reduced quality of life for ageing Australians. This project aims to develop the science for a computer-based technology that will enable surgeons to optimise the match between a patient’s individual needs and a standard implant device.

The student is expected to work closely with the group in Murray Maxwell Biomechanics Lab at Sydney Royal North Shore Hospital on both FEA modelling and experimental studies. S/he will be trained to use Simpleware and ABAQUS for 3D modelling and fracture analysis in the following steps: (1) CT/MRI scanning of femur and hip replacement implants, segmentation of the images and modelling in Simpleware; (2) FE modelling of 3D femur and implants immediately after surgery; (3) modelling of the osseointegration process; (4) fracture modeling of the system in different time steps.

Reference
Design Optimisation for Metamaterials

Supervisor: Professor Qing Li (AMME)

Rm S509, Bldg J07 Mechanical Engineering, ph: 9352 8607, Qing.Li@sydney.edu.au

Metamaterials signify a new class of periodic materials and directly gain unusual properties from their special wavelength-scale microstructures. These properties have great potential to many electromagnetic applications and technological innovations such as super-lens and invisible cloaks. This project aims to develop a systematic method by formulating microstructural design in the topology optimisation framework. The evolutionary structural optimisation will be used to determine the novel configurations of unit cells for desirable physical properties.

The student is expected to conduct (1) modelling of unit-cell of periodic metamaterials; (2) sensitivity analysis; (3) design optimisation for unit-cell configuration. S/he will closely work with the research fellow in the AMME School and School of Physics.

References

Zhou SW; Li W; Sun GY; Li Q (2010) “A level-set procedure for the design of electromagnetic metamaterials” Optics Express 18(7): 6693-6702.


Background: The relationship of the upper and lower jaws is critically important in just about every part of clinical dentistry. It is important to determine the optimal jaw relationships when placing a dental filling, inserting crowns or bridges or removable dentures.

Unfortunately the determination of clinical jaw positions is often an art rather than based on science. Dentists will debate fiercely the correct jaw positions and the way to obtain it.

One common method to determine the jaw position is to electrically stimulate the jaw closing muscles to determine the “neuromuscular jaw position”

Proponents of this method suggest it produces a “functional jaw position” because it is determined by activation, albeit external stimulation, of the jaw muscles.

Opponents to this method suggest it does not produce the optimal jaw position because the electrical stimulation is directed at the outer part of the jaw closing muscles, and not entire muscle. These outer fibres, when activated, produce an anteriorly and superiorly directed force vector which would consequently position the lower jaw in a position anterior to where it should be.

Aim: In this study, you will aim to better understand the difference in jaw positions created by normal jaw closing (asking the subject to bring the teeth together) and neuromuscular jaw closing.

The hypothesis is that the neuromuscular jaw position is anterior to the normal/habitual jaw position.

Methods: The jaw positions of 200 human subjects have been recorded in position (1) the normal jaw closing position and in position (2) the neuromuscular position. For each subject, these positions have been digitised. Using position (1) as the global reference, you will determine the relative displacement of position (2). You will need to develop a way to describe the rotational and translational difference to dentists and others who are not familiar with transformation matrices, vectors or other descriptors of displacement.

Opportunity: Masters or Honours theses
Sydney Westmead Dental Hospital

Biomechanics of Jaw functions

Supervisors: Prof Greg Murray (Jaw Function & Orofacial Pain Research Unit, Westmead Hospital), Assoc Prof John Gal (Jaw Function & Orofacial Pain Research Unit, Westmead Hospital) and Professor Qing Li (AMME)

Prof Greg Murray: greg.murray@sydney.edu.au
Prof John Gal: J.Gal@uws.edu.au
Prof Qing Li: Qing.Li@sydney.edu.au Rm S509, Bldg J07 Mechanical Engineering, ph: 9352 8607

Work Experience Opportunity: Westmead Dental Hospital

A new jaw motion tracking system has been implemented at JFOP consisting of three digital cameras, a controller and LED markers attached to the upper and lower jaws to allow the 3D motion of the mandible to be recorded. Student projects to improve the operation of this system would involve both software and hardware aspects and require a proficiency in C++.

Jaw tracking system software modification.

Currently, the movements of the LED markers are displayed in real-time during the recording session, but it is not possible to display in real-time the movement of a user defined point on the mandible during the recording. Such a user-defined point can be displayed post-recording using existing custom built programs, but is not included in the system program. The proposed project would require this function to be added to the C++ source code of the tracking system.

The project involves quite complex mathematical calculations as well as an ability to understand the existing C++ source code and how to integrate new code. Other software that was used in the creation of the existing source code includes the (free) FLTK (Fast Light Tool Kit) package.

Synchronization of jaw tracking system with jaw muscle activity data acquisition system.

Running in conjunction with the jaw tracking system is a separate EMG recording system. Currently, the two recording systems are synchronised by a complicated process that involves a lash-up of custom-built hardware and extensive post-recording data processing. There is a need to implement a better method of synchronising the start and finishing of the two recording systems perhaps by using free software such as Synergy.

The project requires first, the understanding of the operation of both recording systems and second, some familiarity with the process of interconnecting two different types of software/hardware systems.
Mechanical Finite Element Modelling of Intracochlear Electrode Arrays

Cochlear Project 1: XFEM modelling of brazing process induced cracking

External Supervisors: Dr Anthony Powell (APowell@cochlear.com) (Cochlear Pty Ltd).
Internal Supervisor: Professor Qing Li (AMME) Rm S509, Bldg J07 Mechanical Engineering, ph: 9351 8607 Qing.Li@Sydney.edu.au

Background
Like many biomedical devices, cochlear implant comprises a number of different materials through different manufacturing methods to bond different components and materials together. One of the methods used is brazing. Since different materials have different mechanical properties and the mismatch may cause considerable residual stress during the manufacturing process. High residual stress together with external mechanical loading may possibly lead to cracking and even failure of the device. This project aims to simulate cracking inside cochlear implant system.

Aims
To develop finite element model of bi-material system for simulating crack initiation and propagation under both thermal residual stress induced by the brazing process and additional mechanical loading during application.

Methods
The project would involve
- Development of a XFEM model of the bi-material system with realistic mechanical properties and thermal and mechanical loading used in-vitro tests.
- Some level of validation of the model by correlating cracking initiation site and length of visual/invisible cracks
- Simulation of various cooling processes and the effect on cracking process.

Requirement: Hons thesis project
Mechanical Finite Element Modelling of Intracochlear Electrode Arrays

Cochlear Project 2: Modelling of intracochlear electrode arrays to predict insertion and removal dynamics

**External Supervisors:** Dr Anthony Powell (APowell@cochlear.com) (Cochlear Pty Ltd). Dr Nick Pawsey (NPawsey@cochlear.com) (Cochlear Pty Ltd).

**Internal Supervisor:** Professor Qing Li (AMME) Rm S509, Bldg J07 Mechanical Engineering, ph: 9351 8607 Qing.Li@Sydney.edu.au

**Background**

Cochlear implants provide the sensation of hearing to moderate to profoundly deaf recipients with sensorineural hearing loss. An array of electrodes is inserted into the scala tympani of the cochlea in order to provide electrical stimulation to auditory neurons. Electrode arrays must be designed to facilitate reliable insertion into the desired position in the cochlea, minimising the risk of complications such as tip foldover or buckling. In addition, arrays need to be flexible to minimise contact forces with cochlea structures to prevent damage that may degrade hearing performance.

Arrays may be straight, or pre-curved to match the spiral of the cochlea. Different designs have different insertion methods and risks. All must accommodate a range of cochlea sizes.

**Aims**

To develop a finite element model of electrode arrays, in order to simulate insertion into the cochlea and predict contact pressures between the electrode and the cochlea, both during the insertion and in the electrode’s final position.

**Methods**

The project would involve

- Continuing the development of an existing finite element model to achieve successful simulation of electrode insertion and prediction of contact pressures.
- Preliminary experimental validation of the model against insertion force measurements.
- If above is completed, begin on a sensitivity study of effect of cochlea duct geometry on contact pressure on basilar membrane.

**Requirement:** Hons thesis project
**Mechanical Finite Element Modelling of Intracochlear Electrode Arrays**

**Cochlear Project 3: Modelling of intracochlear electrode arrays to predict mechanical properties and robustness**

**External Supervisors:** Dr Nick Pawsey (NPawsey@cochlear.com) (Cochlear Pty Ltd). Dr Anthony Powell (APowell@cochlear.com) (Cochlear Pty Ltd).

**Internal Supervisor:** Professor Qing Li (AMME) Rm S509, Bldg J07 Mechanical Engineering, ph: 9351 8607 Qing.Li@Sydney.edu.au

**Background**
Cochlear implants provide the sensation of hearing to moderate to profoundly deaf recipients with sensorineural hearing loss. An array of electrodes is inserted into the scala tympani of the cochlea in order to provide electrical stimulation to auditory neurons. Arrays need to be flexible to conform to the spiral shape of the cochlea, accommodate a range of individual cochlea sizes, and to minimise contact forces with cochlea structures to prevent damage that may degrade hearing performance. The fine wires within the array need to accommodate large deformations during the insertion or removal. The mechanical properties, dimensions and position of the wires within the silicone carrier are critical to the robustness and flexibility of the array.

**Aims**
To develop a mechanical finite element model of an intracochlear electrode array, in order to predict overall flexibility of the array, as well as the stresses experienced by its components. This model could be used to investigate the sensitivity of these to various design parameters, such as wire sizes, mechanical properties, wire placement and silicone grades.

**Methods**
The project would involve
- Development of a detailed 3D CAD model of an electrode array
- Use of a commercial FEA software package to develop a model of the electrode using realistic material properties
- Recommendations for design guidelines for electrode flexibility and reliability

**Requirement:** Hons thesis project
Work experience: will be offered in Optimized Ortho Company

Supervision team:
External supervisor: Dr Brad Miles (brad@kneesystems.com), Michael Topham (michael@optimizedortho.com), Jim Pierrepont (jim@optimizedortho.com)
Internal supervisor: Prof Qing Li (AMME), email: Qing.Li@Sydney.edu.au

1. Development of an Automated 3D Implant Positioning Tool for Total Hip Replacement Planning
The student will use Simpleware ScanIP +CAD to develop an automatic method of positioning hip implants within the femur and acetabulum using patient-specific landmarks. This topic will require the student to learn programming languages, in particular Python and MS VBA.

2. Validation of a Patient-Specific Neck Osteotomy Guide for the Direct Anterior and Anterolateral Approaches
A patient-specific neck osteotomy guide has been developed by Optimized Ortho for posterior approaches in Total Hip Arthroplasty. The guide is designed to assist the surgeon intra-operatively and increase the likelihood of achieving a desirable leg length and offset for each patient. The student will use Materialise Mimics Research software suite to validate the osteotomy level of Optimized Ortho’s direct anterior and anterolateral femoral cutting guides.

3. Development and Validation of an Analytical Model for Determining Optimal Combined Alignment
The effect of combined alignment of the femoral and acetabular components in Total Hip Arthroplasty on the Range of Motion of the patient is not well understood. The student will be tasked with developing an existing analytical model created by Hisatome (2011). in Matlab. The final model will predictively measure the impingement and therefore Range of Motion of a patient by demonstrating the maximum functional movements a patient can perform before prosthetic impingement occurs. The analytical model will be validated in Solidwork. The student should be experienced in programming, no particular language is preferred.

4. Development and Validation of a 2D Registration Technique for Intra-Operative Femoral Stem Anteversion Using a Smartphone Camera
Stem anteversion is an important clinical factor when considering impingement within a hip prosthesis. A 2D registration technique will allow for intra-operative feedback on the stem anteversion to the surgeon. The student will develop a technique to capture a 2D image of the stem/femur during the operation and register the image to a virtual pre-operative plan.

5. Determining the Patient-Specific Changes in Functional Combined Anteversion
The combined orientation of both femoral and acetabular components in Total Hip Replacements is not well understood. Throughout functional movements patients experience a
change in orientation of both these components, affecting their Range of Motion and chance of dislocation. The student would be tasked with exploring the effects of combined acetabular and femoral anteversion of patient outcome.

6. **Use of Predictive Analytics to Determine Postoperative Changes in Functional Pelvic Tilt**

Following Total Hip Arthroplasty, the pelvic tilt of a patient frequently changes, resulting in a varied functional orientation of the acetabular and femoral components. The student will investigate the differences between pre- and post-operative pelvic tilts to create a predictive model.

7. **Can a Patient-Specific Guide be used to Control Femoral Stem Anteversion**

Stem anteversion is an important clinical factor when considering impingement within a hip prosthesis. Controlling stem anteversion using a patient-specific guide will be crucial in the long term outcome of the patient’s prosthesis. The student will need a good knowledge of solidworks in order to develop the model to be 3D printed/manufactured.
Work experience: will be offered in 360 Knee Systems Pty Ltd
Supervision team:
External supervisor: Dr Brad Miles (brad@kneesystems.com), Willy Theodore (willy@kneesystems.com).
Internal supervisor: Prof Qing Li (AMME), email: Qing.Li@Sydney.edu.au

1. Investigation of post-operative kinematics with tibia component rotation variation
There are numerous references used to define tibia component rotation and there is yet a consensus which definition showed the strongest relationship with clinical assessment. This topic will require the student to understand various definitions of tibia rotation as well as run simulations to compare kinematics observed with various tibia component rotation placement.

2. Investigation the relationship of patella component placement achieved to post-operative Patient Reported Outcome Measures (PROMS)
Total Knee Arthroplasty (TKA) is considered to be one of the most successful arthroplasty surgery. However, there are still debate whether resurfaced patella can achieve better post-operative outcomes than non-resurfaced patella. Additionally, there is no consistent anatomical references used in placing patella button in a resurfaced patella. The student will process post-operative CT scans and developed an analytical relationship between the measured patella button positions relative to various anatomical references and post-operative PROMS.

3. Development and validation of a 2D-3D registration technique for pre-operative knee X-ray in functional positions
Understanding the pre-operative state of a Total Knee Arthroplasty (TKA) patient is important for surgical planning. One method to assess it is through pre-operative X-ray in functional positions. The X-ray need to be objectively assessed, i.e. measure the limits of the knee in the positions when the X-ray is taken. This topic will require the student to develop a 2D-3D registration technique (using 3D geometry of the patient and register it against a 2D image, e.g. X-ray) to measure the position of the distal femur relative to the tibia and develop a process to validate the registration technique.
Sydney Eye Hospital

Novel Design and Fabrication of Eye Drop Delivery Devices

Supervisors: Prof Qing Li (AMME), Dr Kenneth Ooi kgjooi@yahoo.com.au, and Professor Stephanie Watson (stephanie.watson@sydney.edu.au) Sydney Eye Hospital, University of Sydney,
Rm S509, Bldg J07 Mechanical Engineering, ph: 9352 8607 Qing.Li@Sydney.edu.au

Introduction:
Dry eye, the most common eye disorder, is frequently accompanied by blepharitis (eyelid inflammation) which has an overall prevalence of nearly 40%. Patients with dry eye and blepharitis have their daily activities disrupted and work productivity lowered due to recurrent blurred vision and ocular discomfort. Moderate dry eye damages the ocular surface and can lead to blindness following infection. The consequences of these common conditions occur despite maximal use of lubricating drops and ointments which address only the symptoms and not the underlying cause. We have developed the first patented statin-based eye drop that safely and successfully treats the causes and symptoms of dry eye and blepharitis.

Aims:
We aim to develop new intellectual property by developing a novel delivery device that will combine both statin eye drop and gel or ointment administration to increase patient convenience of use. Medicine that is problematic to administer leads to poor compliance. Currently, different forms of ocular medications (i.e. eye drops, gels, ointments) come in separate delivery devices. Patients typically carry more than one form of medication at a time. This is because eye drops do not tend to blur the vision and may be preferred if the patient is reading or driving, whereas gels and ointments last longer, providing greater lubrication, but blur the vision. Current ocular therapeutics in drop/gel/ointment forms are in separate delivery devices, which is inconvenient. Further, current delivery mechanisms can be difficult to use, particularly for elderly patients with arthritis. At least 50% of patients have reported difficulty with self-administration, frequently saying they have trouble squeezing the bottle. The goal of this work is to manufacture a combination topical Atorvastatin eye drop and gel/ointment device that allows tailored drop and gel/ointment use according to vision, cosmetic, and duration of action needs.

Methods:
Delivery device prototypes have already been conceptualised and will be designed according to viscous and surface tension properties of the topical Atorvastatin formulations which will determine optimal tip length and opening(s), dose dispensing time, size and weight to reduce overflow, drainage and incidence of any systemic side effects. Force requirements will be factored according to known force generating capacities of the 3 most-used handgrips and applicator plastic rigidity. Computer-simulated models will be run according to the above, and also account for dispensing angles. 3-D printed prototypes will then be built according to established protocols.

Expected outcomes:
A more convenient and novel combination topical Atorvastatin delivery system. Incorporating modern ergonomics, it will be easier to use than existing delivery devices and with improved aesthetics it will assist with product marketing.
**Sydney Eye Hospital**

**Design of Biomedical Device for Topical Ophthalmic Use**

**Supervisors:**
Dr. Kenneth Ooi, Ophthalmologist and Clinical Senior Lecturer, Save Sight Institute  
Dr. Aléksey Valyaev, Commercial Development Officer, CDIP  
Prof. Stephanie Watson, Clinical Professor of Ophthalmology, Save Sight Institute  
Prof. Qing Li, Professor of Biomechanical Engineering, School of Aerospace, Mechanical and Mechatronic Engineering

Expressions of interest are sought for the continued development of a novel topical ophthalmic delivery device. A working prototype has already been manufactured and the student would be involved in the refinement of the design. The student is expected to be of interest and strengths in design analysis and fabrication with 3D printing. S/he is also expected to be self-motivated in driving the project and communicating effectively with the supervision team effectively. The project is biomedical industry based and there is the opportunity for an industrial placement at the Sydney Eye Hospital. Further details will be provided under a confidentiality disclosure agreement to interested candidates.

Inquiries can be made to Prof Qing Li +61 93518607, Email: Qing.Li@Sydney.edu.au

**Opportunity:** Masters or Honours theses
Sydney Eye Hospital

Biomechatronic Development of Novel Topical Ophthalmic Devices

Supervisors:
Dr. Kenneth Ooi, Ophthalmologist and Clinical Senior Lecturer, Save Sight Institute
Dr. Aleksey Valyaev, Commercial Development Officer, CDIP
Prof. Stephanie Watson, Clinical Professor of Ophthalmology, Save Sight Institute
Prof. Qing Li, Professor of Biomechanical Engineering, School of Aerospace, Mechanical and Mechatronic Engineering

Expressions of interest are sought for the development of a novel topical ophthalmic delivery device. A working prototype has already been manufactured and the student would be involved in the refinement of the design towards a new application. The candidate is expected from a mechatronic background with interests in biomedical engineering applications. S/he should have some knowledge and skills in circuit board and mechanism design for bioMEMS. The candidate is also expected to be self-motivated in driving the project and communicating with the supervision team effectively. The project is based on biomedical industry and there is an opportunity for an industrial placement at the Sydney Eye Hospital. Further details will be provided under a confidentiality disclosure agreement to interested candidates.

Inquiries can be made to Prof Qing Li +61 93518607, Email: Qing.Li@Sydney.edu.au

Opportunity: Masters or Honours theses
Sydney Orthopaedic Research Institute

Sydney Orthopaedic Research Institute is a not-for-profit organisation dedicated to the study and research of orthopaedic disorders, in particular those associated with the knee joint. The Institute uses high quality research methods to investigate the causes and development of common knee disorders, as well as treatments and rehabilitative procedures employed for these disorders. In addition, the Institute also conducts research on arthritis, cartilage pathologies, ligament injuries, knee trauma, and methods for clinical assessment of these conditions.

External Supervisor Details
Dr Corey Scholes, PhD

cscholes@sori.com.au
02 9904 7182
Suite 12, Level 1, 445 Victoria Avenue, Chatswood, 2067

Prerequisites

- Open to all disciplines
- Curiosity in how the human body works
- Interest in patient-centred research
- Pride and confidence in their work
- Willingness to learn new concepts and skills
- Modelling, Matlab or general computer programming skills an advantage
Quantitative imaging of knee structures following multiple-ligament knee reconstruction

Internal Supervisor: Prof Qing Li Rm S509, Bldg J07 Mechanical Engineering, ph: 9352 8607 Qing.Li@Sydney.edu.au

External Supervisor Dr Corey Scholes, Director of Research cscholes@sori.com.au

**Background** - Multiple ligament knee injuries are serious and complex injuries. They are highly variable, and will nearly always require surgical reconstruction to restore the joint. However, the high prevalence of joint degeneration and osteoarthritis in these patients suggests that current surgical techniques do not fully restore knee structure and function. The emergence of magnetic resonance imaging (MRI) and quantitative image analysis technology has begun to generate considerable information on the key structures of the knee. A number of specific analyses are available now to examine the status of a participant’s knee which differs from the standard clinical MRI. To-date, the status of the articular cartilage, menisci and reconstructed ligaments in multiple-ligament reconstructed knees remains relatively unknown.

**Goal** – This project will perform quantitative analysis on a sample of reconstructed knees using the latest MRI techniques and associate these findings to clinical patient outcomes.

**Suitable for:** Thesis/Project
Background - The relationship between joint disease, joint forces and muscle control is well illustrated. Abnormal forces acting in one part of the knee are related to degeneration of key structures and the severity of symptoms, such as pain and stiffness. This can be caused by traumatic injuries which cause a rupture of one or more knee ligaments. Patients alter muscle control, at the affected joint and across the body, to relieve pain during functional activities such as walking. However, functional recovery after surgery is dependent on the pattern of muscle activity used by the patient during movement. The timing and magnitude of muscle forces regulates the forces acting on the knee and an optimal balance of forces is crucial to maintain long-term joint health.

Goal – This project will use the latest techniques in biomechanics to analyse joint function in a clinical population to identify at-risk individuals for future knee degeneration.

Suitable for: Thesis/Project
FE analysis of the tibiofemoral joint following multiple-ligament knee reconstruction during locomotion

Internal Supervisor: Prof Qing Li Rm S509, Bldg J07 Mechanical Engineering, ph: 9352 8607 Qing.Li@Sydney.edu.au

External Supervisor Dr Corey Scholes, Director of Research cscholes@sori.com.au

Background - The relationship between joint disease, joint forces and muscle control is well illustrated. Importantly, the pattern of loading is known to vary within and between individuals. This is particularly apparent in patients suffering multiple-ligament knee injuries. However, it remains unclear if reconstruction is able to restore normal loading, with emphasis on the articular cartilage and menisci. These structures are vulnerable to overload during locomotion and their dysfunction is thought to initiate joint degeneration leading osteoarthritis. FEA has provided considerable insight into other clinical problems such as joint replacement, but also has the potential to determine the efficacy of current surgical reconstruction techniques in this context.

Goal – This project will use the latest techniques in FEA to analyse articular cartilage and menisci loading in knee reconstructions to develop a method of identifying individuals at risk of future knee degeneration.

Suitable for: Thesis/Project
Three-dimensional reconstruction of menisci during weight-bearing knee flexion

**Internal Supervisor:** Prof Qing Li Rm S509, Bldg J07 Mechanical Engineering, ph: 9352 8607  Qing.Li@Sydney.edu.au

**External Supervisor Dr Corey Scholes**, Director of Research cscholes@sori.com.au

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**Background** - Menisci are important cartilaginous structures within the knee that absorb load, guide joint kinematics and stabilise the joint. Due to their function, the menisci are vulnerable to traumatic tears and degeneration. Innovations in surgical repair have increased the ability of surgeons to preserve the structure despite considerable damage, which previously would have required removal to restore overall joint function. However, there is a lack of objective evidence linking meniscal repair with reduced incidence of osteoarthritis. Furthermore, there remains a lack of information regarding the ability of repaired menisci to replicate the function of uninjured structures. This project will use the latest modelling techniques to compare the loading response of uninjured and surgically repaired menisci.

**Goal** – This project will utilise Matlab and other image-processing platforms to generate 3-dimensional surface models of the menisci and track their deformation and translation during knee flexion.

**Suitable for:** Thesis/Project
The effect of acute knee injury and surgical reconstruction on tibiofemoral kinematics during locomotion

Internal Supervisor: Prof Qing Li Rm S509, Bldg J07 Mechanical Engineering, ph: 9352 8607 Qing.Li@Sydney.edu.au

External Supervisor Dr Corey Scholes, Director of Research cscholes@sori.com.au

Background – Rupture of the anterior cruciate ligament is a common knee injury, which has considerable impact on joint function. A key role of the ACL is to provide sensory information such as limb position and movement velocity as well providing mechanical restraint. However, there is limited information in the literature regarding the sensory mechanisms that are affected by ACL rupture and whether individuals are able to compensate following injury. Importantly, it is not known whether surgical reconstruction helps to restore some sensory input during functional movements such as locomotion. Biomechanical analysis of the knee during locomotion has revealed some information in this regard; however there remains considerable potential for further research to examine this issue using emerging analytical techniques.

Goal – This project will examine the effects of locomotion speed after ACL reconstruction surgery on knee motion using the latest analytical techniques.

Suitable for: Thesis/Project
Passive mechanical properties of muscle in Parkinson’s disease and rigidity

External Supervisor: Dr Joanna Diong, School of Medical Sciences, University of Sydney, (joanna.diong@sydney.edu.au)

External Supervisor: Associate Professor Kay Double.

Internal Supervisor: Prof Qing Li Rm S509, Bldg J07 Mechanical Engineering, ph: 9352 8607 Qing.Li@Sydney.edu.au

People with Parkinson’s disease often experience ankle rigidity or stiffness during walking. Rigidity in Parkinson’s disease makes normal movement difficult and prolonged rigidity may lead to loss of joint flexibility over time by changing the length and stiffness of muscles. The effects of rigidity on muscle length and stiffness in Parkinson’s disease are not well understood.

This study aims to determine how passive (relaxed) muscle length and stiffness are different in people who have Parkinson’s disease and rigidity compared to healthy people. Specifically, passive ankle joint stiffness will be measured at different knee angles in people with Parkinson’s disease who have ankle rigidity and healthy people. A biomechanical model will be used to calculate passive gastrocnemius muscle length and stiffness, and these data will be compared between groups.

This study will be the first clinical application of this biomechanical method in people with Parkinson’s disease to identify how rigidity changes muscle length and stiffness. Findings from this study may guide the clinical management of rigidity in rehabilitation for Parkinson’s disease.

Opportunity

Masters or Honours theses
The Ceramic Knee. Prof Andrew Ruys
The number of prosthetic hip and knee joints implanted is over a million each per year. It would be difficult to over-estimate the impact of the ceramics revolution in Orthopaedics. 10 years ago almost all hip replacements were Cobalt-Chrome on Polyethylene, using ZTA and fine-grained alumina ceramics, increasing fracture energy 10 to 100 times compared with 1970s prototypes. Now ceramic bearings dominate the hip prosthesis market, with their wear rates hundreds of times lower than Cobalt-Chrome on Polyethylene. The ceramic knee is the next frontier. The prosthetic knee is a complex joint with 2 condyles sliding and rolling on a concave meniscal plate generating bending stresses in the condyles, and constantly moving localised point-contact stresses in the meniscal plate. Alumina and ZTA ceramics cannot endure these extreme conditions. This project involves developing a microfiber-reinforced alumina for the ceramic knee. Preliminary work has shown that the fracture energy is more than 1000 times higher than 1970s alumina, and 10 to 100 times higher than ZTA. This thesis involves the next step in the development work.

Bioglass Synthesis. Prof Andrew Ruys
Bioglass is bioactive and capable of bonding osteogenesis (forming a chemical bond with bone in vivo) and the only material known to humankind that is capable of forming a bioactive bond with soft tissue. It was also recently discovered that bioglass-doped polymers could form a bioactive bond with soft tissue. Essentially Bioglass is amorphous hydroxyapatite doped with silicon bone mineralisation catalyst, and sodium to make it biodegradable. The optimal bioglass 45s5 contains just 4 oxides:
SiO2: Glass forming oxide AND bone mineralisation catalyst
CaO: Essential component of bone mineral.
P2O5: Essential component of bone mineral (and secondary glass forming oxide).
Na2O: Network modifier - renders Bioglass sufficiently soluble as to be bioactive and biodegradable. This project involves developing, validating, and optimising techniques for laboratory-scale production of bioglass.

Silver-Doped Bioglass Microspheres. Prof Andrew Ruys
Diabetic ulcers form a bacterial biofilm that isolates the wound from topical antibiotics and systemic antibiotics and therefore cannot be treated by conventional means. The solution is a bioactive, biodegradable, antibiotic soft tissue scaffold. Bioglass microspheres are proving a very effective means of rendering such scaffolds bioactive – capable of soft tissue bonding and stimulating tissue regeneration. The problem is that bioglass is not antibiotic. Silver is a biocompatible metal with well-known antibiotic properties. This project involves developing novel methods of infusing silver into bioglass microspheres.
Arteriovenous Malformation, a Computational Study

Arteriovenous Malfunction denotes a tangle in the blood vessels where the blood from the arteries is bypassed to the veins. This can happen in the brain leading to what are called Brain AVMs. The consequences of AVM could be intracranial haemorrhage, seizures, headache and difficulty with movement, speech and vision. There is also a 25% chance of brain damage and stroke.

The flow of blood from arteries to veins, bypassing the intervening capillary network, occurs because of the fistulous connections established. Though the medical community is trying to gain a understanding of the AVMs many fundamental questions remain unanswered. One of these is - when does a clinically silent lesion declare its presence? Is it by haemorrhage? Or is it by a neurological manifestation suggestive of deprivation of blood to normal areas of brain (called Steal Phenomenon)?

It is observed that the consequences of AVM cannot be explained adequately in terms of pressures and flow rates alone. Sizes of fistulas seem to have considerable influence, which are not easily determined.

It is proposed to search for answers to these questions using the computational techniques. Available software ANSYS will be employed for the purpose. Participating student will be using this software extensively.

The challenge exists in the generation of a suitable mesh for real patient geometries. Some modifications and simplifications of the geometry may have to be made. Application of the software then will generate vast amounts of data which are to be analysed.

The project will be an ideal one for any enterprising student who wishes to expand his learning experience into biomedical engineering.
**SPACE INVADERS: HOW INVADING CANCER CELLS NEGOTIATE TISSUE BARRIERS.**

Our lab investigates the mechanisms underlying the invasion of glioblastoma brain cancer cells. Unfortunately, there are currently no successful treatments for this cancer and there have been no improvements for patient survival over the last 20 years. One of the main difficulties in treating brain cancer is the rogue cancer cells that have already escaped the primary tumour at diagnosis and cannot be detected by current imaging technologies. These escaped cells inevitably lead to recurrence of the tumour. Our goal is to understand how the glioblastoma cells so readily invade the normal brain tissue. In particular we focus on how the mechanical features of the normal brain tissue contribute to the invasive journey taken by the brain cancer cells. To investigate these questions we use a range of cell biology approaches and cell culture models that recapitulate the biophysical characteristics and composition of the brain. Techniques employed include fluorescence microscopy, time-lapse microscopy and cell tracking and molecular biology and biochemistry. We have a range of research projects available for Honours and PhD students.

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**The structural and cellular basis of skeletal fragility in type II diabetes mellitus**

**Internal Supervisor:** Professor Hala Zreiqat, Head Biomaterials and Tissue Engineering Research Unit, email: hala.zreiqat@sydney.edu.au  
**External supervisor:** Dr Tara Brennan-Speranza (Skeletal Endocrine Laboratory, Department of Physiology), email: tara.speranza@sydney.edu.au

Dr Tara Brennan-Speranza’s laboratory investigates the role of the skeleton in whole macro nutrient metabolism, focusing on the proteins, receptors and pathways involved in this multi-system endocrine loop. Studies also include investigations into possible therapeutic agents on the skeleton, with a focus on the actions of bone forming cells (osteoblasts) and bone resorbing cells (osteoclasts).

Patients with T2DM have hyperglycemia and normal to high bone mineral density (BMD). This is usually associated with reduced fracture risk, yet patients with T2DM have a higher incidence of fragility fractures and an increased overall fracture risk. The increase in fractures in patients with
T2DM is independent of factors such as age, sex, BMI, tendency to fall and visual impairment. This implies the increased fracture risk is driven by compromised bone quality. The aim of the current study is to test this hypothesis in mice and elucidate the specific mechanisms of action. Few rodent studies have assessed the total effects of hyperglycemia on the skeleton, with most reporting little change to BMD, but reduced microarchitectural quality at the trabecular compartment and reduced bone mineralization. Further longitudinal studies in adult rodent models are needed to test the specific effects of long-term hyperglycemia on bone.

Mice will be allocated to a normal chow or a high fat (60%) diet for ten weeks. Insulin sensitivity will be monitored by fortnightly insulin tolerance tests (ITTs) and glucose tolerance will be monitored by alternative fortnightly oral glucose tolerance tests (oGTTs). The effects of hyperglycemia on the skeleton will be tested as follows:

**Microarchitecture:** Bones will be harvested and fixed from each mouse for µCT to be performed at the Australian Centre for Microscopy and Microanalysis, Uni of Sydney and 3D histomorphometric analyses to define structural changes.

**Histology:** These same bones will then be decalcified in EDTA over six weeks, paraffin processed and sectioned for the determination of fluorescent calcein staining for dynamic histomorphometry and for immunohistochemical analysis of the incorporation of AGE products: CML and pentosidine.

**Molecular pathway analysis:** Mouse Femurs will be cleaned of soft tissue, flushed of marrow and processed for RNA extraction (right femur) and protein extraction (left femur) for quantitative real-time polymerase chain reaction (qRT-PCR) and western blot respectively to analyse the sclerostin content in bone and BMP7/Smad1/5/8 pathway. These techniques are readily performed in our laboratories.

The effects of hyperglycemia on human osteoclastic bone resorption in vitro

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Increased bone fragility and reduced skeletal muscle quality are under-recognised complications of long-term hyperglycemia in type 2 diabetes mellitus. As a result, patients have an increased risk of falls, fractures, and a reduced quality of life. Overall, human data thus far suggests a deterioration of tissue mineral quality and strength, likely brought about by adverse effects of long-term hyperglycemia on bone matrix and the bone cells. T2DM patients have reduced bone formation markers and some evidence that resorption makers are reduced: serum carboxy-terminal cross-linked telopeptide of type I collagen (CTX), indicating bone cells are adversely affected. This project is aimed at testing whether hyperglycemia directly reduces the activity of the bone resorbing cells, the osteoclasts. Human blood monocytes will be cultured and differentiated on coveslips and treated with increasing concentrations of glucose over several weeks to form mature, bone resorbing osteoclasts. Cells will be stained for numbers and resorption markers and properties. Secondly, cells will be cultured and differentiated on slices of whale dentine in increasing concentrations of glucose. The dentine slices will then be analysed by electron scanning microscopy to determine the amount of resorption carried out by these cells. See figure below.

Human peripheral blood mononucleocytes were cultured on dentine
(A and C) without RANKL and M-CSF or
(B and D) with RANKL (50 ng/ml) and human M-CSF (25 ng/ml) for 21 days. (B) Differentiated
Osteoclasts are multinucleated TRACP+ cells noted by the arrow and (D) identified by lacunar resorption pit formation. One microbar on the micrograph represents 100 \_m. From Sivagarunathan et al, JBMR 2004.

The role of osteocalcin in the modulation of whole body energy metabolism

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Osteocalcin is a bone-specific protein but recent evidence indicates that it plays a previously unsuspected role in the control of glucose and fat (energy) metabolism (Brennan-Speranza et al. JCI, 122:4172-4189, 2012). The mechanism by which the body senses osteocalcin is still unclear although evidence points to a Class C G-protein coupled receptor (the GPRC6A) as the osteocalcin receptor. This project aims to uncover the controversies surrounding osteocalcin-sensing by the body as well as further understanding the pathways by which this little protein from the skeleton controls whole body energy metabolism using molecular and cell biology techniques and mouse models.

Injectable nanocomposite hydrogel materials for cardiac tissue engineering

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Myocardial infarction, commonly known as a heart attack, occurs when blood flow stops to part of the heart causing damage to the heart muscle – otherwise known as coronary artery disease (CAD). Today the most common cause of death globally is CAD contributing to approximately 17% of deaths (8.14 million) in 2013. While the risk factors are well known, management of CAD symptoms is seen as a losing battle often ending in radical by-pass surgeries, angioplasty or insertion of coronary stents; all treatments which fail to provide long-term return of healthy heart function.

One strategy to correct CAD hopes to use synthetic biomaterial structures that can ‘kick start’ the regeneration of damaged tissues. Known as tissue engineering, such biomaterial structures interact with the heart offering instructive cues to the damaged tissue. Alteration to the mechanical, electrical and biochemical properties regulate how cells interact with the material and hence the regenerative outcome.

This tissue engineering project uses scaffolds made from nanocomposite hydrogel materials. To optimize the materials, we use conductive nanoparticles that endow electrical activity along with cutting edge conjugation chemistry techniques to specify bioactivity as well as 3D printing fabrication to create materials that are injectable. Combining these techniques we hope to create an
injectable nanocomposite material for cardiac repair that offers the required electrical, mechanical
and biochemical cues to bolster the regeneration of the heart.

Jelly platforms to understand the regulation of stem cells

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Stem cells are considered as a potential source of cells for tissue engineering applications and
regenerative medicine due to their ability to differentiate into multiple distinct lineages. The
successful use of these cells for a variety of applications including tissue engineering and
regenerative medicine depends on understanding how these cells regulate their differentiation
towards a particular lineage. This will be achieved through engineering artificial polymeric
jelly substrates with tunable physical cues and analysing the interactions of the stem cells
with the engineered matrices. Biomaterial platforms such as hydrogels will be used to
understand the mechanisms and explore the regulation of stem cells. The specific aims of this
project will be to:

1) Fabricate hydrogel system with niche like characteristics.
2) Tailor the system to incorporate mechanical cues necessary for stem cell
differentiation.
3) Investigate the fate of stem cells in response to the physical stimuli (mechanical cues)
particularly in terms of change in gene expression, matrix production and signaling
pathways in a 3D microenvironment.

Mechanobiology for cancer diagnosis and therapy

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Cancer cells have the ability to reprogramme their energy metabolism in order to survive the
often-harsh conditions of the tumour microenvironment. This microenvironment of the
tumour contributes greatly to the response of tumour cells. In recent years it has been shown
that the physical environment (mechanical cues) of the cancer cells can be an important
determinant of the cell behaviour. Mechanics can affect intracellular signalling events,
influencing carcinogenesis, cancer progression and the tumour response to therapy. This
project is focussed on using a hydrogel system to understand how cancer cells respond to
drugs when there are changes in the tumour microenvironment through the mechanical cues.
The specific aims of this project will be to:

1) Fabricate the hydrogels with various mechanical cues
2) Investigate the response of cancer cells encapsulated in the hydrogels with various mechanical cues to
   novel drugs