UNIVERSITY OF CALGARY

Engineering Solutions for Health: Biomedical Engineering

Research Strategy

March 2015

Biomedical engineering is the application of engineering tools and approaches to advance knowledge and solve problems in animal and human biology, medicine and health care.

Engineering Solutions for Health: Biomedical Engineering

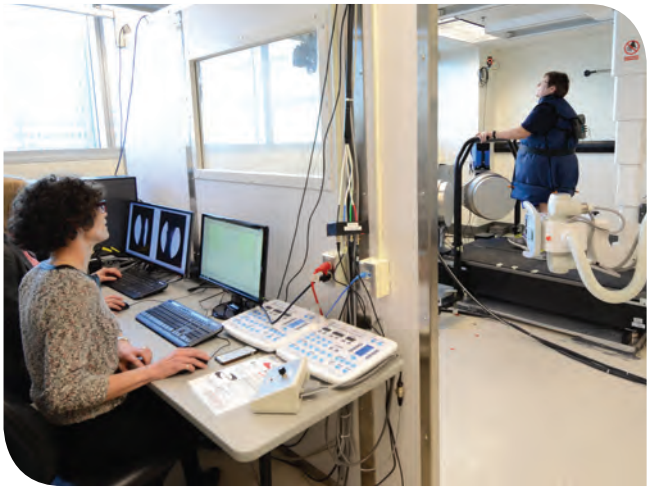
Research Strategy

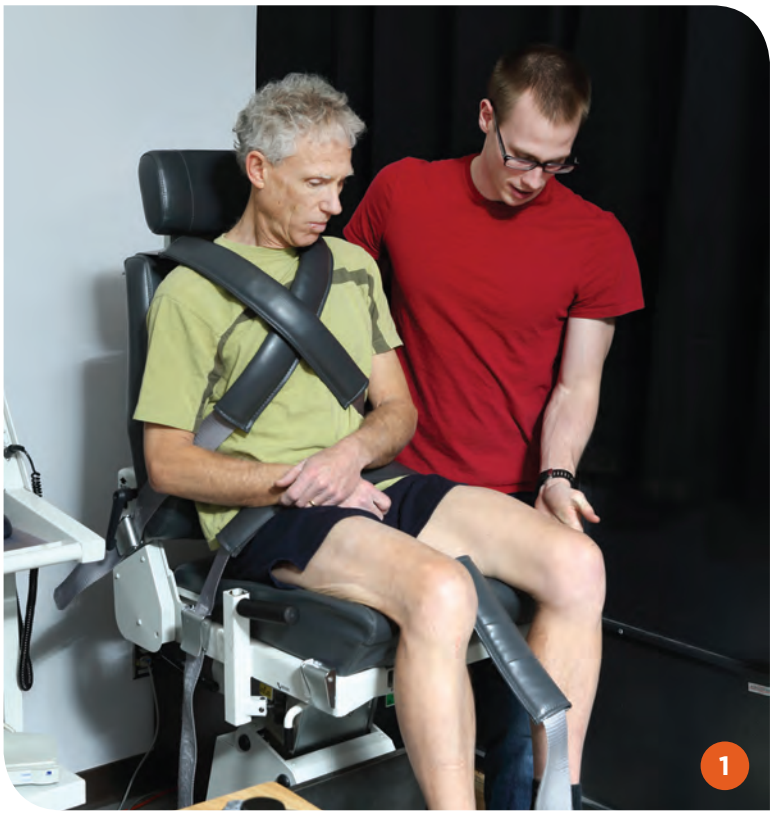
Biomedical engineering has dramatically advanced health care and health-related research over the past half-century for both human and animal populations, and will have an even greater influence in the future. High-quality health care is the foundation of a healthy society: health is at the core of quality of life and also drives social and economic development. Biomedical engineering makes important differences every day to individuals by extending their lives, ensuring the safety of their food and water supplies, improving their quality of life, promoting independence, and providing more effective options for front-line health care professionals.

The University of Calgary has a strong track record of great accomplishments in biomedical engineering, based on making significant investments in this area to build a solid foundation of truly interdisciplinary research and training. **Engineering Solutions for Health: Biomedical Engineering** is one of the University of Calgary's strategic research themes.

Through the implementation of the Biomedical Engineering Research Strategy, the university will leverage its accomplishments and investments to deliver innovative, sustainable biomedical engineering solutions for multifaceted health needs. Integrated cross-disciplinary project teams of biomedical engineers, clinical researchers, and scientists will partner with health care, animal care, agricultural and technology communities and industries. These integrated teams will lead the development and implementation of new biomedical devices, technologies and strategies for monitoring and prevention of diseases and injuries; accurate diagnostics; and novel treatments, as well as using systems engineering principles to continuously improve the health system.

This strategy will target health problems with the highest burden in terms of decreased quality of life, financial cost, mortality and morbidity — particularly cardiovascular disease, cancer, injuries, musculoskeletal diseases and neurological conditions. Biomedical engineering research and health-related technologies developed at the University of Calgary will improve the health and quality of life of people and animals around the world — and also diversify Alberta's knowledge-based economy through technology transfer and company start-ups that support growth in the bio-industry sector.

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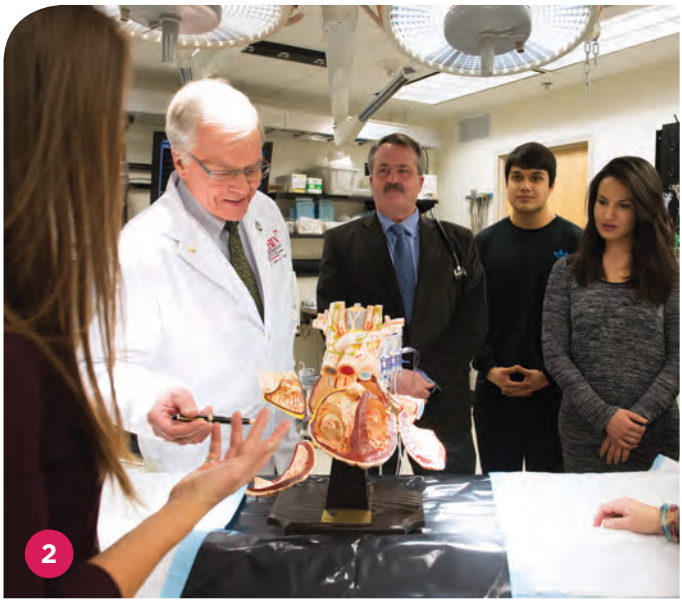
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The Biomedical Engineering Research Strategy identifies three priority research themes (see page 10) and one emerging research theme (see page 20); each one with a specific goal:

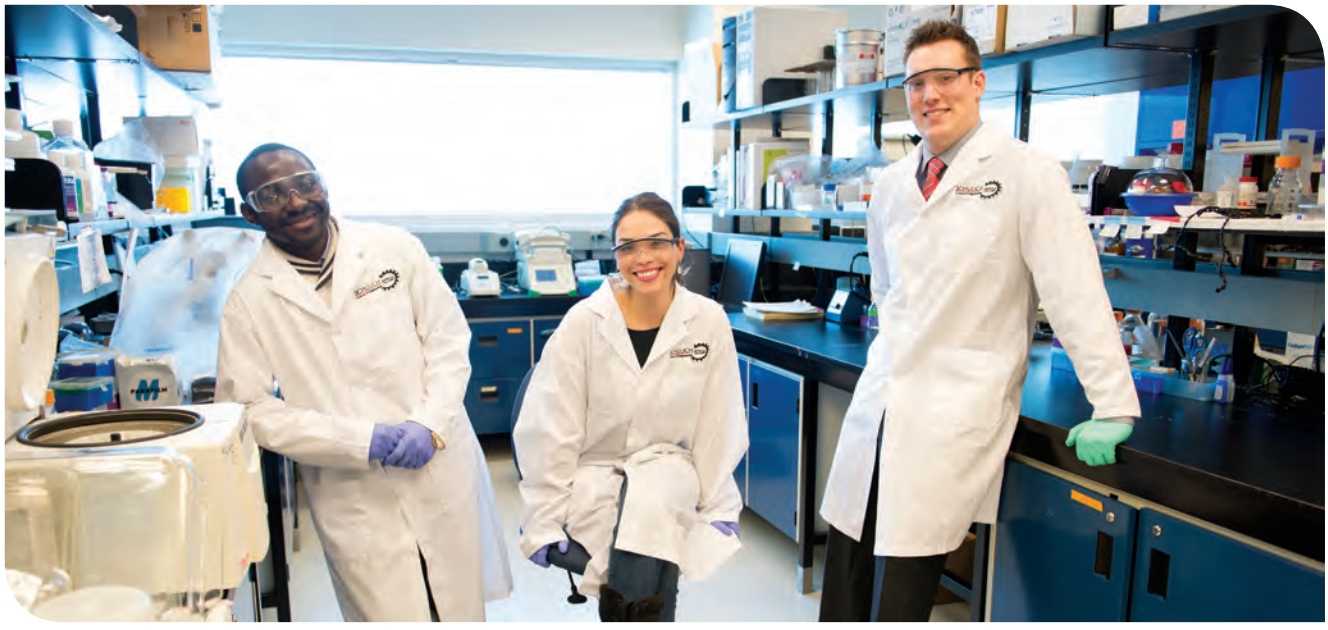
1. To invent and implement technologies that will keep people healthy and minimize complications from diseases, while also helping predict injury and illness.

2. To develop more accurate imaging and diagnostics to detect disease earlier, provide biomarkers for evaluating new therapies, and enable personalized treatments optimized for the individual patient.

3. To develop high-quality, long-lasting treatments for injury and disease, based on stem cells, targeted drugs and novel devices.

4. To deliver research built on our emerging strengths, using engineering tools and approaches to improve patient flow through the health care system.

The Biomedical Engineering Research Strategy will leverage and strengthen our ***Confederation of Scholars***, a platform for interdisciplinary collaboration to advance research and its applications. The University of Calgary has a long and successful history of collaborative biomedical engineering research and high-quality training across the institution. In particular, the integrated nature of engineering, kinesiology, medicine, veterinary medicine, science and nursing at the university is a unique strength in Canada. Biomedical engineering scholars are already mobilized in integrated teams to tackle key research priorities while at the same time advancing their own disciplinary research: the additional cross-disciplinary links resulting from our investment in this strategy will build on this strong foundation and promote a dynamic and productive research environment, no matter what the challenge.



The challenge

Delivering improved quality of life through biomedical engineering solutions

Maintaining health and identifying, diagnosing and treating disease or injury are complicated challenges that can be addressed through advances in biomedical engineering technologies and approaches. With these advances, people with complex medical conditions will live longer, and enjoy better quality of life. Moreover, industrial engineering and operations management approaches are ideally suited to solving problems that arise from the complex relationships in our health care system among patients, health professionals, community groups, governments, industry and insurers.

Biomedical engineering is one of the fastest-growing sectors in global health innovation and product development. In 2013, *Forbes*[1] placed biomedical engineering at the top of their "most valuable majors" list of university programs. Medical devices and technologies are a US $140-180 billion/year industry that is growing at more than 10 per cent annually. Internationally, the medical devices market is a US $327.7 billion industry. The United States ranks first in the world with more than a third of this market. Canada ranks ninth, with US $6.8 billion in estimated sales revenue[2]. While Canada has been very successful in creating innovations, a key challenge lies in commercializing these innovations to make them available locally and to the world[3].

Biomedical engineering technologies and solutions will help maintain and improve quality of life for people of all ages, but seniors (65+) — the fastest-growing age group in Canada — will likely enjoy the greatest benefit. By 2031, Canadian life expectancy is predicted to increase to 81.9 years (men) and 86 years (women), and the over-65 age group is expected to increase from 15 per cent to nearly 25 per cent of the population[4]. This has significant implications for health system costs, as the per capita annual cost of health care is already increasing exponentially after the age of 65 (from C $4.5K to C $20K after age 85 [in 2010 dollars][5]).

Canada's current annual spending on health is estimated at C $211 billion in 2013 — more than 11 per cent of the federal budget[6]. Other countries — USA, Netherlands, France and Germany — typically spend an even larger percentage of their national economies. Canadian provinces each spend an average of 38 per cent of their budgets. In Alberta, 45 per cent of the budget is spent on health care[7] — a proportion that increases every year. Considering the unsustainable growth in these costs, there is an opportunity for biomedical engineering solutions that not only improve quality of life but also contribute to the economy. Medical technologies and devices, and health biotechnology and pharmaceuticals are the two largest sectors in the province's life science industry, which in 2012, spent C $182 million on research and development with revenues of C $977.4 million and employed more than 14,000 people[8]. Alberta is committed to diversifying the economy, and biomedical engineering is well positioned to be a significant driver in this area.

[1] The 15 Most Valuable College Majors, May 15, 2012, Forbes
[2] Espicom, The World Medical Market Book, 2013
[3] Canada's Commercialization Challenge, Canadian Science Policy Conference, 2013
[4] Statistics Canada
[5] National Health Expenditure Database, Canadian Institute for Health Information
[6] OECD Health Data, 2013 June edition
[7] National Health Expenditure Database, Canadian Institute for Health Information
[8] Deloitte and BioAlberta 2013 State of the Industry Report

The close links between the Faculty of Veterinary Medicine and Cumming School of Medicine will ensure that biomedical engineering solutions can be translated between human and animal medicine. Ensuring that our food supply is safe is a costly and important public health objective — and our animals represent another potential market for new devices and technologies. Along with improving human health, biomedical engineering technologies and solutions will also contribute to the health and well-being of companion, service, and food-production animals — all of which will significantly benefit the Alberta economy as well as improving quality of life.

imagine...

Diana, 75, has geriatric syndrome including sleep problems, difficulty walking and early osteoporosis. There are multiple technologies developing at the University of Calgary that will allow her to keep her independence and maintain a high quality of life. These include accurate, easy-to-use devices for observing multiple variables such as real time non-invasive biochemical and activity monitoring that will enable her to properly, safely and fully participate in activities designed to keep her healthy.

A changing paradigm in health

Health systems that have historically been focused on the treatment of disease are poised to benefit substantially from advances in biomedical engineering. For many individuals — healthy, injured, or sick — more accurate monitoring and early intervention could reduce the need for costly and invasive treatment while supporting independence, which is central to quality of life. The University of Calgary's Biomedical Engineering Research Strategy aims to develop human and animal health support systems and technologies that enable this new paradigm: maintaining health and preventing disease for healthy people and delivering rapid diagnoses, timely monitoring and effective treatments for those who are acutely injured or who have chronic disease.

The strategy identifies three priority research themes that capitalize on the university's strengths in biomedical engineering:

- **Integrated approaches to enable prevention of injury and disease, and support healthy aging**
- **Technologies for improved diagnostics**
- **Engineered novel therapeutics**

A critical emerging research theme has also been identified, in which the University of Calgary has unique expertise and potential:

- **Optimized health care system performance**

The Biomedical Engineering Research Strategy will build on the University of Calgary's capacity, advance our strengths, and deliver unique and innovative solutions.

Research strengths and capacity

The vibrant combination of leading experts from multi-disciplinary backgrounds, unique research infrastructure, a strong track record of successful collaborations and outstanding training programs in biomedical engineering provides the foundation to realize our goal to deliver biomedical engineering solutions for today and tomorrow.

Building on our significant biomedical engineering strengths

The University of Calgary has more than 250 researchers working in multidisciplinary teams across faculties to advance fundamental understanding of human and animal health and develop new technologies and innovative solutions. Our biomedical engineering researchers work in multidisciplinary teams at more than 25 unique state-of-the-art facilities including the Human Performance Lab, the McCaig Institute for Bone and Joint Health, the Libin Cardiovascular Institute, the Hotchkiss Brain Institute, the Zymetrix BOSE Biomaterials and Tissue Engineering Technology Development Centre, the Veterinary Sciences Research Station, and the Ward of the 21st Century. In addition, the Faculty of Veterinary Medicine offers an exceptional translation platform for pre-clinical models and applications.

At the core of this collaborative biomedical engineering community are our high-quality training programs:

- *The Biomedical Engineering Graduate Program* has more than 60 principal investigators from five faculties — engineering, medicine, kinesiology, veterinary medicine and science — working within an outstanding research infrastructure, funded in part through significant investments from the federal government through Canada Foundation for Innovation (CFI) grants. They have trained more than 250 graduate students in biomedical engineering over the last 15 years. They collaborate with industry to solve complex challenges and translate these solutions into products and services that help individuals and society.

- *The Biomedical Engineering Specialization (BMES)*, established in 2003, trains 32 undergraduate students a year across all engineering departments. Most of these students are engaged in undergraduate biomedical engineering research and nearly half complete an eight-month biomedical engineering research thesis in their fourth year. BMES is delivered through the Centre for Bioengineering Research and Education (CBRE), which coordinates faculty conducting bioengineering research and teaching in the Schulich School of Engineering. The CBRE facilitates interactions with other faculties, industry and government for promotion of research, technology development and commercialization along with hands-on and industry-relevant training.

- *Biomedical Engineers for the 21st Century* is a unique Natural Sciences and Engineering Research Council (NSERC) — CREATE-funded training program that includes international exchanges to give graduate students the opportunity to gain advanced skills for biomedical engineering careers in industry, government or academia.

Unique to Canada, Alberta has established province-wide targeted Strategic Clinical Networks (SCNs) (10 in 2014), which are now responsible for improving the delivery of nearly all health care in the province. SCNs are organized around specific clinical areas, and link patients, practitioners, researchers and policy-makers to improve the quality of care; ensure that research is targeted to the areas of greatest need; and drive the uptake of research findings into clinical practice. These networks represent a window of opportunity for true two-way discourse and a chance for real change in the health care system. The SCNs also link with Health Technology Assessment and Innovation (HTAI) in Alberta Health Services and other provincial entities to help integrate new technologies into the Alberta health system and are focused on improving the health care system itself to improve delivery.

Alberta's unified health care system offers one access point for four million people and our system is large enough to implement change but not so large as to inhibit it. The system provides an invaluable source of anonymized patient data on when and how people access health services. It also provides data on biomedical device usage and interventions, as well as a pipeline to test and market biomedical engineering products. These represent unique opportunities for biomedical engineering that are not available elsewhere.

The Biomedical Engineering Research Strategy builds on the researchers' strong track record of demonstrated excellence in the development of high-quality engineering solutions for health within our priority research themes, such as the development of new devices, unique methodologies and innovative technologies.

imagine...

Osteoarthritis affects 5 out of 9 adults over 50. Many have greatly benefited from biomedical engineering technologies including artificial joints, multimodal imaging technologies and movement analysis. Even greater advances are being developed at the University of Calgary for prevention, early detection, better diagnosis, more effective treatments and monitoring.

Research themes

Challenges to be addressed — building on achievements

The overarching principles that guide our research in all themes are improving health and quality of life and reducing a high health burden, particularly in cardiovasculardisease, cancer, injuries, musculoskeletal diseases, and neurological conditions.

The strategy identifies three priority research themes and one emerging research theme, built on a foundation of significant existing or emerging research strengths at the University of Calgary. Within these themes are lead challenges that will direct us over the next three to five years.

Priority Research Theme: Integrated approaches to enable prevention of injury and disease and support healthy aging.

1

Independence for quality of life.

Engineering methodologies can increase our fundamental understanding of human and animal health and disease across the lifespan. Based on this understanding, new integrated biomedical engineering technologies and solutions will be created for monitoring health and promoting prevention thereby enabling independent living.

The fundamental objective of research within this theme is to enhance quality of life and health of an aging population by providing integrated, multi-system performance data at the right time, reinforced with monitoring and feedback. Research within this theme focuses on three components: 1) helping people stay healthy and preventing injuries; 2) optimizing health in daily living following recovery or rehabilitation of a disease or injury, and 3) managing complex, and multi-factorial chronic diseases that constitute the major health burden for today's societies.

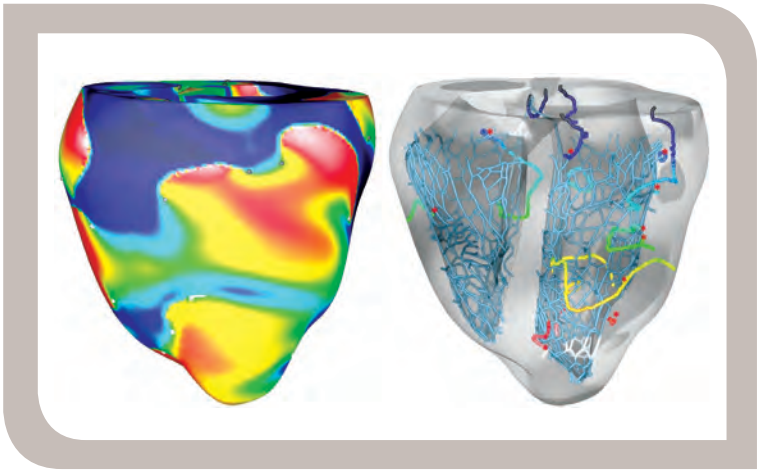
Biomedical engineering approaches reveal fundamental knowledge of how cells, tissues and whole organisms function and respond to loading, exercise and movement, which is vital to maintain health during development, normal function, and aging. The University of Calgary has core strengths in fundamental and applied research involving movement, biomechanics, and neuromotor control, as well as cardiovascular, gastrointestinal, respiratory, and mental health. All of these organ systems are tightly interrelated, yet not often studied in an integrated, quantitative manner. Multidisciplinary teams will study the interdependence of these systems across the lifespan, giving us unique opportunities to promote wellness and vitality at all ages.

Building on evidence-based fundamental understanding of health and disease, ranging from molecules through tissues to individuals, we will monitor multiple variables via sensitive wireless devices and technologies and integrate system performance to maintain personal health and wellness. Further, using accurate monitoring, remote feedback, and expert knowledge databases, the teams will optimize decisions and interventions that promote health in real time. Moreover, remote biomedical sensors can alert medical and paramedical professionals to potential problems in patients with chronic diseases — enabling timely interventions that improve outcomes and prevent hospitalization.

Current strengths at the University of Calgary in advanced molecular-, cellular-, organ- and human-imaging and motion capture, as well as biomedical modeling and simulation, form the engineering basis for our approach. Integrated activity and health monitors, biosensors, and new cardiovascular monitoring devices can enhance wellness, accelerate rehabilitation and prevent chronic disease through controlled interventions tailored to match individual patients.

Lead challenges include:

- Detection and monitoring technologies for improving whole body and mental health including personalized disease monitors, such as biosensors for real-time diagnostics, instruments for point-of-care testing, and technologies to assess body or organ function;
- Processes for preventing the risks associated with acute and chronic diseases, including engineering technologies and devices to support safe and healthy aging, assist with balance control to reduce the risk of falls, assist with navigation and location-tracking, and support mobility independence for seniors;
- Understanding and predicting the role of multiple inputs (such as diet and activity level) under normal and altered conditions (exercising,



imagine...

Henry is 80 years old and recovering from a heart attack. He may not get full recovery with current treatments and is at risk for further complications. Technologies under development at the University of Calgary will assess the type of disease, limit disease progression and prevent loss of quality of life for Henry, as well as identify whether others in Henry's family are at risk for heart disease.

extended bed-rest) in developing, adolescent, mature and elderly populations. This could include subject-specific devices to provide guidance on activity levels to prevent chronic joint injuries based on oxygen consumption, joint movement and muscle activation patterns; and

- Investigating integrated (multi-system) mechanisms of healthy aging including cardiovascular, musculoskeletal, nervous and respiratory systems. Individuals with conditions such as diabetes, asthma, obesity or mental illness could be provided with devices with real-time feedback for physician consultation to enable activity modification based on blood levels of critical components (e.g., oxygen and insulin), heart rate, as well as local environmental factors (e.g. smog, altitude, temperature).

Calgary biomedical engineering achievements and expertise

University of Calgary research teams have developed innovative devices and protocols to study the molecular and cellular mechanisms of brain, cardiovascular, and musculoskeletal diseases in living systems.

Researchers have pioneered unique approaches to study muscle activation and molecular motors, established guidelines for comfort in footwear, developed high-performance footwear, and invented shoe designs for rehabilitation, incorporating concepts that are commercially marketed by major footwear suppliers.

Having developed dynamic 3D fluoroscopy systems to look inside functioning joints and quantify movement and forces acting on joint surfaces and bones, university researchers can probe how healthy joints change across a lifespan of growth, injury, weight change, and exercise.

Researchers have leveraged state-of-the-art medical imaging infrastructure and novel analytical approaches to support and participate in international pharmaceutical trials that help bring new medications to market.

University of Calgary biomedical engineering teams have expertise in developing methods for identifying and promoting heart health including identifying rhythm disturbances, heart failure, ischemia, or stroke and giving people feedback and other tools to optimize their health. They are developing computer models to help understand healthy blood circulation and the effects of aging, new protective gear for injury prevention, and devices to monitor sleep patterns and treat sleep apnea. They are also considering new tools for understanding blood flow and oxygen consumption in the brain as well as the influence of environmental factors such as sleep and exercise to develop strategies for maintaining health.

Priority Research Theme: Technologies for improved diagnostics.

2

See inside the body to see the future of health care.

Early and accurate detection is crucial to precisely identify and treat the correct disease or dysfunction. Biomedical engineering offers ways to develop new instrumentation, data handling systems, and technologies that assess organ and body function, dysfunction, and disease at earlier stages, with higher sensitivity, and with more high quality information to enable earlier and more effective treatment.

The fundamental objective of research within this theme is the development of accurate, timely, multi-modal diagnostic technologies that detect problems earlier and inform therapeutic strategies and timely interventions.

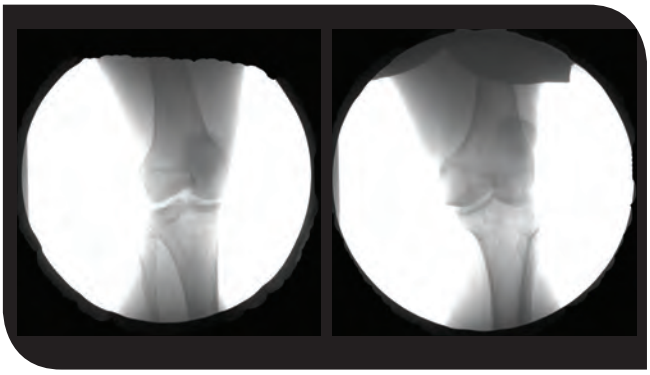
A clear diagnosis is needed when wellness or healthy aging is compromised. Depending on the nature of the medical issue, multiple methods are used to assess the problem, including imaging, signal measurement or testing of tissue or fluid samples. Many times this detection is not early enough or specific enough to develop treatments to reverse or cure disease or organ dysfunction.

We are well positioned to address this challenge, having established expert teams in skeletal, brain, and circulatory magnetic resonance imagery (MRI) and computed tomography (CT), cell and blood vessel optical imaging, image analysis and computational modeling, cardiovascular physiological monitoring, cardiac cell electrophysiology, neural biosensors and nanoparticle synthesis and testing. The University also has unique experience in working together across areas with multi-modal imaging.

Issues arising from injury or disease involve many cell types and organ systems. Advancing engineered diagnostic strategies includes developing new ways to evaluate large datasets and integrate data from multiple sources to synthesize an accurate diagnosis; develop new instrumentation and techniques to assess organ or body function; advance imaging techniques to improve sensitivity and quality or quantity of information, and develop fluid tests that provide molecular or cellular profiles. Large sets of physiological data, when integrated with patient demographics, inform research in our emerging theme in health systems research to drive policy creation for the health care system.

Lead challenges include:

- Improved understanding of the damage and repair processes in disease — including stroke, cardiovascular diseases, joint trauma, bone fractures, epilepsy, multiple sclerosis, dementia and cancer — by advancing and integrating imaging, computational modeling, and molecular and cellular-based technologies;
- Earlier and more specific detection of cardiovascular disease by combining blood tests, dynamic imaging, and computational modeling; and
- More detailed assessment of bone health and repair through functional, multi-modal imaging and analysis.



Calgary biomedical engineering achievements and expertise

University of Calgary research teams have developed new analytical techniques to extract information from digital medical images. Calgary Scientific Inc. is a spin-off company that commercializes our medical imaging technologies and is delivering these robust and accessible platforms to the broader medical community.

Researchers have pioneered the development of routine protocols for cardiovascular magnetic resonance (CMR) imaging, developed novel software in cardiology diagnostics, and established a spin-off company, Circle Cardiovascular Imaging Inc.

They have also developed the first "brain on a chip" that connects brain cells to a silicon chip, demonstrating that living cells can communicate directly with an electronic device. The team responsible for this breakthrough was also the first to develop patch-clamp chips that offer ion-channel analysis of brain and cardiac cells for drug screening. The resulting spin-off company, NeuroSilicon, was able to take a research product to market in under two years.

University researchers are also developing novel multi-modal 3D imaging methods to identify breast cancer much earlier and to image joints and other tissues for new ways to help surgeons plan their procedures.

In addition, researchers have developed new systems to diagnose and monitor scoliosis progression, as well as the Eagle Brace, a flexible device that can be designed and built for the specific needs of individual patients.

University of Calgary biomedical engineering teams have expertise in developing imaging and optical instrumentation, personalized cardiac pacemakers, blood vasculature-function monitoring devices, cardiac-function analysis software and early diagnostic devices, blood tests for early disease diagnosis, micro-needles, bio-nano sensors and wireless remote-controlled devices that monitor brain function.

imagine...

Pointer is a beloved six-year-old dog with chronic hind-limb lameness, joint laxity and radiographic evidence of degenerative joint disease. Researchers developed a unique and sensitive gait evaluation system for quadrupeds that discerns that joint pain sensors, rather than joint inflammation or the sensors of joint instability, are primarily involved in mediating chronic joint pain. These studies help to define the targets and develop scientific strategies for chronic joint pain in animals and humans, ultimately leading to better treatments for Pointer.

Priority Research Theme: Engineered novel therapeutics. 3

Developing personalized repair.

Developing novel therapeutic devices and molecular medicines and harnessing the power of stem cells to exploit the body's inherent repair mechanisms will be advanced by biomedical engineering technologies. With a focus on developing new personalized treatments to repair, regenerate or replace dysfunctional cells and tissues, these integrated therapies are designed to work with the body's natural healing processes.

The fundamental objective of research within this theme is to develop novel treatments for injury and disease — using stem-cell-based technologies, new drugs and devices, and better surgical tools. Many conventional treatments for humans and animals are not long-term solutions for injury or disease — they often lead to temporary and incomplete improvements in health, function, or quality of life. Recent advances in biochemistry, molecular biology, stem cells, materials science, manufacturing and many engineering disciplines will allow us to transform medicine by developing new methods for regenerating injured tissues and novel treatments with potent and sustained effects.

Engineered therapeutics will be a key focus in this new approach to treating patients — combining advanced engineering methods with an in-depth knowledge of healthy and diseased cells, tissues, and organs to develop rational scientific therapies. Other areas of focus include designing new biomaterials and devices; creating nanomaterials and microfluidic systems; growing cells in bioreactors; integrating cells, materials and signals within the most appropriate mechanical environment; and developing new testing and analysis systems.

This is a multi-faceted challenge. A core University of Calgary strength is the ability to work synergistically on a continuum of research from molecular and cell engineering to the translation of engineered therapeutics in large-animal models. The intersecting research areas within this challenge will cut across multiple-organ systems to create more effective treatments by selectively regenerating tissues to improve health and quality of life.

The University of Calgary has assembled a strong group in this theme, comprising researchers from the Schulich School of Engineering, the Cumming School of Medicine, and the faculties of Kinesiology, Science, and Veterinary Medicine. With the latter, the teams have expertise to support unique opportunities to test newly engineered therapeutics using large-animal models as pre-clinical trials for humans or use in animal medicine. Many group members are working in established collaborative teams focused on specific organ systems including bone, cartilage, pancreatic islets, heart, blood vessels, nervous system, retina and skin.

Lead Challenges include:

- Engineering functional tissues for regenerative medicine by incorporating molecular, cellular, tissue and whole organism analysis, micro-environmental effects (such as mechanical forces), stem cells, and bioreactor technologies;
- Enabling more advanced treatments through new technologies building on bioprocesses, microfluidics, 3D-printing and nanomaterial design;
- Improving surgical outcomes through design of computer-assisted surgical techniques and tools and testing systems for device development; and
- Advancing pharmaceutical development through the creation of drug-delivery systems, model systems and new devices that more accurately assess the therapeutic targets, benefits and potential side effects of novel drugs.

imagine...

Agnes is 32 years old and has been burned in a house fire. She may not achieve full recovery with current treatments and may suffer secondary effects (i.e. scarring) that further reduces quality of life. But our stem cell bioengineering and biomaterials developments can help Agnes with new skin treatments based on her own cells, that, by more completely regenerating all skin layers, can improve overall skin function and her quality of life. A team of bioengineers, cell biologists, nurses, surgeons, and rehabilitation providers, are working with patients like Agnes, to develop solutions integrating end user input.

Outsmarting the brain.

It's hard to fix what you can't see. Finding ways to peer inside the living body has been one of the most vexing puzzles. neuroArm was the world's first robot for brain surgery, guided by real time magnetic resonance imaging, leading to unprecedented surgical accuracy at the microscopic level. Invented at the University of Calgary and built by the makers of Canadarm — the team continues to refine these smarter tools for better for better health outcomes.

Calgary biomedical engineering achievements and expertise

University of Calgary research teams have developed and translated a novel technology, which resulted in the neuroArm surgical robotic system that has been used to pioneer the surgical removal of complex brain tumors *while the patient is inside an MRI*, allowing for advanced visualization during surgery.

Researchers were among the first to expand human neural stem cells in stirred suspension bioreactors and are now extending these results to mesenchymal stem cells for bone and cartilage, skin stem cells for burn survivors, and pluripotent stem cells for cardiac regeneration. They have also developed new ways to generate enough cells safely and rapidly for personalized therapies and for engineering replacement tissues, pharmaceutical testing systems to increase the success of drugs coming to market and new surgical techniques to improve patient recovery.

Researchers have helped develop better therapeutic biomaterials as effective treatments for dry-eye disease and osteoarthritis, which may also prolong the performance of implant materials used for joint arthroplasty. This technology has been successfully moved from the lab to a commercial entity, Lμbris LLC.

Researchers have created a model that was the first in the world to isolate mechanical factors from biological factors in studying osteoarthritis in humans, informing our goal of early risk detection.

University of Calgary biomedical engineering teams have expertise in developing stem cell and tissue engineering approaches for bone and cartilage repair; implantable and regenerative devices for vascular and heart treatment; devices to repair damaged nerves and to regain lost brain function; implantable devices to control seizures, tremors, addiction and pain; brain pacemakers and robotic surgical-imaging rehabilitation devices; artificial prostheses; bio-imaging technologies, bio-films and biomaterials to prevent infection after implantation; biomechanics analysis for arthritis; biomechanical approaches and devices for cardiovascular disease; neuromuscular adaptations for aging, bone and joint injuries; and technologies for mitigating diabetes complications.

Emerging Research Theme: Optimized health care system performance.

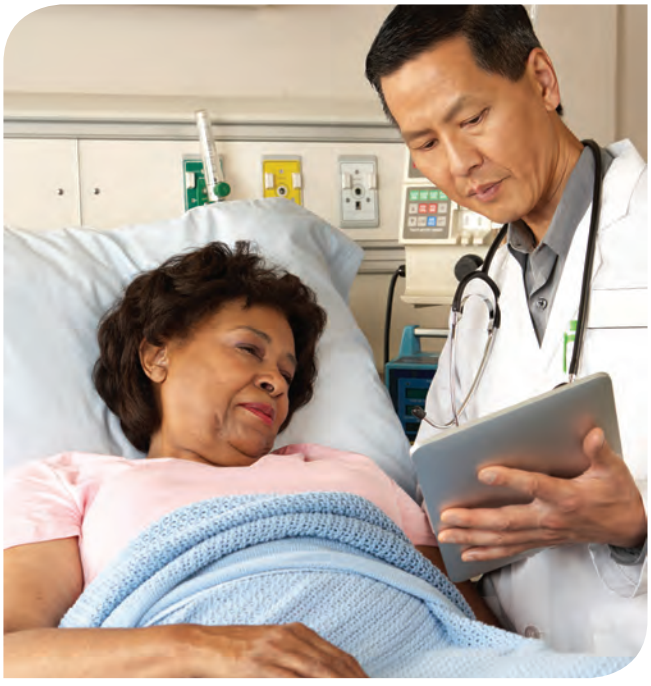
Getting the patient the right solution to the right problem at the right time.

Engineering tools and approaches are ideally suited to improving the flow of patients, data and resources through the healthcare system. Research within this theme will investigate new tools for evaluating healthcare system performance and technology assessment.

The three priority research themes speak to the importance of monitoring for improved wellness and healthy aging, technologies to improve diagnostics, and sustainably engineered therapeutics. The fundamental objective of research within this emerging theme is to apply engineering tools and approaches to the health care system to enable improved system quality and productivity, including the cost-effective delivery of new biomedical engineering solutions.

Our health care system is challenged by the complex relationships among patients, health care providers, community groups, governments, industry and insurers. Health services have experienced a substantial shift from acute care to chronic care and for moving care out of hospitals and back into the home, requiring return visits to care sites and electronic communications and digital records to replace paper records. Meanwhile, health conditions are increasingly multi-factorial and complicated. These challenges are ideally suited to approaches developed in operations research and industrial engineering. For example, advanced operations modelling and simulation tools can be used to develop optimal strategies for delivering health care services in complex and uncertain environments. We will leverage the University of Calgary's strength in population health and health services research to deliver biomedical engineering solutions that will improve the performance of health systems in Alberta, other Canadian provinces, and internationally.

Work in this theme will use engineering tools and approaches to provide innovative solutions that contribute to a high-quality, patient-focused,



imagine...

Karen has had a stroke and needs treatment quickly to maximize the chances of a full recovery. Operational modelling technologies at the University of Calgary will ensure that Karen and all stroke victims are able to access the care they need by optimizing the system for delivery of care across all phases — pre-hospital, emergency, rehabilitation and secondary stroke prevention.

4

accessible and sustainable health system. Our biomedical engineering experts will apply methods from engineering operations research, operations management and complex analytics, in collaboration with colleagues in the Cumming School of Medicine, the Faculty of Nursing and the Haskayne School of Business to design, plan, and operate the system optimally for delivery of health services. The strategy will capitalize on the single health care system and the Strategic Clinical Networks within Alberta — using this vehicle and engagement of diverse stakeholders/knowledge users for informing, developing, implementing and integrating technologies and improvements in health services.

The systematic application of tools and methods from operations research and operations management to design and plan activities in the health care system could yield substantial benefits given the costs and complexity of health care. The University of Calgary is uniquely positioned to foster the growth and maturation of this important emerging research theme — and to deliver significant improvements to the performance of our health system.

Key areas of investigation:

- Operations research and operations management tools and approaches for improving the quality and productivity of the system for the delivery of health and wellness services;
- Life-cycle assessments and examination of economic, legal, regulatory, policy, and social issues of proposed biomedical engineering solutions;
- Novel methods to create scalable and sustainable biomedical engineering solutions based upon the ability to capture value through social entrepreneurship; and
- Clinical studies, leveraging expertise in patient safety and quality of care, to provide quantitative user outcome measures, which can be augmented by qualitative data.

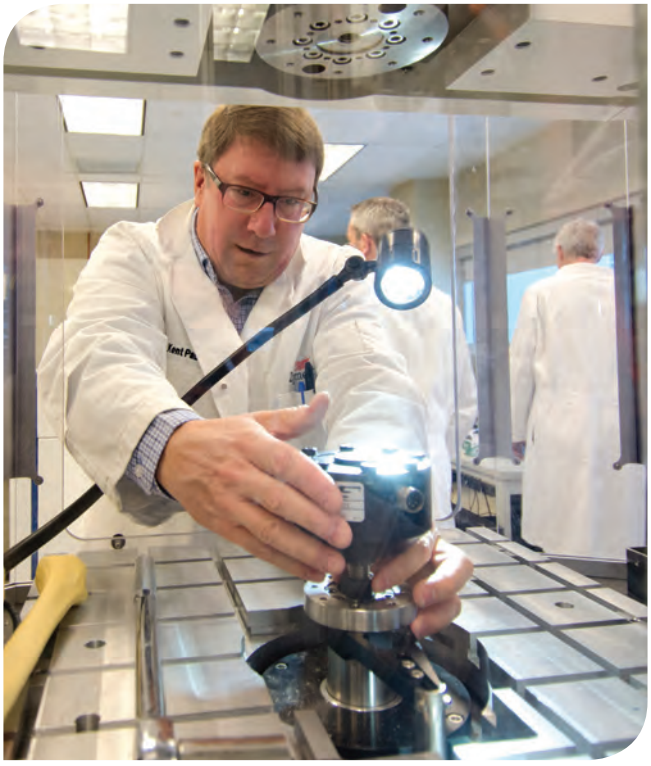
Key partners and leading infrastructure

More than 25 key partners, national strategic networks, research centres and institutes support our multidisciplinary biomedical engineering researchers. Here are a few:

Ward of the 21st Century: The University of Calgary and Alberta Health Services created the Ward of the 21st Century (W21C) as a research and beta test-site for prototypical hospital design, novel approaches to health care delivery, human factors research, and innovative medical technologies. Researchers and industry experts bring new ideas, prototypes or health care products for testing in pre-clinical and clinical environments to enhance patient safety and quality of care now and in the future. Partnering in the W21C provides biomedical engineering researchers with a critical step along the technology development pipeline. It also enables access to end users for clinical needs assessment in the early evaluation phase.

Human Performance Laboratory: The Human Performance Laboratory (HPL) in the Faculty of Kinesiology is a multidisciplinary research centre concentrating on mobility and longevity to better understand the basics of human mobility and help people be active and mobile throughout their lives. From anatomy to muscle mechanics, physiology to motor control, and biochemistry to biomechanics, HPL supports a thoroughly integrated and multidisciplinary approach to research. The equipment and computer facilities are unparalleled and HPL is host to much collaborative research from around the world.

Zymetrix — BOSE Biomaterials and Tissue Engineering Technology Development Centre: Zymetrix was established to facilitate innovation in biomedical materials and medical technologies in Alberta. As a core facility, it provides access to biomaterials and device characterization equipment, and specialized technical expertise. Zymetrix develops and provides novel testing and analysis platforms for academics and industry partners to support the research, development, and commercialization of new biomaterials, medical devices, engineered tissues, and pharmaceuticals. Zymetrix leverages market knowledge and industry collaborations to help inform UCalgary medtech initiatives. Zymetrix is part of the broader Alberta innovation community; and through its activities, it strives to support and cultivate a vibrant medtech development community that not only trains biomedical innovators of the future, but has the capacity to retain and employ this intellectual capital for the future prosperity of Alberta.



Innovate Calgary

Innovate Calgary is a full-service organization that fosters the advancement of technology business for researchers, entrepreneurs, technology companies and investors within the advanced technology sector.

Innovate Calgary is the technology-transfer and business-incubation centre for the University of Calgary and works closely with the research services office and the office of the vice-president, research. It provides expert advice and assistance with:

- Intellectual property management/licensing
- Company creation and incubation
- Analysis of commercial potential for technologies
- Mitigation of financial and resource risks relative to commercialization
- Leasing/tenancy opportunities (Alastair Ross Technology Centre and the Research Transition Facility)
- Entrepreneur development services and programs

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INNOVATE CALGARY

Institutes

- McCaig Institute for Bone and Joint Health
- Libin Cardiovascular Institute of Alberta
- Hotchkiss Brain Institute
- Alberta Bone and Joint Health Institute
- Alberta Children's Hospital Research Institute
- Southern Alberta Cancer Research Institute
- Snyder Institute for Chronic Diseases

Centres and Facilities

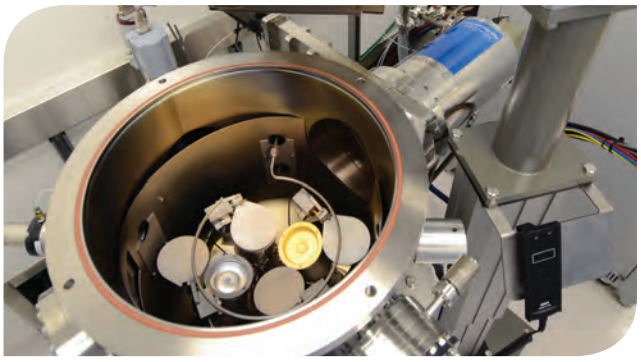
- Calgary Centre for Innovative Technology Bioengineering Laboratories
- The Experimental Imaging Centre for Preclinical Imaging
- Seaman Family MR Research Centre
- Stephenson Cardiovascular MR Centre
- Child and Adolescent Imaging Research (CAIR) Centre
- Boone Pickens Centre for Neurological Sciences and Advanced Technologies
- Southern Alberta Cancer Research Institute Cell Imaging, Microarray and Translational Labs Facilities
- Microscopy and Imaging Facility (MIF), Cumming School of Medicine
- Snyder Institute Live Cell Imaging Facility

Laboratories and Infrastructure

- Pharmaceutical Production Research Facility (PPRF)
- Cellular and Molecular Bioengineering Research Laboratory
- Healthcare Operational Excellence (HOPE) Laboratory
- Bone Imaging Laboratory

Alberta Centre for Mobility and Joint Health:
The Centre for Mobility and Joint Health (CMJH) provides a unified musculoskeletal (MSK) research facility for clinical tests and for developing integrated personalized health solutions that are founded on strong basic science. Housed at the McCaig Institute for Bone and Joint Health, CMJH integrates three technology platforms designed to provide a deep, comprehensive understanding of MSK health: mobility assessment; quantitative medical imaging; and biomarker analysis. The CMJH fills the critical gap that connects basic research to clinical care.

Advanced Micro/nanosystems Integration Facility:
The Advanced Micro/nanosystems Integration Facility (AMIF) provides support and resources for biosensors and BioMEMS-related developments. AMIF provides low-volume and custom micro- and nano-systems integration, packaging, and post-processing services, together with expert consultation and training. AMIF's equipment includes deposition (insulator and metal), spin-coating, a full photolithography suite, wet- and dry-etching as well as some metrology capability.



Building on and expanding our Confederation of Scholars

A key element of this Biomedical Engineering Research Strategy is the ongoing development and growth of our already strong Confederation of Scholars. Biomedical engineering at the University of Calgary has a long and successful history of collaborative research and high-quality training across a number of faculties, including engineering, medicine, science, kinesiology, veterinary medicine and nursing. Numerous collaborations established before 1990 have grown organically to create our present robust biomedical engineering community.

The scholars have long been engaged in national and international presentations, workshops, conferences, and policy discussions. Biomedical engineering researchers advance their individual research programs and build networks in their particular areas of expertise and also share their interdisciplinary and collaborative research activities. Biomedical engineering researchers have organized and participated in each of the 15 annual Alberta Biomedical Engineering Conferences in Banff, exchanging ideas, techniques and philosophies. Teaching activities in the Biomedical Engineering Graduate Program and undergraduate Biomedical Engineering Specialization have provided further links across faculties and disciplines. This interdisciplinary excellence and a strong international reputation for excellence led biomedical engineering to be named as one of the university's strategic research priorities.

Building on strengths: enhanced communication, collaboration and translation within an expanded Confederation of Scholars

Based on successes in key areas, such as the multidisciplinary Alberta Osteoarthritis Team, teams will be created to apply the same approach to other areas — closing communication gaps amongst biomedical engineers, health care professionals and health services professionals. This growth in the Confederation of Scholars will strengthen fundamental biomedical engineering research, and furthermore, all stakeholders will be engaged to identify both needs and potential solutions, and opportunities to translate emerging solutions.

To build on the strengths of the Confederation of Scholars in biomedical engineering, the strategy explicitly links scholars and front-line workers in the health professions (such as physicians, veterinarians, nurses, therapists, and paramedics) with biomedical engineering researchers. The researchers will continue to visit clinics and hospitals to better understand the practical considerations of health care delivery; health professionals will continue to visit biomedical engineering laboratories to better understand how discoveries are made, developed and translated into pre-clinical models and clinical practice. The Confederation's ongoing linkages to Alberta's Strategic Clinical Networks will ensure that our research is directly relevant to the needs of patients, clinicians, and policy-makers.

Building on our research platforms

Our biomedical engineering research will draw on, and contribute to, the expertise and infrastructure from six of the seven research platforms identified in the University of Calgary Strategic Research Plan:

1. **Synthesis and visualization:** This platform will play a key role in all of our themes. Medical imaging and computational modeling of animal and human systems require state-of-the-art visualization techniques to allow health care professionals to obtain as much information as possible from imaging data sets. Frequently this requires incorporating data from multiple imaging modalities. Biobanking, biomarker, genomics and other complex datasets will use synthesizing platforms to interpret complex features and relations amongst data.

2. **Analytics and simulation:** This platform will support research into fundamental physiological mechanisms such as system responses to loading in mobility, cardiovascular fluid dynamics and electrophysiological responses in neurons and cardiac myocytes. Simulation approaches will also play an important role in health care technology optimization for improved patient outcomes, as well as modelling patient flow through capacity-limited health care facilities.

3. **Research enablers:** Biomedical engineering research initiatives will rely heavily on state-of-the-art animal care facilities at the university, including the Health Sciences and Life Sciences Animal Resource Centres and the Clara Christie Centre for Mouse Genomics. The large-animal facilities in the Faculty of Veterinary Medicine will provide important capacity for pre-clinical testing. The University of Calgary is also home to one of Canada's top pre-clinical MRI centres.

4. **Commercialization:** This platform will employ innovative strategies and tactics to support the commercialization of new technology applications emerging from collaborative biomedical engineering research projects. Expertise and infrastructure supporting biomedical engineering, such as available through partners Zymetrix and Innovate Calgary, will be employed.

5. **Knowledge translation:** The co-creation of knowledge and the implementation and mobilization of this knowledge through engagement with relevant stakeholders (medical caregivers and patient advocacy groups) including the biomedical engineering research community is essential to impact health care practice and to improve patient and health system delivery outcomes.

6. **Policy creation:** The output from biomedical engineering research will inform evidence-based health policy through the Strategic Clinical Networks. We will highlight new opportunities that will catalyze health and wellness-related policy research.

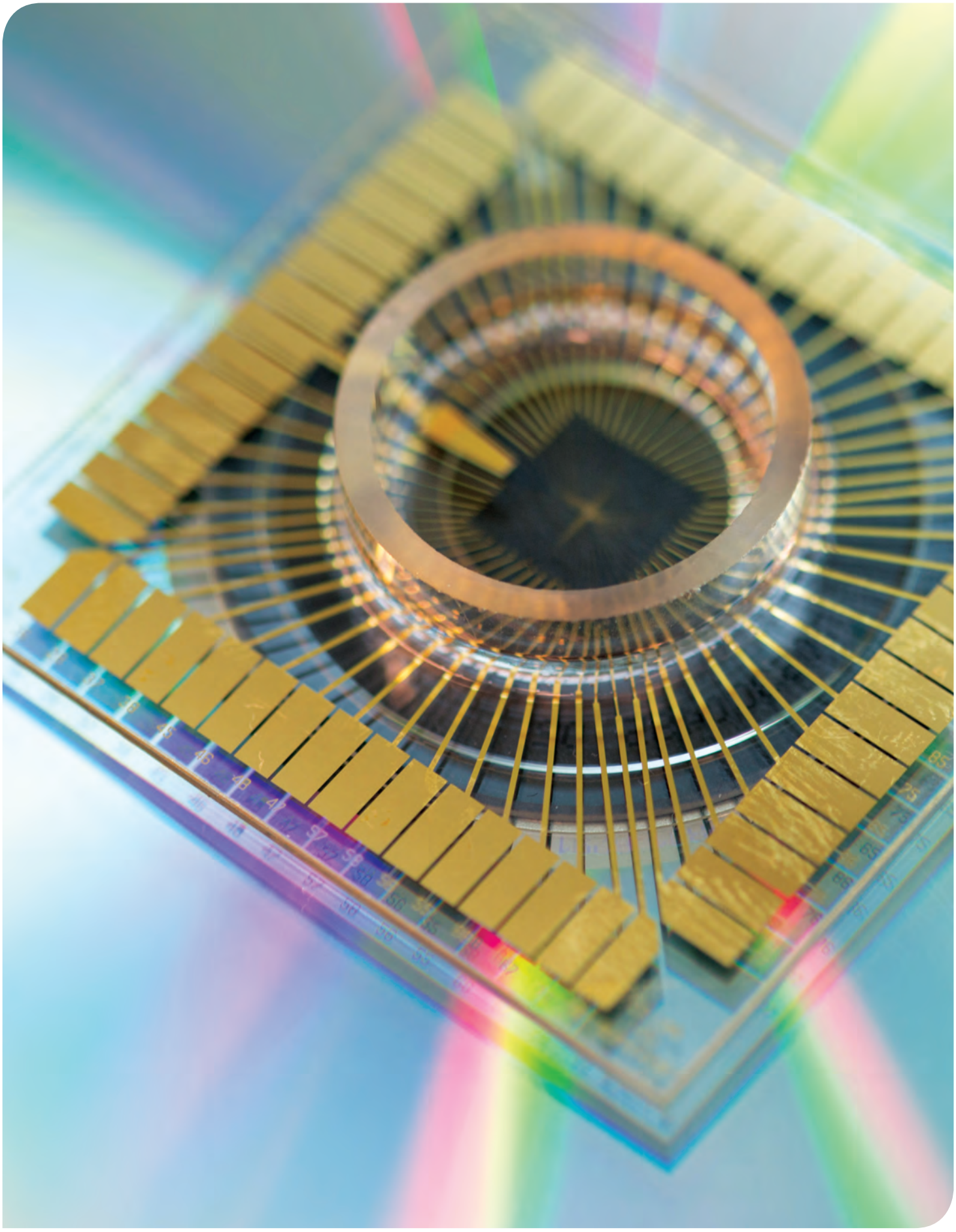
Discovery, engagement and translation

A better quality of life for Albertans to share with the world

University of Calgary biomedical engineering researchers are applying engineering principles and approaches to arrive at powerful, robust, and broad solutions for the health care field. This comprehensive Biomedical Engineering Research Strategy forms the foundation for maintaining and improving quality of life through prevention, improved diagnostics, novel therapeutics, and ultimately improving health system performance — ensuring return on investment for all Canadians.

University of Calgary biomedical engineering researchers will work across disciplines and systems — including clinicians, patients, and knowledge-translation scientists — and with industry and policy-makers to develop a strong platform of understanding. From this foundation, they will drive new discoveries, create new technologies and procedures, and assist in the implementation of these technologies. These technologies will benefit individuals, medicine and veterinary medicine, the Alberta bio-industry, and health care systems around the world. We have the interdisciplinary expertise to address biomedical engineering solutions for wellness, healthy aging, injuries and chronic diseases through focused, integrated teams to identify new approaches and develop novel quantitative diagnostic and monitoring technologies and tools to advance our fundamental understanding in the area of our research themes and create associated engineering solutions and technologies for health.

Restructuring existing technology platforms, and working collaboratively with experts across faculties, facilities and disciplines will make it possible to address key biomedical engineering problems in a pioneering way. An action plan will be developed for the implementation of this Research Strategy, which will focus on building capacity, developing new integrated research teams, and engaging all stakeholders, including industry, government, patients and health care providers.



The University of Calgary is a leading Canadian university located in the nation's most enterprising city. The university has a clear strategic direction to become one of Canada's top five research universities by 2016, where research and innovative teaching go hand in hand, and where we fully engage the communities we both serve and lead. This strategy is called *Eyes High*, inspired by the university's Gaelic motto, which translates as 'I will lift up my eyes.' As part of the roadmap to achieve these goals, the university's Strategic Research Plan identifies six research themes that will leverage our distinct capabilities while addressing the unmet needs and challenges of our society as a whole:

- Energy innovations for today and tomorrow
- Engineering solutions for health: biomedical engineering
- Brain and mental health
- Infections, inflammation and chronic diseases in the changing environment
- New Earth-space technologies
- Human dynamics in a changing world: smart and secure cities, societies, and cultures

This comprehensive Biomedical Engineering Research Strategy forms the foundation for maintaining and improving quality of life through prevention, improved diagnostics, novel therapeutics, and ultimately improving health system performance — ensuring return on investment for all Canadians.

Learn more about the University of Calgary's Strategic Research Plan and Biomedical Engineering Research Strategy.

Contact the Office of the Vice-President (Research) at vpr@ucalgary.ca