DEPARTMENT OF
BIOMEDICAL
ENGINEERING

MARQUETTE UNIVERSITY

MEDICAL COLLEGE OF WISCONSIN

# SENIOR DESIGN PROJECTS 2017

# industry sponsors

### 2016–2017
**Siemens Medical Solutions USA Inc.,** Hoffman Estates, IL
**Safe Place Bedding, LLC,** Conesville, OH
**9 Degrees of Human,** Milwaukee, WI

### 2015–2016
**Medtronic USA Inc.,** Minneapolis, MN
**Trek Bicycle Corporation,** Waterloo, WI
**Cardiac Profiles Inc.,** Franklin, TN
**Zimmer Biomet,** Warsaw, IN

### 2014–2015
**GE Healthcare,** Waukesha, WI
**Medtronic USA Inc.,** Minneapolis, MN
**Rowheels,** Fitchburg, WI

### 2013–2014
**Cytophil, Inc.,** East Troy, WI
**DesignWise Medical,** Loretto, MN
**GE Healthcare,** Waukesha, WI
**Siemens Healthcare,** Hoffman Estates, IL
**Medtronic USA Inc.,** Minneapolis, MN

### 2012–2103
**NeoCoil, LLC,** Pewaukee, WI
**Gauthier Biomedical,** Grafton, WI
**3M,** Minneapolis, MN

### 2011–2012
**GE Healthcare,** Waukesha, WI
**Medtronic USA Inc.**, Minneapolis, MN
**Innovator of Disability Equipment and Adaptations, LLC,** Pewaukee, WI

### 2010–2011
**Cardiac Science Corporation,** Deerfield, WI
**DePuy Orthopedics, Inc.** Warsaw, IN
**GE Healthcare,** Waukesha, WI
**Medtronic USA Inc.**, Minneapolis, MN

### 2009–2010
**DePuy Orthopedics, Inc.** Warsaw, IN
**GE Healthcare,** Waukesha, WI
**3M,** St. Paul, MN

### 2008–2009
**DePuy Orthopedics, Inc.**, Warsaw, IN
**Siemens Medical Solutions**, Hoffman Estates, IL
**GE Healthcare**, Waukesha, WI
**ACTRA Rehabilitation Associates**, Brookfield, WI
**Gauthier Biomedical Inc.**, Grafton, WI
**Stevenson Industries**, Simi Valley, CA

### 2007–2008
**3M,** Saint Paul, MN
**Siemens Medical Solutions,** Hoffman Estates, IL
**Baxter Healthcare**, Deerfield, IL

### 2006–2007
**Medtronic USA Inc.,** Minneapolis, MN
**DePuy Orthopedics, Inc.,** Warsaw, IN
**Siemens Medical Solutions,** Hoffman Estates, IL
**GE Healthcare,** Waukesha, WI

**ON THE COVER:**
A young child with a bilateral above-knee amputation evaluates her new adaptive tricycle built by a senior design team to use side-to-side hip motion for propulsion. See page 15 for more information.

# to our industry partners

We are pleased to present the Biomedical Engineering Senior Design Projects completed during the 2016-2017 academic year with the new joint department between Marquette University and the Medical College of Wisconsin.

The Department of Biomedical Engineering at Marquette University is dedicated to preparing students for their professional and personal lives after graduation. Undergraduate students can specialize in biomechanical, bioelectrical, or biocomputer engineering. In addition to courses in engineering, mathematics, and the life sciences, students are required to complete several design challenges in the freshman year and a year-long project-based capstone design course in the senior year. Students develop their teamwork skills, learn about the product development process used in industry, and are made aware of the unique requirements and constraints of medical device design. They consider legal and regulatory issues, use standards where applicable, conduct economic analyses, and learn about packaging, sterilization, and testing of medical devices. Several project deliverables, similar to those used in industry, are required. This capstone design experience provides students with the knowledge base and skill sets needed to be effective contributing members of a medical device company, clinical engineering department, or academic research laboratory, and create value for their customers.

This was the first year of our new joint Department of Biomedical Engineering between Marquette University and the Medical College of Wisconsin. This year we continued our 12-year collaboration with the Milwaukee Institute of Art and Design (MIAD). Five of our project teams collaborated with industrial design students from MIAD during the spring semester. This was the sixth year of external funding for service learning, assistive technology, and other projects. We appreciate this support made possible by R25 EB013070 from the National Institute of Biomedical Imaging and Bioengineering and the Marquette University Strategic Innovation Fund.

In our Biomedical Engineering Department, students may enhance their design experience and preparation for careers in the engineering profession through work experience. At the Les Aspin Center for Government Studies, students can work as interns for the US Food and Drug Administration and learn first-hand how the FDA functions and what is required to market a regulated medical device. Students participating in our highly popular and nationally recognized Cooperative Education Program gain work experience at medical device companies prior to graduation.

As you read through this report and learn of the benefits of industry sponsorship of senior design projects, please consider becoming a sponsor. We recognize the value to our students and program of strong ties to industry, and we are interested in working with additional companies to help us prepare our students for careers in biomedical engineering.

Respectfully,

*Jay R. Goldberg, Ph.D., P.E.*
Clinical Professor of Biomedical Engineering,
Senior Design Course Instructor

*Lars Olson, Ph.D.*
Associate Professor and Interim Chair,
Department of Biomedical Engineering

# industry sponsorship

## Senior Design Course Sequence:

At Marquette University, all senior biomedical engineering students are required to successfully complete a set of project-based capstone design courses (BIEN 4920, Principles of Design, and BIEN 4998, Senior Design). At the end of these courses, students will demonstrate:

- The ability to connect and apply the knowledge and skills developed in previous engineering (and other) courses towards a design solution (to a specific problem) that creates value for a customer
- The ability to plan and produce a product or service that will meet customer needs
- The ability to work effectively in teams
- Written technical and oral communication skills

## Senior Design Project:

The major component of the course is a design project that is managed by a multidisciplinary team of three to five students for an entire academic year. During the year, project teams identify customer needs, develop potential designs, construct and test prototypes, and deliver a design and/or working prototype to their industry sponsors. Project teams develop project schedules, maintain project notebooks, conduct economic and risk analyses of their design solutions, and develop and present written and oral project proposals and final reports.

Many of the projects are industry sponsored and provide students with an opportunity to learn about the needs of the medical device market and the operations of a company. Experience gained from industry sponsored projects helps prepare students for careers in the medical device industry. Teams are advised by a biomedical engineering faculty member and a representative from the sponsoring company.

## Benefits of Sponsorship:

**Benefits to companies sponsoring design projects include:**

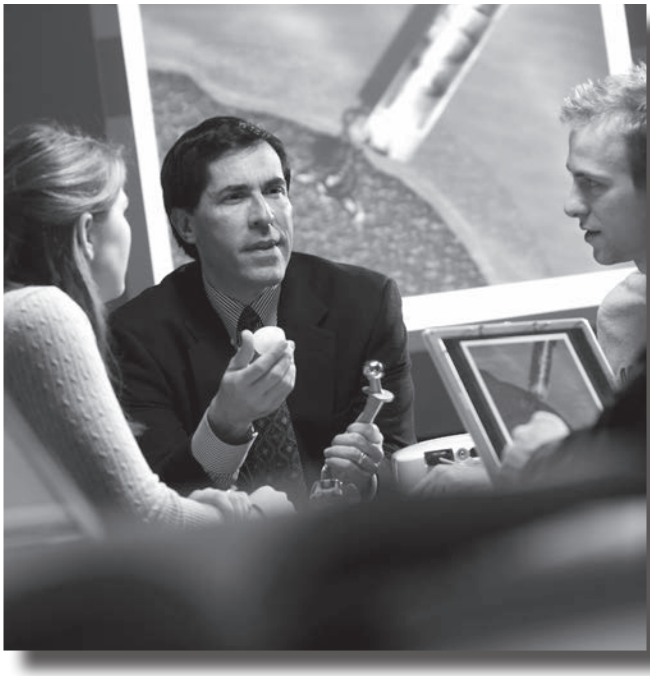
- Additional resources at little cost to company

Three to five senior engineering students will be dedicated to each project for two semesters. The sponsoring company can specify the composition of the project team (biomedical, electrical, computer, and mechanical engineering students). This can be very beneficial to companies with limited engineering resources and can allow companies to focus efforts on higher-priority projects.

- Involvement and participation in the training of new engineers and potential employees

- On-campus advertisement of the sponsoring company

Involvement in the senior design project will provide the company access to and a higher profile among graduating engineers.



**Benefits to students of industry-sponsored projects:**

- Opportunity to work on real-world problems important to industry
- Exposure to the medical device industry and market
- Experience with project management and product development
- Familiarity with requirements and constraints of medical device design

## Requirements for Industry Sponsorship:

**Personnel:** Sponsoring companies must identify at least one company representative to act as an industry advisor to the project team. The industry advisor would be the company contact for the project team, advise students on issues involving customer needs, provide technical expertise and advice, and approve design concepts and prototypes. Faculty advisors will be responsible for administrative issues (grading, meeting deadlines, monitoring progress of teams, dealing with team personnel issues, etc.) and providing guidance to the team.

**Time:** At a minimum, industry advisors must be available to discuss project requirements, customer needs, and potential designs. Communications can be in-person or by phone, e-mail or video conference. The advisor determines the frequency of communications.

**Travel:** The sponsoring company determines the need for travel.

**Funding:** Depending upon the needs and expectations of the sponsor, a fund of $1000–$1500 may be necessary to pay for prototypes and testing.

**Other:** Students have access to Marquette University's computer network, libraries, Discovery Learning Laboratory (machine shop, collaboration space, 3D printers, prototyping resources), faculty expertise, and engineering laboratories. Sponsors may want to provide additional resources (prototyping facilities and/or personnel, laboratories, etc.) to their project teams if desired.

**Types of Projects Appropriate for a Senior Design Project:**

- Lower priority projects for which the company lacks resources
- Projects that can be completed in nine months or less
- New products (hardware or software)
- Product improvements (new features, packaging, materials, etc.)
- Process improvements
- Development of test procedures and/or test equipment

**Protection of Proprietary Information:**
Sponsors can request that members of their project teams sign non-disclosure agreements to protect confidential and trade secret information.

## To Sponsor a Biomedical Engineering Senior Design Project:

If you have any questions about our senior design program or if you are interested in sponsoring a senior design project please contact Dr. Jay Goldberg at (414) 288-6059 or jay.goldberg@mu.edu.

**We look forward to working with you.**

## HEMODYNAMIC LAB CART

**Project Team:** Clayton Cox, Hannah Fleischman, Justin Hauter, Allie Othman, Abe Ortiz

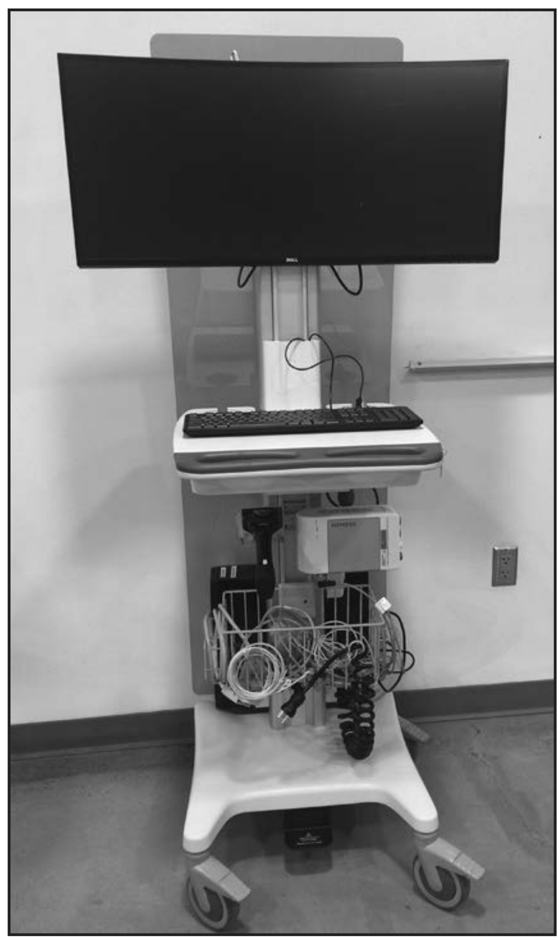
**MIAD Partners:** Denae Vanden Heuvel, Han Kim

**Faculty Advisor:** Dr. Said Audi

**Sponsor:** Dana Cook, Emily Skanron, Siemens Medical Solutions USA, Inc.

To identify potentially life threatening cardiovascular issues, many hospitals conduct tests in electrophysiology and hemodynamic labs. These tests are run with the primary goal of checking the heart's function to detect abnormalities. To prevent or diagnose life-threatening heart failures, doctors and nurses must be able to perform their jobs with precision and ease. Electrophysiology and hemodynamic labs require numerous connection cables, particularly for medical devices connected to patients and power sources. Labs in hospitals today are already cluttered with many cables around the room for other various medical devices. This is a real problem that creates financial and physical space constraints on hospitals. It would be a significant improvement for hospitals to be able to use lab space for many different procedures and not be dedicated to only one procedure.

To provide more versatile lab spaces and address issues of cable management associated with stationary lab units, the project team partnered with Siemens Healthcare to design a lab cart that would house the Siemens Healthcare hemodynamic recording system, Sensis. The cart was designed with the primary objective of making Sensis portable and transferable as well as helping manage cables and keeping the labs organized. The cart design complies with IEC 60601-1 and is structurally sound. The team also designed and 3-D printed a prototype of a new cable management solution. Calculations, testing, and sponsor feedback indicated that the team successfully designed and delivered a cart that satisfied all customer needs.



# HEART PICTURE ILLUSTRATOR

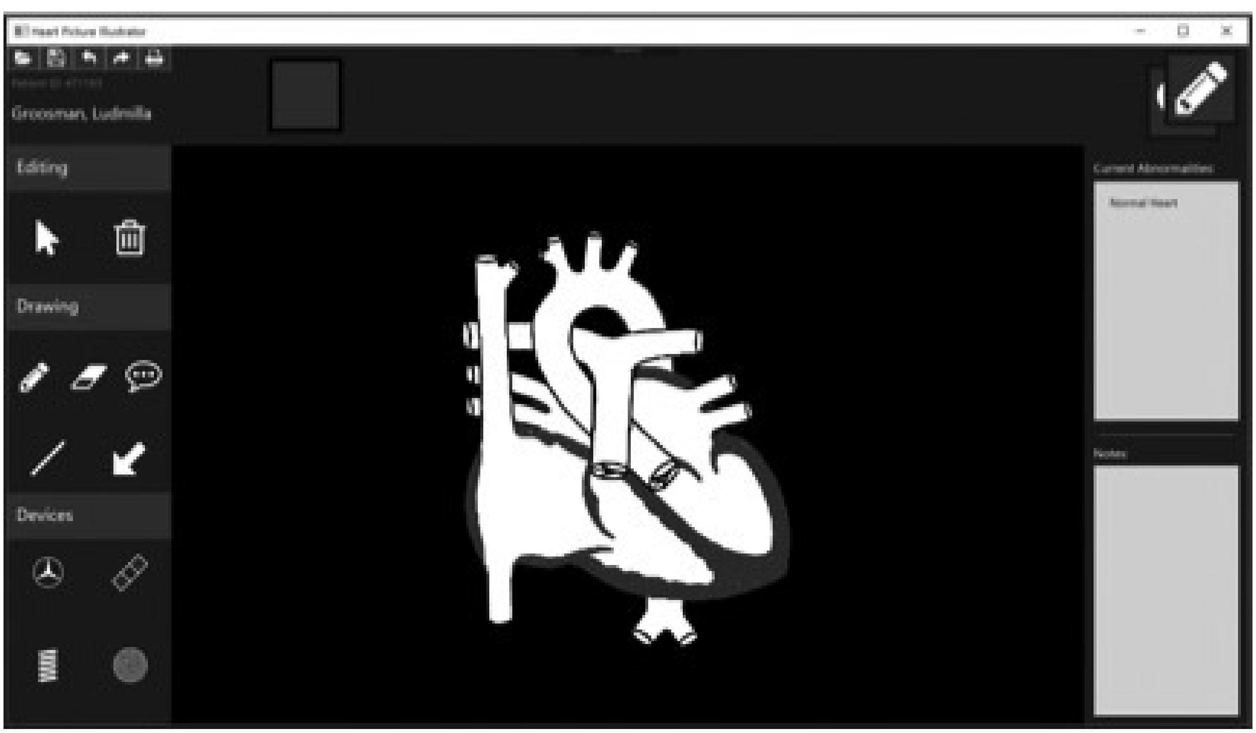
**Project Team:** Marielle Billig
Joaquin Castro-Calvo
Paul Dang
Samuel Newberry
Taylor Wenzel

**Faculty Advisor**: Dr. Guilherme Garcia

**Sponsor:** Dana Cook
Siemens Medical Solutions
USA, Inc.

Congenital heart defects (heart defects present at birth) are often severe and require one or more surgical interventions. Cardiologists often have to draw by hand diagrams of the heart when explaining to parents the child's heart defect and what surgery is needed to repair it. These hand-drawn pictures create a time burden for healthcare professionals, and make it difficult for patients and their families to understand the pathology and associated surgical interventions.

The purpose of this project was to create a software tool to allow cardiologists to quickly create quality images of heart defects and surgical interventions. The software included a database of heart defects and allowed for free-drawing to customize the images (e.g., drawing, erasing, and adding lines, arrows, and comment boxes). The software tool also included the option to draw devices, such as stents, valves, and patches, to illustrate potential surgical interventions.



# REAL-TIME STREAMING ANALYSIS OF PHYSIOLOGICAL DATA RESULTING IN ACTIONABLE ALERTS

**Project Team:** Adam Hastings, Andrew Serfas, Kevin Wright

**Faculty Advisor**: Dr. Robert Scheidt

**Sponsor:** Andrew Kusters, Clement Zablocki V.A. Medical Center

There is a demand in clinical environments for a product that can couple many physiological parameters together. Currently, there is an unmet need to analyze this large patient dataset in clinically meaningful ways. Although retrospective analysis of patient data after an adverse event exists in the majority of hospitals, very few use real-time streaming analytics that allow for predictive and proactive intervention. Due to an overwhelming amount of patient data and the limitations of human analysis, indicators of patient deterioration are sometimes missed, causing intervention to start late.

The purpose of this project was to create a proof of concept prototype to process large amounts of physiological data while simultaneously analyzing the data in real time. As a result, an algorithm can be developed in order to provide patients and their doctors with better patient care and monitoring. Specifically, this project focused on patients at the Clement Zablocki V.A. Medical Center in Milwaukee who developed atrial fibrillation after coronary artery bypass graft (CABG) surgery. The algorithm was developed using historical patient data and involved statistical analysis, principal component analysis, multiple linear regression, and standardization techniques. These processes were conducted to derive the hard coded coefficient values needed for the predictive algorithm whose output represents the likelihood of a patient developing atrial fibrillation. Lastly, the results of the predictive algorithm were sent to a web application where physicians with Internet access could view their patient's status in real time.

The predictive algorithm was applied to the test dataset of 20 patients (10 with atrial fibrillation and 10 without atrial fibrillation), which the team had never viewed or analyzed. Results indicated a sensitivity of 100%, specificity of 50%, and accuracy of 75%. Additionally, the final design was able to meet 11 of the 14 customer needs and target specifications. Of the target specifications not met, all represented additional features not currently used that could be incorporated in the algorithm by a future design team.

This project was supported by R25 EB013070 from the National Institute of Biomedical Imaging and Bioengineering.



# THIRD-WORLD HEALTHCARE SYSTEM

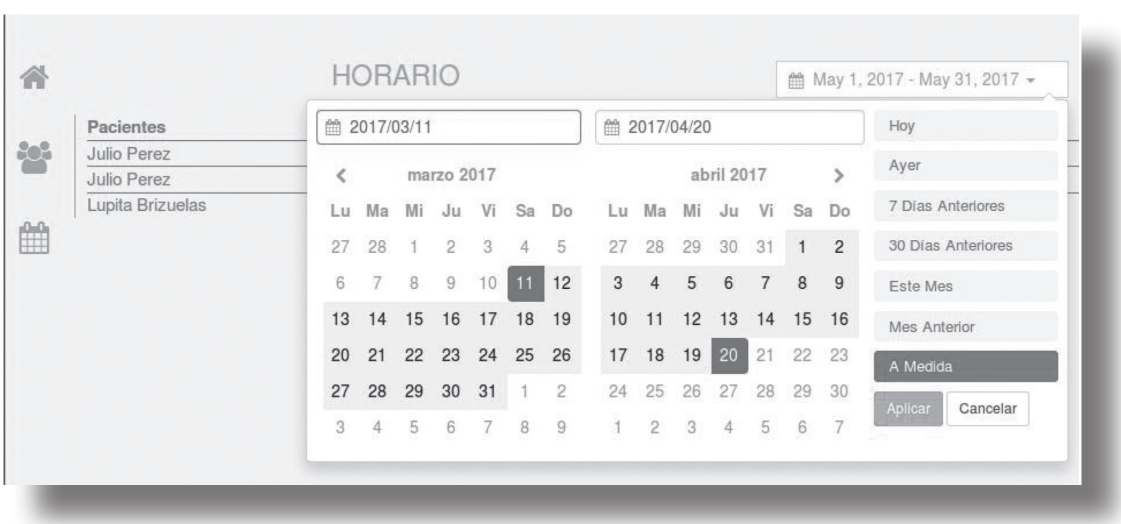
**Project Team:** Britt Ahlgrim
Sydney Barovsky
Ben Durette
JP Rivera
David Vitale

**Faculty Advisor:** Dr. Lars Olson

Currently, health clinics in third-world countries lack the technology, infrastructure, and funding to afford a system for tracking patient information in a reliable and maintainable way. Tracking patient information and appointment history is currently done manually on paper, without a means of quickly identifying which patients need to be seen next and which patients are most in need of care. The healthcare system in El Salvador identifies standards that indicate how frequently patients need to be seen based on their last visit, risk factors, age, and other indicators. With the paper system in place, workers at the clinics need to sift through hundreds of papers to identify which patients are the highest priority to be seen, which clinicians and doctors they need appointments for, and the patients who need to schedule a home visit.

The purpose of this project was to create an affordable and reliable healthcare information system to store patient information, and easily identify which patients the health promoters and doctors should see next. The system designed is a web application, which is very easily distributable on low cost hardware. The application allows health workers to add and modify patient names, view specific patient information, and keep a history of appointments for each patient. The web application automatically determines the next date a patient should be seen, and clearly indicates this to the health workers so that the system is more efficient and effective than the manual paper system.

Verification testing indicated that this web application meets all customer needs and provides all of the required functionality. The base application allows for security of the information, a readable view and input of patient data, and an electronic appointment scheduling system. This base application can be distributed through many different mediums to our target customers, options which may be explored by the faculty project advisor and Ministry of health in El Salvador.



This project was supported by R25 EB013070 from the National Institute of Biomedical Imaging and Bioengineering.

# LOW-COST VENTILATOR

**Project Team:** Molly Connolly
Julie Griep
Benjamin Hamel
Rebecca Jaeger
Drew Vanderwiel

**MIAD Partners:** Bohan Liu
Rodney Mustelier

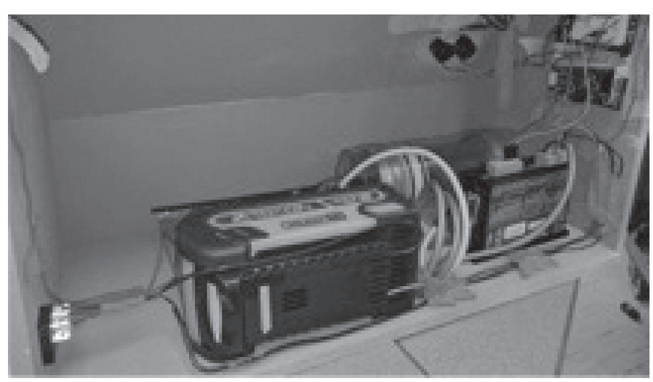
**Faculty Advisor**: Dr. Lars Olson

The purpose of this project was to design a low-cost ventilator that provided the basic functionality present in expensive ventilators at a fraction of the price for use in developing nations.

Development of a low-cost ventilator addresses two issues currently precluding the widespread use of ventilators in developing nations: (1) ventilators are prohibitively expensive for developing nations (the average cost of a ventilator is roughly \$20,000-\$40,0000), and (2) developing nations often lack the electrical infrastructure to provide reliable power (ventilators must have constant power for operation). As a result, clinics resort to sharing ventilators between hospitals or manually ventilating a patient 24/7, ultimately reducing the quality of patient care and increasing the risk of brain damage and death. Project needs were collected from customers located in Central and South America, which guided the development of the target specifications and implementation.

The final low-cost ventilator design was composed of a rechargeable battery, one large piston, an LED screen, two dials, and a stepper motor. To house the components, a lightweight case comprised of a foam-based material was constructed. The cost to manufacture the low-cost ventilator was under \$600.

To verify functionality, specific tests were conducted to determine if target specifications were met. The results of the experimental verification process provided demonstrable confirmation that the low-cost ventilator met all requirements. Future improvements to the current low-cost ventilator will focus on power efficiency, device functionality, and cost effectiveness.

This project was supported by R25 EB013070 from the National Institute of Biomedical Imaging and Bioengineering.



# GO BABY GO!

| | |
|---|---|
| **Project Team:** | George Curtis<br>Jessica Dreyer<br>Stephanie Graetz<br>Kevin McEvilly<br>Benjamin Olson |
| **Faculty Advisor**: | Dr. Gerald Harris |
| **Clinical Advisors:** | Dr. Ben McHenry<br>Chris Cayo |

*Go Baby Go!* is a national, community-based research, design, and outreach program that adapts ride-on cars for children aged 0-3 years with restricted mobility. In many situations children who lack independent mobility use wheelchairs or strollers, or they are carried by parents and caregivers. These forms of assistance do not allow movement independence or exploration of the environment. Another limitation is the high cost of electric wheelchairs which can exceed $30,000 and is usually not covered by insurance.

Without proper mobility and physical therapy, a child can suffer setbacks in cognitive, language, and social development. Independent mobility allows learning of *cause and effect* interactions with the environment to stimulate development.

The purpose of this project was to modify existing ride-on cars for children with disabilities. The goals of the design project were to 1) allow independent mobility, 2) provide safety features which could be activated by parents and caregivers, and 3) reduce the start-up acceleration and stopping deceleration to reduce the child's cervical torque. The resulting *Go Baby Go!* car design includes six improved features: 1) remote kill switch, 2) manual kill switch, 3) Raspberry Pi processor and motor controller for programmed acceleration/deceleration, 4) headrest, 5) 5-point seat harness, and 6) manual acceleration feature with remote control steering. Use of the *Go Baby Go!* cars with these design features offers a cost-effective method to improve mobility while also stimulating socialization without the stigma associated with typical assistive devices.

Testing to verify the design indicated that the device reduced the rate of initial acceleration from 4 $m/s^2$ to 1 $m/s^2$, while providing the parents and caregivers with a way to supervise and take precautionary measures to ensure the child's safety. Final testing and evaluation of family acceptance, usability and adaptability will be completed.

This project was supported by a Marquette University Strategic Innovation Fund Grant.



# LEG EXTENSION ASSISTIVE DEVICE

**Project Team:** Madalyn Bockheim, Andy Downey, Ella Engels, Isabelle Rusden, Nick Wielgos

**MIAD Partners:** Leah Blanck, Beau Branger

**Faculty Advisor**: Dr. Jay Goldberg


Those who are dependent on a wheelchair for everyday use and independence are prone to pain and discomfort in the lower extremities. Lack of movement in the legs causes circulation issues which leads to swelling, blood clots, and pain. Movement of the lower legs is very effective in preventing swelling and reducing discomfort. In many cases, people in wheelchairs are not able to move their legs themselves; caregivers must be available to stretch the lower extremities of the wheelchair users.

This project involved designing an affordable, easy-to-use, and durable adaptive technology that allows for a wheelchair user to stretch her legs without the help of a caregiver. The primary customer was an 11-year-old girl with Spinal Muscular Atrophy. Because of her medical condition, she uses a motorized wheelchair for everyday mobility, providing her with greater independence. A device was constructed to attach to her wheelchair that lifts her lower legs to a 45-degree angle using an actuator and a leg frame. It is controlled with a user interface mounted near the armrest of the wheelchair. The device allows her to independently stretch her legs throughout the day using her controller. This device relieves lower leg pain and provides her with greater independence at home and school.

Testing verified that the device is comfortable, safe, and robust. It stretches her legs to a specified angle up to 45 degrees, improving the client's health and quality of life, and providing her with greater independence.

This project was supported by R25 EB013070 from the National Institute of Biomedical Imaging and Bioengineering.

# IMPROVED DESIGN OF SURGICAL HAND DRILLS

**Project Team:** Cody Haberkorn
Garret Klompenhouwer
Elizabeth Menden

Alison Parker
Tom Wentworth

**Faculty Advisor**: Dr. Scott Beardsley

**Industry Advisor:** Michael Telwak

In 2014, nearly 30,000 orthopedists performed an average of 29 procedures per month, and the number of surgeries is expected to grow with the aging American population. It is crucial to ensure that surgeons are equipped with the best available tools to provide the safest and most successful operative environment for their patients.

While current surgical hand drills are effective, their overall design is not optimal. This is due in part to the variety of requirements that must be met during use in the operating room and throughout post-operative sterilization and maintenance. This project involved the design of an improved surgical hand drill design based on a Stryker System 6 reciprocating saw. The three areas of focus for improving the design included improved heat transfer, motor accessibility, and water resistance. Design modifications to improve heat-transfer emphasized a reduction in the incidence of motor overheating and a lower in-the-handle temperature for the surgeons. Heat fins were added to the Stryker drill to improve the heat transfer from the motor to the environment. To facilitate motor accessibility, a specialized hand tool was developed that could be used to remove the Stryker end plate and extract the motor. The hand tool provides easy access to the internal motor components in-house maintenance. The third component of the design incorporated a polymeric foam lining around the trigger articulation, end cap and battery port. The lining provides a tighter seal at the interface between the drill components, keeping water out.

Design verification demonstrated 1) a duty cycle improvement of 50% associated with reduced motor heating, 2) motor accessibility in less than five minutes, and 3) water resistance capable of withstanding the sterilization process. These design improvements reduced overheating during use, allowed for easy maintenance, and improved the ability of the drill to withstand sterilization following each operation.

This project was supported by a Marquette University Strategic Innovation Fund Grant.

PROJECTS • 2016–2017

# PEDIATRIC WHEELCHAIR ACCESSIBLE SWING

**Project Team:** Andrew Goddard, Robbie Dietz, Fernando Hernandez, Lukas Powers, Sam DeLouis

**MIAD Partners:** Nora Sandstrom, Maria Castillo

**Faculty Advisor:** Dr. Jay Goldberg

**Sponsor:** John Wojtalewicz, Milwaukee Center for Independence

The Milwaukee Center for Independence (MCFI) is a system of choice schools within the Milwaukee metropolitan area that helps and assists students and families with special needs. No matter the type of mental and physical disabilities their students possess, MCFI aims to assist all students in obtaining their highest level of independent living within the constraints of their disabilities. MCFI assists students with overcoming their physical problems and helps them overcome social and financial problems.

MCFI has a playground that the students use daily. Along with the many different types of equipment the students can play with, the facility includes a variety of playground swings that accommodate students with different kinds of physical disabilities. In the past, MCFI had a plastic swing that was used by students confined to pediatric wheelchairs. Staff members would assist the students from their pediatric wheelchair into the plastic swing structure. Recently, the chains supporting the plastic swing structure broke leaving the structure useless. MCFI requested an improved swing structure for the students who require a pediatric wheelchair. This project involved the design, fabrication, and installation of a wheelchair accessible swing for MCFI.

Testing to verify that the swing functions as required and is safe for students at MCFI was completed. The swing was able to accommodate loading and unloading of the chairs easily, while keeping the wheelchair and subject safe and secure through both the normal and extreme swinging cycles tested.

This project was supported by a Marquette University Strategic Innovation Fund Grant.

# ADAPTIVE TRICYCLES FOR PEDIATRIC AMPUTEES

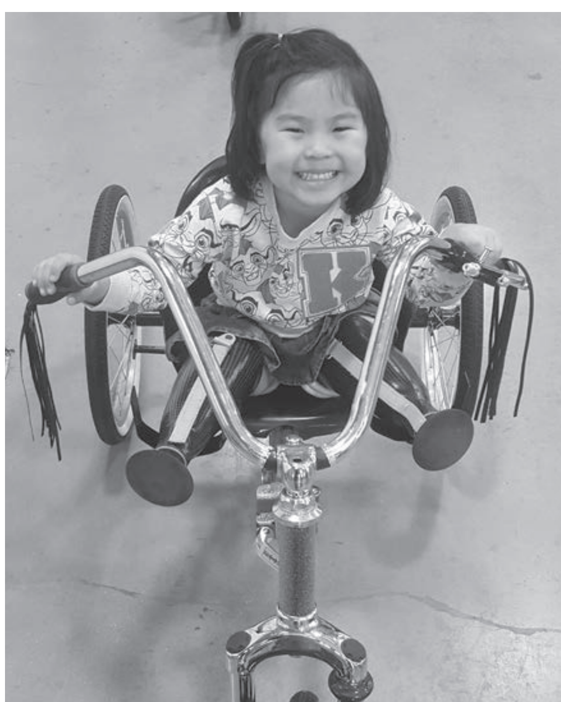
**Project Team:** Emily Canfield
Tom Lake
Emilie Simpson
Joey Zanfardino

**Faculty Advisor:** Dr. Barbara Silver-Thorn

There are approximately 1.5 million amputees in the U.S., with 185,000 new amputees each year. Of the amputee population, approximately 1 million are lower extremity amputees. Although the cause of amputation is most commonly due to vascular impairment or trauma, some amputations are attributed to congenital deformities. The clients for this project were two children, aged 3 and 4 years, with congenital limb deficiency. One child is a bilateral transfemoral amputee; the second child is a unilateral transtibial amputee. Both clients currently have adapted bikes available to them at home, however, the bikes are cumbersome and too large. Furthermore, due to their lower limb range of motion and restrictions due to prosthetic use, both children have difficulty pedaling using traditional pedaling mechanisms.

The purpose of this project was to create two separate bikes that fit the individual needs of these children at a cost of < $700 per bike. The bikes had to fit the children's physical measurements and accommodate knee and hip strength and range of motion. For the bilateral transfemoral amputee, the designed adapted bike used hip adduction and a differential for forward progress, which was then translated into movement using a differential. For the unilateral transtibial amputee, the pedaling mechanism used a four-bar locomotion. Both solutions allowed the clients to sit comfortably and "pedal."





This project was supported by R25 EB013070 from the National Institute of Biomedical Imaging and Bioengineering.



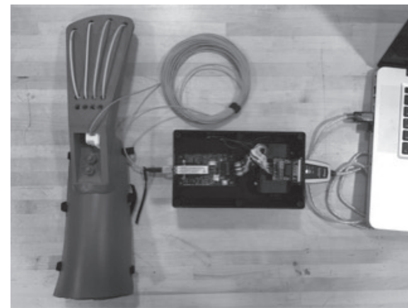
# FUNCTIONAL IMAGING FOR STROKE PATIENTS

| | |
|---|---|
| **Project Team:** | Joseph Ebel<br>Jared Baranowski<br>Nathaniel Ford<br>Kelsey Tynes<br>Christine Smith |
| **MIAD Partners:** | Carol Mason<br>Jessica Cannon |
| **Faculty Advisor:** | Dr. Brian Schmit |
| **Clinical Advisor:** | Dr. John McGuire |

Stroke is a debilitating disease that can manifest in both high functioning, and severely damaging forms. When clinicians are examining stroke patients, a principle interest is the functionality of the brain. By using fMRI to examine the brains of affected patients, and observing their specific pathology, a better understanding of the neural networks and pathways affected by stroke can be understood.

The purpose of this project was to provide the clinical advisor with an MRI safe device to be used by stroke patients. The device would passively extend the digits of the hand, which would allow determination of the functionality of the patient's brain post-stroke.

The final product consists of several major components. A 3D-printed outrigger extends over the hand of the patient and acts as a moment arm to assist in opening the hand of the patient. Next, Theraband latex tubing runs along the top of the outrigger and connects to the fingers of the patient. The Theraband acts like a spring and converts potential energy to kinetic energy, pulling the finger open. The outrigger and Theraband are then anchored to an arm brace consisting of molded thermoplastic.



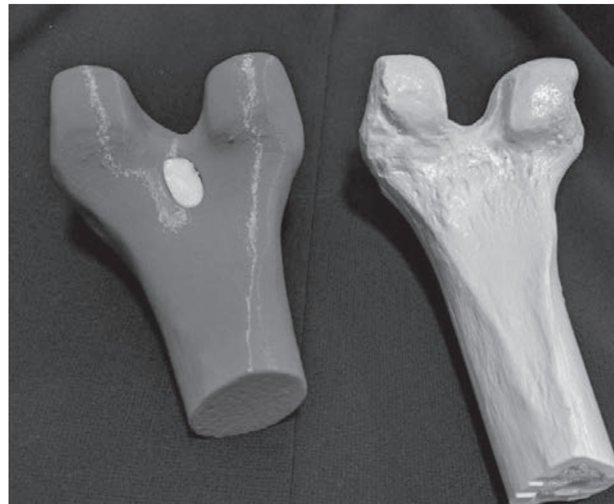
This arm brace goes over the wrist and forearm of the patient and has a second piece that is placed on the underside of the forearm and wrist. The brace acts to limit wrist flexion of the patient when opening and closing the hand. A fiber optic bend sensor attached to the outrigger and middle finger of the patient provides position data of hand movement.

The team developed an MRI compliant device that would passively extend the digits of the hand and provide the clinician with data describing the patient's hand movement over the time course of the scan. When the patient enters the MRI chamber, the device will be affixed to the forearm by the physician. A task-based fMRI procedure requiring the patient to extend and flex digits with assistance from the device is performed. Once this is completed, the sensor will record position data that will then be written to a text file. This output data, in conjunction with the fMRI results, will give the physician the information he needs to gain insight into the functionality of the brain post-stroke.

Testing was completed to verify that the device passively extends the digits of a human hand as well as obtains data regarding the movement of the digits. The device is able to provide a 48 lbf assistive load to help extend the patient's digits. It also has an optical sensor that can acknowledge movement of the fingers and relay the information in a display for the physician. Verification and validation testing indicated that all customer needs were met.

This project was supported by R25 EB013070 from the National Institute of Biomedical Imaging and Bioengineering.

# DESIGN OF BONE GRAFTS FOR CHILDREN WITH OSTEOSARCOMA



**Project Team:** Amanda Shannon, Fadumo Mohamud, Danny Edwards, Martin Rodriguez

**Faculty Advisor:** Dr. Samuel Bechara

**Sponsor:** Dr. Lobat Tayebi, Marquette University School of Dentistry

According to the National Cancer Institute, osteosarcoma is the most common bone tissue malignancy in children, such that approximately 900 US cases present each year and its rate of occurrence continues to increase. Early diagnosis at the low-grade stage (parosteal osteosarcoma) has improved medical intervention and survival rate (intervention being the surgical resection of the malignant tissue and subsequent graft implantation to reconstruct the bone segment). Currently, bone segment reconstruction is achieved using either an autograft, allograft, or bone graft substitute yet each is faced with considerable clinical disadvantage regarding post-operative patient quality of life.

A novel approach to bone segment reconstruction via bone graft biomaterial optimization and extrusion-based additive manufacturing, highlighting patient-specific morphology, load-bearing potential and osteoinductive property, was developed. A triphasic ß-tricalcium phosphate-hydroxyapatite-zirconium dioxide (ßTCP-HA-$ZrO_2$) bioceramic, with osteoinductive properties, was developed. Both ßTCP and HA are inorganic compounds endogenous to cortical bone. These crystals signal preosteoblast cell recruitment and their metabolites undergo reuptake for subsequent refortification of the bone mineral infrastructure. When combined with $ZrO_2$ at an optimized mass ratio, the team developed a porous scaffold with physiological load-bearing potential, currently unachievable by clinical-grade bioceramics. Maximal physiological load was quantified as total axial compression applied to the distal femur (body weight and local muscular compression), at 20% stance of the gait cycle. Secondary mechanical stresses (i.e. shear and bending) were evaluated using ANSYS, an established finite element analysis resource. Regarding extrusion-based additive manufacturing, the clinical process of current MRI-based volume reconstruction to 1) capture patient femur bone-morphology, 2) excise the tumorous segment, and 3) 3D-bioprint the ßTCP-HA-$ZrO_2$ equivalent for subsequent heat treatment was simulated. The clinical process timeframe, from an MRI-based diagnosis to patient discharge, was estimated and evaluated upon consulting with orthopedic surgeons.

This project was supported by R25 EB013070 from the National Institute of Biomedical Imaging and Bioengineering.

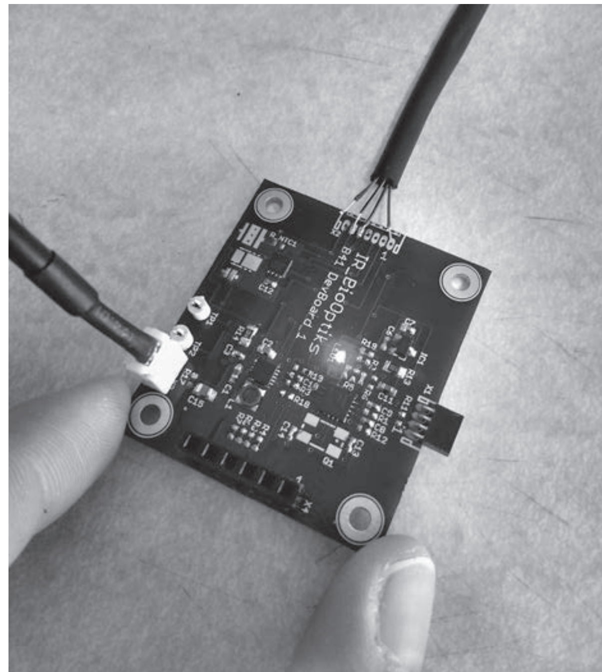


# NERVE REPAIR OPTICAL CAPSULE

**Project Team:** Brianna Moczynski
Jalen Battle
Amedee O'Gorman
Wesley Richerson

**Faculty Advisor:** Dr. Jay Goldberg

**Sponsor:** Dr. Jenna Cusic




Traditionally, red light has been used as a common homeopathic therapy to improve the immune system, repair tissue, and improve joints. Recently, research on external far red light treatment has shown to have a positive impact on nerve regeneration through increased metabolism and blood flow. The recent results showing the effectiveness of red light therapy have suggested that there is potential for promoting axonal regrowth of damaged nerves. Currently there are few treatment options for damaged nerves outside of several drugs, of which often only treat the symptoms of the damaged nerve and can have undesirable side effects on the patient.

The goal of this project was to design and develop an implantable light emitting device, which could deliver a minimum of 50 mW/cm$^2$ of 670 nm wavelength red light for 10 minutes a day over the course of 12 weeks to rats as part of a research study at the Medical College of Wisconsin (MCW). The device was also required to remain at a temperature of less than 40 degrees C to ensure safety of the test rats. The device will be used in research of implantable red light therapy devices that could be eventually used in humans to treat and repair peripheral nerve damage.

The final device design was verified through several tests to confirm the heat dissipative qualities of the light source, the accuracy of the device temperature measurement capabilities, total device power consumption, light source timing, and overall device weight, price per unit, and size. All of the requirements presented by the clinical advisor at the beginning of the year were met.

# department of biomedical engineering

Biomedical Engineering is a discipline that advances knowledge in engineering, biology and medicine to improve human health.

Students in biomedical engineering participate in cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice. Biomedical engineers develop strategies to effectively solve challenging problems in medicine and biology.

Most graduates secure employment working in the medical device/biotechnology industry. Some graduates use our "renaissance" training as a stepping stone for careers in fields such as medicine, law, healthcare management, and academics.

## Distinctive Features of Biomedical Engineering at Marquette University and the Medical College of Wisconsin

Marquette University has the largest engineering school at a Jesuit University. The new joint department formalizes the long-standing relationships with the Medical College of Wisconsin and the Zablocki Veteran's Administration Medical Center. We also have strong ties to the Rehabilitation Institute of Chicago, and manage a number of Centers including the Orthopaedic Rehabilitation and Engineering Center (OREC), the Falk Neurorehabilitation Engineering Research Center and the Rehabilitation Engineering Research Center on Accessible Medical Instrumentation.

The department has unique laboratory capabilities including CT and SPECT microfocal imaging, biotelemetry, implantable devices, telerehabilitation, and neurorehabilitation robots, in areas including neurorehabilitation, imaging systems, and cardiovascular technologies.

The joint Biomedical Engineering department offers degrees at the bachelors, masters and doctorate levels.

### Co-op and Internship Program

Marquette University has developed one of the leading co-op/internship programs among Biomedical Engineering Departments in the nation. More than half of the undergraduate biomedical engineers gain co-op or internship experience before graduation. The Biomedical Engineering department has forged partnerships with many major medical device companies in the Midwest who rely on the excellent reputation established by our students as co-ops, interns and permanent employees. The Co-op and Internship Program offers students the opportunity to gain meaningful practical and professional experiences in the health care industry, in addition to their on-campus educational experiences. ➤

Marquette University began its Engineering Co-op Program in 1919. Students usually enter the Co-op program at the end of their sophomore year and complete three to four terms of off-campus employment. The employment experience is alternated with semesters of on-campus study, extending graduation by only one year. Internships, in comparison, are summer only engineering experiences.

### Les Aspin Center for Government (FDA Internships)

The Les Aspin Center for Government at Marquette University and the Department of Biomedical Engineering offer internships on biomedical research and regulatory issues. The Les Aspin/Biomedical Engineering Internships began in 1997 with Biomedical Engineering undergraduates participating in this innovative program in Washington, D.C. To date, more than 100 biomedical engineers have completed Les Aspin Biomedical Internships. The internships are completed at the Food and Drug Administration, Office of Science and Technology in Rockville, MD.

## Undergraduate Offerings

**Choose from Three Specializations**

The Biomedical Engineering Department offers a strong undergraduate education. There are three tracks in the Biomedical Engineering curriculum:

- Bioelectronics
- Biomechanics
- Biocomputing

All undergraduate tracks in Biomedical Engineering are compatible with other programs offered by the Opus College of Engineering. Each track contains the requisite humanities courses, and requires 132 credit hours for graduation. Students automatically earn a minor in biology, and can earn an optional minor in areas such as mathematics, electrical, mechanical, or computer engineering. In addition, all tracks retain most of the core courses of the initial year, which allows the student flexibility to transfer to other curricula if so desired. The Biomedical Engineering curriculum is interdisciplinary in nature, incorporating courses in biology, chemistry, physics, mathematics, computer science and engineering.

We provide a solid foundation in the mathematical, physical, and life sciences necessary for the engineer to function effectively in a medically or biologically oriented problem solving environment. Social science and humanities courses prepare students to deal with contemporary ethical, cultural, and social issues.

In addition, we prepare biomedical engineers to communicate with life scientists, physicians and other health care providers to describe and model complex biological systems, collect and analyze experimental or clinical data, understand the capabilities and limitations of sophisticated instrumentation, and understand the principles of design.

## Undergraduate Design Curriculum

Biomedical engineering students in our Department learn about design throughout the four year curriculum.

**Freshman Year:**

Students first gain experience with the design process in the freshman year during BIEN 1100 and 1110 (*Introduction to Biomedical Engineering Methods I and II*). In these courses, they participate in several team design challenges such as:

- Physiological monitoring: Design of an algorithm for analysis of ECG, blood pressure, and other waveforms
- Medical imaging: Design and testing of an imaging phantom
- Entrepreneurship: Semester-long team-based medical device design project including a business plan and elevator speech

These experiences help develop teamwork skills, and teach students about the engineering design process, including technical, legal/ethical, regulatory, and economic design constraints. Students learn to identify customer needs, develop a list of performance requirements and specifications, convert requirements into design concepts, and build and test prototypes. During BIEN 1110, students learn about basic business concepts and entrepreneurship (as part of their design projects) culminating in a presentation of their new product ideas to students, faculty, and industry representatives at the college-wide Design Day event.

**Sophomore and Junior Years:**

During the sophomore and junior years of the biomedical engineering curriculum, students take courses that include individual and team-based design projects which allow them to apply what they are learning in the course to the solution of a related problem. This helps them relate theory with practice.

In the junior year, students can take BIEN 3400 *Clinical Issues in Biomedical Engineering Design*, an elective in which students observe procedures in the clinical environment and learn to identify unmet clinical needs and opportunities for new product development. Their final project proposals can serve as the basis of their senior capstone design projects.

**Senior Year:**

During the senior year, students are required to take BIEN 4920 *Principles of Design* and BIEN 4998 *Senior Design*. These courses require students to apply what they have learned during their previous years of the undergraduate curriculum in a multidisciplinary team-based project experience. They further develop their design, analytical, project management, communication, time management, and teamwork skills. They learn about the product development process, the medical device industry, testing for safety and efficacy, design validation, standards and regulations, risk management, project scheduling, patent issues, and a variety of design issues. Students complete a design project from problem definition to design validation (per ISO 9001 and 13485) and gain experience in generating the same project deliverables as required in industry. ➤

## Five Year B.S./M.S. Program

This program allows qualified students to receive a Bachelor of Science Degree and a Master of Science Degree in Biomedical Engineering in just five years. Students with qualifying grade point averages apply to the program during their Junior year. They begin their thesis research the summer between their Junior and Senior years, and continue their research during the summer between their Senior and fifth years and throughout their fifth year, culminating in the preparation of a written thesis and defense.

## Research in Biomedical Engineering

Biomedical Engineering faculty and students at Marquette and the Medical College of Wisconsin are engaged in a wide range of research activities, with many opportunities available for students at both the graduate and undergraduate levels.

## Research-oriented Faculty

More than 60 faculty who are active in research have primary (21), secondary (16), or adjunct (>30) appointments in our department, and are available for supervision or co-supervision of students.

## Research Laboratories and Centers

The number of research laboratories and centers within our department has been growing dramatically, with the Biomedical Engineering Department now housing 10 research laboratories and three centers.

Most recently, the NIDRR awarded our department a **Rehabilitation Engineering Research Center on Technologies for Children with Orthopedic Disabilities (TECH4POD)**. Faculty, students, clinicians, and researchers from six area institutions are developing a national center with a focus on advancing engineering research and development based on innovative technologies addressing children with orthopedic disabilities.

## Externally Funded Research

More than $5 million/year in externally funded research, the largest of any department on campus, flows through the Department of Biomedical Engineering. Research and training grants are managed by Biomedical Engineering core faculty and support research projects for more than 50 graduate students.

## Strong Partners

We are a member of the **Clinical and Translational Science Institute of Southeast Wisconsin.** Supported by a $20M grant from NIH, this consortium of eight Milwaukee institutions is dedicated to transforming biomedical research in southeast Wisconsin, accelerating the translation of research discoveries, and advancing patient care and education. The eight member organizations include the Medical College of Wisconsin, Marquette University, Milwaukee School of Engineering, University of Wisconsin-Milwaukee, BloodCenter of Wisconsin, Children's Hospital and Health System, Froedtert Hospital, and the Clement Zablocki VA Medical Center.

## Targeted Areas of National Leadership

While our students and faculty are engaged in many areas of research, three areas of excellence stand out: Functional Imaging, Rehabilitative Bioengineering, Systems Physiology, Cardiovascular Physiology, and Biocomputing.

# faculty

**Olson, Lars E., Ph.D.**
*Associate Professor and Interim Chair.*
Optical instrumentation, tissue engineering, biological transport and circulation physiology, mathematical modeling of physiological systems, biosensors

**Audi, Said H., Ph.D.**
Pulmonary mass transfer, tracer kinetics, pulmonary hemodynamics

**Beardsley, Scott, Ph.D.**
Neuroengineering, computational modeling, perceptual learning, functional imaging

**Dash, Ranjan, Ph.D.**
Computational biology and bioinformatics

**Garcia, Guilherme, Ph.D.**
Respiratory fluid mechanics

**Gilat-Schmidt, Taly, Ph.D.**
Medical imaging, image processing and reconstruction, systems engineering

**Goldberg, Jay R., Ph.D., P.E.**
*Director, Healthcare Technologies Management Program*
Medical device design

**Greene, Andrew, Ph.D.**
Cardiovascular physiology

**Harris, Gerald F., Ph.D.**
Quantitative assessment of neuromuscular function, human motion analysis, orthopedic biomechanics, data acquisition and control, real time analysis

**Hoffmann, Brian R., Ph.D.**
Metabolism

**LaDisa, John F., Jr., Ph.D.**
Cardiovascular biomechanics, adult and congenital heart disease, stent design and development

**Jeutter, Dean C., Ph.D., P.E. (Emeritus)**
Implantable transcutaneous radio frequency power transfer, biotelemetry, biomedical instrumentation, radio frequency circuit design and development

**Joshi, Amit, Ph.D.**
Optical imaging

**Ropella, Kristina M., Ph.D**
*Professor and OPUS Dean*
Signal processing, cardiac and neuro-electrophysiology, functional magnetic resonance imaging

**Scheidt, Robert A., Ph.D.**
Human motor control, systems identification, rehabilitation engineering, embedded systems, product development

**Schmit, Brian D., Ph.D.**
Spinal cord injury, human neurophysiology, neurorehabilitation, instrumentation, biomechanics

**Shimoyama, Mary E., Ph.D.**
Analytics, informatics, software engineering

**Silver-Thorn, M. Barbara, Ph.D.**
Prosthetic limbs, soft tissue mechanics, rehabilitation engineering, orthopaedic and dental biomechanics

**Winters, Jack M., Ph.D.**
Neuromuscular control systems, movement and tissue biomechanics, rehabilitation engineering, telehealth, neurofuzzy computing

**Yu, Bing, Ph.D.**
Optical imaging

## ASSOCIATE FACULTY

**Ackman, Jeffrey, M.D.**
Orthopedic surgery

**Cariapa, Vikram, Ph.D.**
Rapid prototyping, process controls, neural networks, design of experiments

**Carroll, Jospeh, Ph.D.**
Ophthalmology

**Clough, Anne V., Ph.D.**
Mathematical and computer modeling of biomedical systems, image processing and analysis, modeling of pulmonary hemodynamics, integral equations

**Hill, Joseph, Ph.D.**
Technology transfer

**Josse, Fabien J., Ph.D.**
Biochemical sensors, acoustics, acousto-electronic devices

**Koch, Kevin, Ph.D.**
MR imaging

**Krenz, Gary S., Ph.D.**
Mathematical modeling of hemodynamic properties of the lung, microangiographic measurements, pulmonary vascular morphogenesis

**LaViolette, Peter, Ph.D.**
MR imaging, cancer

**Liebenthal, Einat, Ph.D.**
Functional neuroimaging

**Marklin, Richard W., Ph.D.**
Ergonomics in office and industrial settings, human factors, cumulative trauma disorders

**Nagurka, Mark L., Ph.D., P.E.**
Biomechanics, vehicle dynamics and controls, and control system design

**Schmainda, Kathleen, Ph.D.**
MR imaging, cancer

**Terhune, Scott, Ph.D.**
Microbiology, molecular genetics

**Tugan Muftuler, Lutfi, Ph.D.**
MR imaging, neurosurgery

**Voglewede, Phillip A., Ph.D.**
Lower limb prostheses, dynamics, kinematics

# OPUS COLLEGE OF ENGINEERING

Since 1908, the Marquette University Opus College of Engineering has been uniquely blending professional engineering preparation with a liberal arts education to provide the world with well-balanced leaders in their profession.

## Our Mission

The mission of the College is to excel in four critical areas:

- To prepare all students for successful careers based on a strong moral and ethical foundation
- To advance the state-of-the-art in engineering
- To serve our professional and technical communities
- To contribute to our global society

The Opus College of Engineering offers six undergraduate degrees in eleven programs/majors through four departments: Biomedical Engineering; Civil & Environmental Engineering; Electrical and Computer Engineering; and Mechanical Engineering. Marquette also offers a wide range of graduate and doctoral programs.

## Accreditation

All undergraduate programs offered by the Marquette University Opus College of Engineering are accredited by the Engineering Accreditation Commission of ABET, 111 Market Place, Suite 1050, Baltimore, MD 21202-4012, 410-347-7700.

## The University

Founded in 1881 in Milwaukee, Wisconsin, Marquette University has been educating people of faith to be leaders in their professional lives, their communities and in society for more than 120 years.

Since the first graduating class of five men were awarded bachelor of arts degrees in the 1880s, Marquette has grown into a modern coed campus of more than 11,000 students who learn and grow through nationally admired undergraduate, graduate and professional programs.

MARQUETTE UNIVERSITY

**BE THE DIFFERENCE.**

Opus College of Engineering
Department of Biomedical Engineering
P.O. Box 1881
Milwaukee, WI 53201-1881

**www.marquette.edu/engineering/biomedical**

150/TFC/07-17