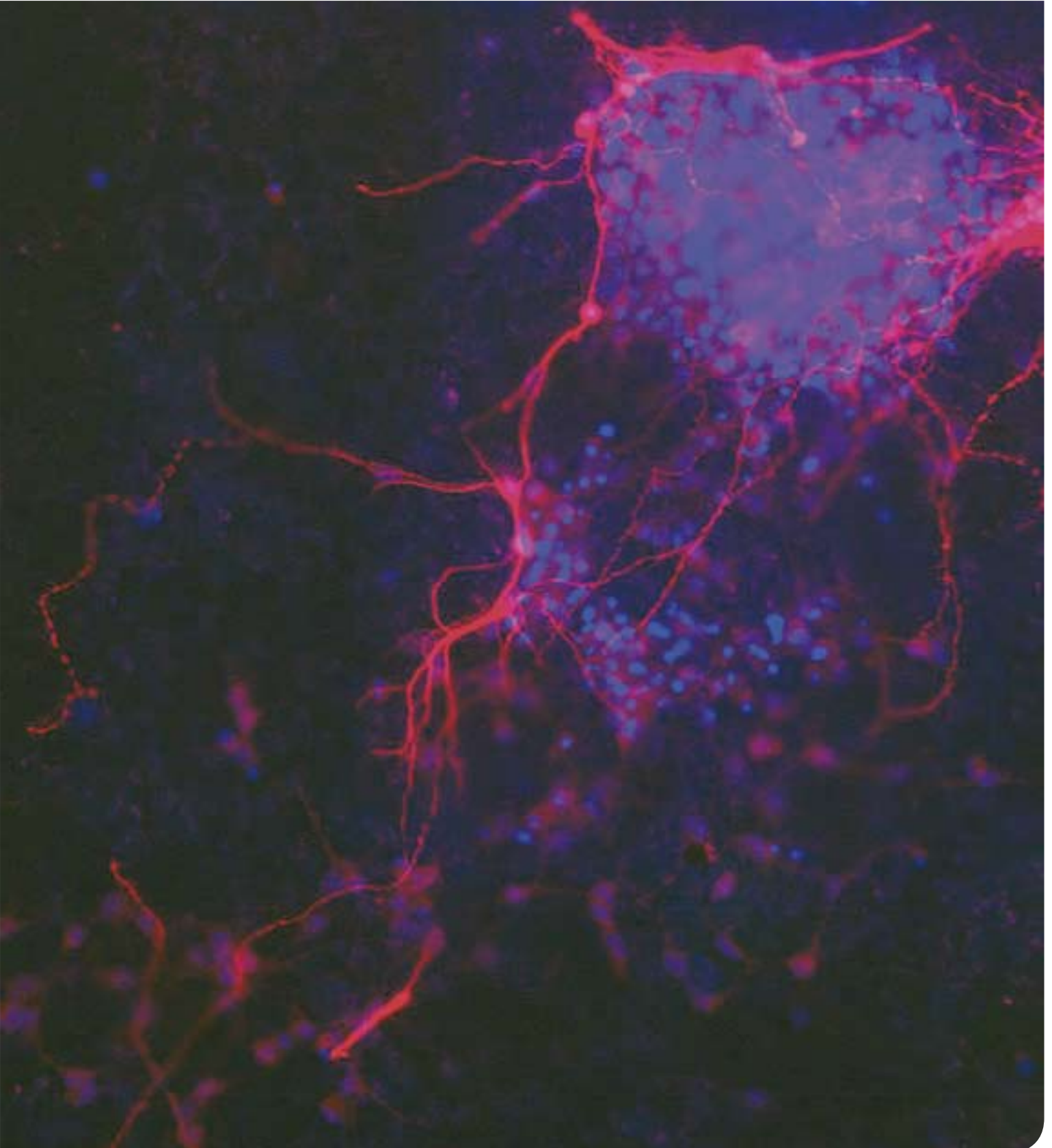




Biomaterials

Department of Materials Engineering



Biomaterials

The intersection of biomedical science and materials engineering is an exciting one, and falls predominantly in the province of biomaterials and tissue engineering. Many of the advances being made at the interface of these two disciplines are at the centre of new medical and health-based technologies and are changing the way we live and treat illness.

Monash University is a leader in many aspects of biomedical engineering and exciting opportunities exist within Materials Engineering in the area of biomaterials and tissue engineering. Australia has an urgent need for biomedical engineers with a solid grounding in biomedical science and materials engineering.

Biomaterials are materials that are used in medical devices or are in contact with biological systems and do not adversely affect the living organism and its components. The field of biomaterials is highly multidisciplinary and involves principles from medicine, materials science and engineering, chemistry and biology. It involves the engineering and testing of the materials into useful devices for therapies. Its multidisciplinary nature often means that materials engineers work closely with surgeons, microbiologists, ethicists, and lawyers to name a few.

Applications include:

- implants eg. titanium hip joints, artificial lenses
- tissue engineering for the regeneration of damaged or diseased tissues eg. nerve regeneration for spinal cord injuries
- 'smart' surfaces for the culture of embryonic stem cells
- artificial muscles using electroactive polymers
- using peptides and DNA molecules as building blocks to build new nano-structures
- 'bionanotech' engineering approaches to manipulate cell function
- site specific drug delivery using nano-structured materials
- improved dressings for chronic wounds

How important are biomaterials?

Commercially, biomaterials are of enormous importance. It is thought that biomaterials-based devices cost some \$AUS400 billion dollars per year which constitutes roughly 8% of money spent on health-related issues (1). Even a specialist business such as making spinal implants is currently a \$2.5 billion industry today but is expected to involve some \$25 billion in sales for this orthopaedic device alone in future years (2). The wound repair market in the US, for example, is currently \$520 million, heading up to \$900 million in a matter of years (3). One of the most widely used biomaterials-based prosthetics is the hip replacement and it is estimated that 1,000,000 of these are implanted per year worldwide. (4)

Opportunities and careers

The use of materials in biomaterials applications gives them enormous value, compared to being used in other applications. For example, it has been estimated that \$600,000 worth of materials used traditionally in non-bio areas, has the value of some \$10.5 billion when constructed into biomedical devices (5). This helps explain why there is so much commercial interest in biomaterials.

Potential jobs at the intersection of biomedical science and materials engineering

Tissue engineering – is the application of engineering and biological principles to assist regeneration of lost or damaged tissues or organs. Underpinning tissue engineering are scaffolds, which are 3-dimensional engineered materials that provide the foundation for cell growth and function. After the scaffold has served its purpose it degrades away – similar to the temporary scaffolding for the repair or construction of buildings.

There is an urgent demand for materials engineers to design and fabricate artificial scaffolds which are load bearing, control cell function and promote the growth of new blood vessels deep inside the construct. Scaffolds are currently being engineered to allow nerves to regrow for the repair of spinal cord injuries or to repair large bone defects. Neural tissue engineering of the brain is a particular strength within the Department of Materials Engineering.



Hip implant using 'smart' materials to improve integration into the body.

Prosthetic devices – hip, knee, elbow implants. These must be made of combinations of materials, which are strong, hard, abrasion resistant, corrosion resistant, biocompatible and have low friction. They also must be surface modified to reduce inflammation and host rejection when implanted in the body. Titanium hip implants are often coated with ceramics that mimic natural bone to improve integration.

Drug delivery – Traditionally drugs are delivered orally or intravenously, however this approach targets all tissues, both healthy and ill without discrimination. Degradable polymeric delivery systems are being investigated to release drugs at a specific site in the body eg. at the site of a hip implant. Site-specific application of drugs dramatically reduces drug concentration in the body, limiting undesirable side effects and increasing drug potency. In addition, many new drugs have poor solubility in the body rendering them ineffective. Encapsulation of drugs within polymeric nano-scale particles is being investigated as a means to overcome these problems and is being used for new treatments of neurological disorders and to target tumours.

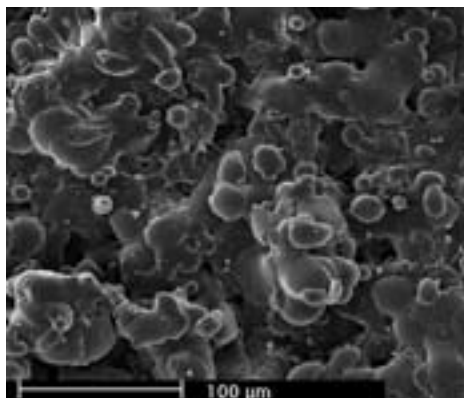
New materials for control of stem cell behaviour: a major issue with the use of stem cells is their limited number for therapeutic applications and the difficulty in controlling the differentiation of these cells. A major research initiative is the design and fabrication of 3-dimensional artificial niches to increase the proliferation of stem cells and to control the differentiation status of these cells.

Gene therapy – involves the insertion of genes into cells for the treatment of diseases. Genes are generally delivered using viruses however there are associated problems with host immune reactions. Synthetic polymeric nanoparticles that self assemble are actively being investigated as alternatives to viruses.

Surface treatment of materials – it is often financially restrictive for biomedical companies to synthesize new materials from scratch. However, existing biomaterials are often surface modified to dramatically improve their interaction with the body. For instance, many contact lenses are modified by depositing nano-sized polymeric films on the surface to improve the wettability of the lens, making them more comfortable to wear.

New “protein repellent” surfaces – the performance of many biomedical devices such as biosensors are highly dependent on the surface resisting the build up proteins found naturally in the body – these surfaces are commonly called “low fouling”. New polymeric materials are being engineered to resist the adherence of proteins and to gain a fundamental understanding of protein-surface interactions.

Biomimetic materials – The construction of artificial materials that mimic natural forms. Common examples are: nano-rough surfaces (dirt falls off, lotus leaf effect) or materials, which try to emulate the toughness of nanocomposite abalone shell or the extraordinary adhesive (and self-cleaning) properties of the gecko pad (millions of tiny hairs)



SEM of experimental flame sprayed coating for surface treatment of titanium implants.

What type of area is important in biomaterials?

Successful biomaterials work requires scientists to have knowledge of a wide range of areas: toxicology, biocompatibility, healing, mechanical and performance requirements, industrial expertise, ethics and regulations expertise.(8) These are the sorts of areas that would be studied in a biomedical science/ engineering (with specialisation in Materials Engineering) degree.

What sort of jobs would they do?

As for other materials scientists and engineers, materials engineers with training in the biomedical science area would work in the development of new materials and products, as well as in sales and marketing, technical services, management, quality control, process control, and as consultants. They would also be well placed to undertake research into biomaterials.

What is the state of the biomaterials-related industries in Australia now?

Biomaterials are clearly a booming area of high commercial activity, with an expanding industrial base. This is as true in Australia as anywhere else, and is well recognised by the Australian Government which notes that Australia has a reputation for leading advances in biotechnology and biomaterials, particularly in “biomaterials for medical uses such as surgically-implanted devices or scaffolds, targeted drug delivery”. (6) (7)

Many of the biomedical companies, for example, on the Australian Biotechnology Organisation corporate register (9) require scientists who have an understanding and ability to manipulate materials properties related to biotechnology, generally to develop devices. Examples of the type of companies in Australia that would employ Biomaterials Engineers are:

Aortech: artificial heart valves

PolyNovo: biodegradable materials for medical devices and tissue engineering

Cochlear Lt: bionic ear

Ciba Vision: contact lenses

CSIRO: contact lenses, heart valves, tissue engineering

ASCC: smart polymers for maintenance of stem cells

Biota: biomaterials for drug delivery

BresaGen: scaffolds for treatments of Parkinson's disease

Chiron: polymers for peptide synthesis

CSL: polymers for drug delivery

ALL major hospitals (prosthesis development)

Patent attorneys: dramatic increase in patents in this area

Future directions

It has been said that “The most important advance in the 21st century will be the introduction of atomic-scale prostheses to repair and restore human body function... the fusion of atomic-scale engineering technology with our bodies will enormously enhance human performance” (10). The fusion of nanomaterials engineering (which deals with the manipulation of ten's of atoms, and thus works at the 10^{-9} m size-scale) and biotechnology will allow unprecedented scope for materials scientists and engineers to tackle diseases and medical problems in a smarter and more targeted manner. The Department of Materials Engineering aims to teach the necessary skills in its undergraduate and research programs.

What are your options?

Bachelor of Biomedical Science/ Bachelor of Engineering (Specialising in Materials Engineering)

This is an exciting new double-degree program, allowing the choice of subjects from the faculty of medicine in the field of biomedical science and those of materials engineering, leading to a unique and highly useful combination.

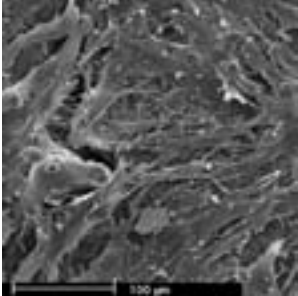
Bachelor of Science/Bachelor of Engineering (Specialising in Materials Engineering)

It is possible to do a combined engineering/ science degree where the science physiology major is combined with a full materials engineering degree. An alternative is to choose any two science majors in combination with a Bachelor of Engineering specialising in materials engineering.

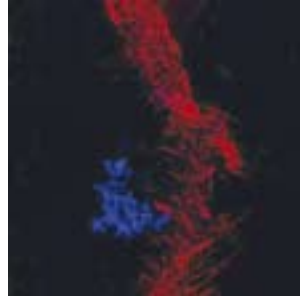
Benefits of undertaking a combined degree

- Obtain two fully-recognised degrees in materials engineering and biomedical science in 5 years
- Obtain the multi-disciplinary skills essential within leading biotech industries
- Be at the forefront of leading biomedical engineering research and applications
- Obtain versatility in gaining employment as either a materials engineer or biomedical scientist, or in the fascinating interface between the two fields.

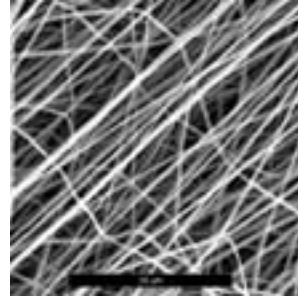
Some examples of our biomaterials research projects



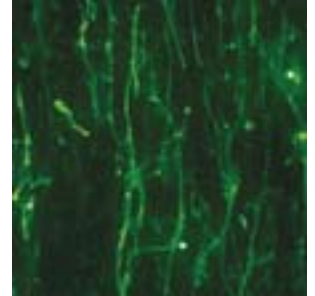
SEM of polymer coating on titanium to provide improved protein delivery.



Neural stem cells attaching to a modified electrospun scaffold.



Partially aligned polymer nanofibres, and neurons growing along the direction of the nanofibres.



Engineering smart nanomaterials to repair damaged neural pathways in the central nervous system

Neural tissue engineering (NTE) is a method of regeneration of damaged neurons providing cellular niches, which promote attachment, growth, proliferation and migration. Electrospun scaffolds are ideal for NTE, as nano-scale architectures can be fabricated that have dimensional similarities to the native basement membrane.

Neural stem cells' differentiation is dependant on the physical and chemical properties of the scaffold. The physical environment provides cues that can be exploited to enhance and direct differentiation. Furthermore, electrospun scaffolds can be easily functionalised to promote adherence. The longer-term goal of this research is to utilise cell-scaffold constructs that will assist in functional recovery of the damaged spinal cord in vivo.

Biocompatible power sources

Biocompatible power sources are the key to many implantable biomedical devices including pacemakers, cochlear ear implants and sensors. Recently some exciting work in the field of magnesium biocompatible batteries has evolved. This battery will be used to stimulate nerve regeneration by controlling the release of growth hormones from conducting polymers; this work is in collaboration with Professors Gordon Wallace and Graeme Clarke who head up the Bionics program within the Centre for Electromagnetic Materials. This program is ultimately aimed at nerve regeneration for spinal cord repair.

The battery itself is comprised of a Mg or Mg alloy anode, a cathode and a biocompatible ionic liquid-based electrolyte. Research is aimed at understanding the interfacial behaviour in the battery as well as

the influence of material morphology and composition for each of the key components (ie. anode, electrolyte and cathode) in achieving sufficient current densities. Possible methods of encapsulation in an oxygen permeable, biocompatible polymer are also being investigated.

New materials for implants

A big challenge to materials engineers is developing high performance biocompatible materials to be used in implant surgery. The demand for such materials is huge. It is particularly the need for materials that match the mechanical properties of the bone that drives interesting developments in materials design. Currently, titanium alloys are the materials of choice for manufacturing bone implants, eg. in hip prosthetics. A broad solution to the problem of implant biocompatibility is coating of titanium alloys with hydroxyapatite, which is a major constituent of physiological bone. However, the coating tends to deteriorate with time, which may lead to failure of the implant. Researchers are exploring the possibilities of improving the performance of bone implants by providing pathways for in-growth of bone cells into a metallic 'scaffold', thus enhancing the cohesion and reducing the need for a repeat operation.

A further challenge to be addressed is physical irritation and local chronic inflammatory reaction that a permanent implant may cause. Sometimes a second operation is needed for the implant to be removed. Given the ability of the human body to gradually recover and regenerate damaged tissue, the ideal solution would thus be a bioresorbable implant, which would offer a physiologically less invasive repair and temporary support during tissue recovery. We are working on developing materials, which would be suitable for temporary implants. The need for such materials is particularly great in vascular surgery where a temporary, bioresorbable stent could provide support to the walls of a blood vessel when it is required and dissolve when its mission is fulfilled – without a further invasion of the surgeon. Tough

requirements on such materials with regard to their strength, fatigue resistance and biocorrosion properties are being addressed by developing processing techniques that help in establishing the desired combinations of properties. Work in this area requires cross-disciplinary collaboration between materials engineers, biologists and clinical doctors and offers exciting research opportunities for undergraduate and graduate students.

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