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ROCHESTER CENTER FOR BIOMEDICAL ULTRASOUND
Shear wave elastography is a method of measuring the stiffness of tissue using ultrasound. The shear wave speed is estimated from the particle velocity measured with respect to position and time. This estimation is demonstrated in a tissue mimicking phantom (left). Images may be created by repeating this estimation over a whole region of interest. Custom simulation software can be utilized to create simulated shear wave elasticity images (middle). This software approximates the propagation of shear waves through viscoelastic material (right).
MESSAGE FROM THE DIRECTORS

DIANE DALECKI, PH.D., DIRECTOR

This year’s annual report summarizes progress in research, education, and innovation from the RCBU. Recent scientific advances from RCBU laboratories across diverse topics in biomedical ultrasound imaging and therapy are included within this report. RCBU members continue to advance the development of novel elastography techniques for wide ranging applications, ultrasound technologies for tissue engineering and regenerative medicine, quantitative ultrasound tissue characterization, non-linear and contrast imaging, and new therapeutic applications of ultrasound. The RCBU continues to play a prominent role in clinical and technological advances in the use of ultrasound for diagnostic imaging and therapy. Nonlinear imaging techniques, sonoelastography, and ultrasound contrast agents all have foundations from innovations within RCBU laboratories. The UR is consistently rated as one of the best educational institutions in the nation for patent licensing and revenue.

A list of selected patents by RCBU members in diverse areas of biomedical ultrasound is included within this report. Collaborative projects between RCBU clinicians, engineers, and scientists continue to fuel new discoveries in diagnostic and therapeutic applications of ultrasound. Our student members are also an important component of the RCBU. The RCBU provides exciting opportunities for education and research training in biomedical ultrasound. A wide range of relevant course offerings complements the rich environment for collaborative multidisciplinary research in diverse areas of ultrasound. Included within this report are announcements of national awards and fellowships garnered by RCBU student members, highlights of student research, and educational advances by RCBU members. We welcome your comments on any of the enclosed.

DEBORAH J. RUBENS, M.D., ASSOCIATE DIRECTOR

Ultrasound continues to grow at the University of Rochester Medical Center, up 20% from 2011, now at 36,595 exams for Imaging Sciences in 2015. Our clinical enterprise now includes Strong West, and our patient sites at University Imaging at Science Park as well as at Penfield. Our affiliate hospitals, Highland Hospital, F.F. Thompson in Canandaigua, Auburn Hospital and Noyes Hospital in Dansville, are also running busy ultrasound programs, as is the Women’s Imaging site at Red Creek and our associates at University Medical Imaging. All together these combined facilities perform 74,883 ultrasound examinations/year.

On the national and international level, the year has been a busy one, with multiple faculty members lecturing and participating in varied ultrasound endeavors. Dr. Rubens was appointed to the Board of Trustees for the American Registry for Diagnostic Ultrasound (ARDI), which registers and certifies 30,000 imaging technologists in the United States including Ultrasound (US), Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Nuclear Medicine and Radiation Therapy. She will serve a four year term with the specific responsibility as liaison to Ultrasound. Dr. Susan Voci continued her roles as Councilor at the American College of Radiology (ACR) and member of the ACR Ultrasound Section for the Diagnostic Radiology resident annual examination. Dr. Rubens was an invited lecturer at Vanderbilt’s 39th Annual Diagnostic Sonography Symposium. Collectively, Drs. Bhatt, Dogra, Rubens, Sidhu and Voci presented multiple lectures, workshops, posters and papers at the Society of Abdominal Radiology, the American Institute of Ultrasound in Medicine, the American Roentgen Ray Society, the Society of Radiologists in Ultrasound and the Radiologic Society of North America. Internationally, Dr. Rubens lectured for the American Institute of Radiologic Pathology at the 13th Myanmar Radiological Society meeting. She also was a guest speaker at the Mexican Radiology and Imaging Society. Dr. Bhatt presented at the Annual Ultragain meeting in India and Dr. Dogra spoke in India, Mexico, Kenya, and China.

ABOUT THE RCBU

The Rochester Center for Biomedical Ultrasound (RCBU) was created at the University of Rochester to unite professionals in engineering, medical, and applied science communities at the University of Rochester, Rochester General Hospital, and the Rochester Institute of Technology. Since its founding in 1986, the RCBU has grown to nearly 100 members, with several visiting scientists from locations around the world. The Center provides a unique collaborative environment where researchers can join together to investigate the use of high frequency sound waves in medical diagnoses and therapy. The Center’s mission encompasses research, education, and innovation.

RESEARCH

RCBU laboratories are advancing the use of ultrasound in diagnosis and discovering new therapeutic applications of ultrasound in medicine and biology. The Center fosters collaborative research between laboratories and investigators with expertise in engineering, clinical medicine, and the basic sciences. It provides an ideal forum to exchange information through formal Center meetings and regular newsletters. Interactions of RCBU members with industry, governmental organizations, and foundations encourage mutually beneficial research programs.

EDUCATION

RCBU laboratories provide a rich environment for graduate training in biomedical ultrasound. Students have access to state-of-the-art research facilities to engage in leading-edge research in ultrasound. The University of Rochester offers graduate-level courses in biomedical ultrasound. RCBU laboratories provide opportunities for post-doctoral research in ultrasound and collaborations with other areas of biomedical engineering. The Center offers short courses in specialized topics in ultrasound that attract national and international experts.

INNOVATION

The RCBU maintains a long history of leadership and innovation in biomedical ultrasound. RCBU members hold numerous patents in ultrasound and imaging that can be found on pages 17 and 18 of this report. The University of Rochester is a leader in technology revenue among all higher education institutions in the nation. RCBU innovations have produced steady progress in new imaging modalities and therapeutic applications of ultrasound.
Visualizing principal strains of the common carotid artery using plane wave imaging

Rohit Nayak, MS, Stephen Huntzicker, PhD, Jacques Ohayon, PhD, Giovanni Schiffito MD, Marvin M. Doyley, PhD

Rupture of lipid-rich plaque in the carotid artery may lead to stroke—a leading cause of death and long-term disabilities. The rupture propensity of plaques is governed by the material properties of the plaque components. Recent work from the laboratory of Professor Marvin Doyley investigated the feasibility of using plane wave imaging to visualize principal strains in vascular tissues. Principal strains represent the largest strain component at any spatial location. Their hypothesis was that principal strain elastograms can detect the early onset of atherosclerosis.

To validate principal strain imaging, the team conducted simulations and studies in vivo. The simulation study was performed with homogeneous and heterogeneous finite element (FE) vessel models with inner and outer radii of 1.5 mm and 6 mm, respectively, and arterial wall stiffness of 45 kPa. The heterogeneous vessel contained an eccentric plaque with a soft lipid core and thin (350 µm) fibrous cap of stiffness 1 kPa and 700 kPa, respectively. The simulated ultrasound beam was equipped with a linear transducer array with 128 elements, each of size 0.2 mm x 4 mm (height), pitch of 0.03 mm, and center frequency of 5 MHz. The sound system was equipped with a linear transducer array (RP, Analogic, Canada) equipped with a 5-MHz, 128 element transducer array and a parallel data acquisition system (Ultra-sonix DAQ, Canada). Beamforming was performed off-line using the delay-and-sum technique. Displacement elastograms were computed by applying a 2D cross-correlation-based echo-tracking technique to the pre- and post-dilated RF echo frames. Principal strains were estimated by computing the eigenvalues of the full 2D strain tensor. Further, the elastographic contrast-to-noise ratio (CNR), signal-to-noise ratio (SNR), and root mean square error (RMSE) were computed to evaluate the quality and accuracy of the principal strain elastograms.

Figure 1(a) is a representative example of a principal strain elastogram obtained from a simulated homogeneous vessel. Figure 1(d) shows the corresponding circumferential strain elastogram, which demonstrates that in the absence of shear strain principal (major) and circumferential strains are equivalent—both were radially symmetric, and decayed inversely with increase in radial distance. In both cases, the CNR was approximately 16.2 ± 0.44 dB. Figure 1(b) is an example of a principal strain elastogram obtained from a heterogeneous vessel. The corresponding circumferential strain elastogram is shown in Figure 1(e). Principal strain elastograms revealed high strain within the plaque and the interface between the vessel wall and the fibrous cap, which was expected because the radial strain was dominated by shear strain. Figures 1(c) and 1(f) are principal and circumferential strain elastograms obtained from a healthy volunteer. The principal strain elastogram displays a radially symmetric strain distribution—as expected for a healthy, homogenous vessel (Fig. 1a); however, this was not apparent in the circumferential elastograms because in this case the principal strain elastograms were dominated by radial strains. The results from this preliminary study suggest that principal strain can improve the efficacy of non-invasive vascular elastography, and compounded plane wave imaging can produce clinically useful principal strain elastograms.

Using ultrasound to direct microvessel network formation and morphology

Eric Comeau, MS, Maria Helguera, PhD, Diane Dalecki, PhD, Denise C. Hocking, PhD

Engineering microvessel networks that structurally and functionally mimic native microvasculature is critical for the fabrication and survival of a wide range of bioengineered tissues. Recent collaborative efforts from the laboratories of Diane Dalecki and Denise Hocking have led to the development of a non-invasive ultrasound-based method to spatially pattern cells within 3D hydrogels, and the team has shown the feasibility of translating this technology to microvascular tissue engineering. Investigations by BME graduate student Eric Comeau have focused on determining how acoustic frequency and amplitude affect initial cell patterning and resulting microvessel network morphologies. In these studies, human umbilical ven endothelial cells (HUVECs) were suspended in soluble type I collagen, and solutions were exposed to ultrasound standing wave fields (USWFs) generated with acoustic sources of 0.5, 1, and 2 MHz. Samples were exposed for 15 min, during which time cell patterning and collagen polymerization occurred. High-frequency (38 MHz) ultrasound imaging was used to visualize initial cell patterns through the depth of 1-cm thick gels. Gels were also cultured for 10 days and images of microvessel networks obtained using light microscopy. Image analysis was used to quantify initial cell patterning and resulting microvessel morphology as a function of acoustic frequency and pressure. USWFs rapidly patterned cells into planar bands. High-frequency ultrasound was used to generate B-scan images of the full depths of USWFl-patterned hydrogels (Fig. 1 A, B). B-scan images were used to quantify distances between planar bands of cells and the density of cells within planar bands. Distance between planar bands of cells decreased with increasing acoustic frequency, and cell concentration within each planar band increased with increasing pressure amplitude. After 10 days, microvessel networks were present throughout the volume of USWF-patterned samples. The morphology of the resultant microvessel networks was influenced by acoustic parameters employed for the initial cell patterning (Fig. 1 C, D). Microvessel networks formed in response to patterning with 0.5-MHz USWFs formed capillary-like networks characterized by vessels less than 25 µm in diameter (Fig. 1D). In contrast, three different microvessel morphologies formed in response to 1-MHz USWF patterning. Capillary-like networks formed as a result of 0.1 MPa exposure to branching microvessels with diameters of 50-200 µm formed in response to 0.2 MPa exposure; and hierarchically-branching networks formed in response to 0.1 MPa exposure (Fig. 1C). Microvessel networks formed with 2-MHz USWFs were capillary-like for exposures at 0.05 MPa and branching networks at 0.1 MPa and 0.15 MPa. Sham-exposed samples underwent limited network formation. Investigations from the team have demonstrated that USWF-patterning of HUVECs leads to rapid formation of 3D microvessel networks within collagen hydrogels. The frequency and pressure amplitude of the USWF control both the initial cell patterning and the resulting microvessel network morphology. Furthermore, high-frequency ultrasound imaging provides a valuable tool to visualize and quantify 3D cell patterning throughout thick collagen gels.

Abdominal aortic aneurysm elasticity imaging

Michael S. Richards, PhD, Doran S. Mix, MD, Michael C. Stoner, MD, Steven W. Day, PhD, Camille C. Johnson, Ling Yang, BS, Nathan Couper, MS, Ben Zarras, BS

As part of a recently awarded NIH R21 grant, the laboratory of Professor Michael Richards is studying the mechanics of abdominal aortic aneurysms (AAA) and developing ultrasound elastography techniques to characterize AAA. The team has developed image registration algorithms to accurately measure accumulated, regional strains from ultrasound images of AAA cross-sections over an entire cardiac cycle. In addition, they have developed novel phantom fabrication techniques to validate and test their image processing methods in vitro. A clinical study, enrolling patients of the vascular surgery clinic with abdominal aneurysms, was also initiated in collaboration with Dr. Michael Stoner and Dr. Daran Mix in the Division of Vascular Surgery at the University of Rochester. This study seeks to use ultrasound images of aortas and elasticity image processing methods (Fig. 1, next page), along with non-invasive blood pressure measurements, to assess the condition or stability of aneurysms more accurately than a size metric alone. Currently, over 100 patients have been enrolled in the study and follow-up scans of approximately 15 patients have been obtained. Preliminary findings suggest that the presence of high overall pressure normalized strain and high regional differences in pressure normalized strain are indicative of aneurysms with a high growth rate, and that lower pressure

Figure 1. USWF-induced patterning and network formation. B-scan images of cells patterned at 1 MHz (A) and 0.5 MHz (B). Scale bar = 2 mm. C & D) Microscopy images of resultant microvessel networks formed from initial patterning in A and B, respectively. Scale bar = 150 µm.
Ultrasound non-invasively patterns microparticles in situ

Eric Comeau, MS, Carol H. Raeman, AAS, Denise C. Hocking, PhD, Diane Dalecki, PhD

Technologies that enable rapid patterning of cells and microorganisms within three-dimensional (3D) hydrogels are needed to advance the fabrication of complex engineered tissues. Ultrasound standing wave fields (USWFs) provide a non-invasive approach for patterning cells and/or microparticles rapidly. Furthermore, USWF-patterning of endothelial cells can accelerate microvessel network formation, and direct microvessel morphology within 3D hydrogel constructs (see related story on pages 5 and 6). Ultrasound propagates through tissue as a focused beam, and thus is ideal for translation in vivo. Recent efforts in the Dalecki and Hocking labs have been dedicated to developing a dual-transducer USWF system to enable rapid, non-invasive, volumetric patterning of cells and microparticles within hydrogels in situ. A dual-transducer system comprised of two, ultrasound sources was developed to generate an USWF in the region of intersecting sound fields (Fig. 1A). USWFs are characterized by pressure nodes and anti-nodes, and the distance between them is given by d = λ / [2sin(θ/2)] where λ is the wavelength of the incident sound field and θ the angle of incidence. Solutions of Sephadex particles spaced 840 ± 24 μm apart were simulated. Arrival time error and correlation coefficient between arrival time estimates and speckle position were most strongly determined by the sweep-receive pattern.

Ultrasound non-invasively patterns microparticles in situ

Ultrasound measurement of regional strain (%)

Figure 1. Ultrasound measurement of regional strain (%) accumulated between diastole to systole. A) 4.7 cm AAA with 1.0 cm/year growth. B) 4.7 cm AAA with 0.6 cm/year growth.

Ultrasound-induced pro-migratory effects on collagen

Emma Grygotis, BS, Diane Dalecki, PhD, Denise C. Hocking, PhD

Tissue engineered dermal replacement materials are a promising strategy for treating chronic wounds when conventional therapies fail. Currently, collagen is used widely in wound dressings and for skin substitutes. Although several such materials have been approved for clinical use, many rely on cell-mediated assembly of an extracellular matrix (ECM) scaffold, resulting in labor-intensive manufacturing and high costs. Advances from the laboratories of Denise Hocking and Diane Dalecki have demonstrated that exposing collagen to ultrasound during collagen gel polymerization influences collagen fiber length, diameter, alignment, and porosity of resultant hydrogels. Recently, this team has focused on understanding underlying mechanisms for the ability of ultrasound to produce pro-migratory collagen microstructures.

In a recent set of experiments, ice-cold solutions of 0.8 mg/mL type I rat tail collagen with 0.2% agarose were transferred to 6-well bioflex membrane plates for ultrasound exposures. Collagen gels were polymerized for 15 min in the...
observed on collagen gels fabricated with USWF at 10 and collagen to support cell migration. These effects were not sham gels consisted of dense, randomly oriented fibers, and radially-aligned collagen fibers that were further remodeled proportional to ISPTA. Rapid, directional cell migration was time points. Second harmonic generation (SHG) microscopy was used to visualize cell distribution 20 min and embryonic fibroblasts were seeded on the surface of collagen shams). Following polymerization, fibronectin-null mouse absence of ultrasound exposure (i.e. temperature control bath was used to replicate USWF-induced heating in the exposure condition were measured using thermocouples. In subsequent experiments, a temperature-controlled water bath was used to replicate USWF-induced heating in the absence of ultrasound exposure (i.e. temperature control shams). Following polymerization, fibronectin-null mouse embryonic fibroblasts were seeded on the surface of collagen gels and allowed to migrate for 24 h. Phase contrast microscopy was used to visualize cell distribution 20 min and 24 h post seeding, and cell migration was quantified as the difference in area of the cell-free regions between the two time points. Second harmonic generation (SHG) microscopy was used to visualize collagen microstructure prior to and 24 h after cell seeding, cells were visualized using intrinsic autofluorescence. The magnitude of ultrasound-induced heating was proportional to T exposure. Rapid, directional cell migration was observed on collagen gels fabricated with USWF at 10 and 20 W/cm², and was not observed on temperature-controlled sham gels or gels exposed to USWF at 30 W/cm². Collagen gels that supported cell migration were characterized by radially-aligned collagen fibers that were further remodeled by cells (Fig. 1A, arrow). In contrast, temperature-controlled sham gels consisted of dense, randomly oriented fibers, and contained smaller pores (Fig. 1B) than ultrasound-exposed gels. Exposure of soluble collagen to ultrasound during po- lymerization resulted in structural changes (increased fiber alignment and porosity) that correlated with the ability of collagen to support cell migration. These effects were not observed in temperature-controlled, sham gels. Future studies will investigate the contributions of mechanical effects of ultrasound on fiber alignment, pore size, and cell behavior in collagen hydrogels.

Analysis and visualization of microvessel networks in engineered tissues

Amy Becker, Eric Comeau, MS, Denise C. Hocking, PhD, Diane Dalecki, PhD, Maria Helguera, PhD

Professor Maria Helguera is developing new texturing analysis software tools to rapidly visualize and quantify structures within engineered tissues. These include a comparison of vessel length and size between controls and laser treated explants. The analysis results are consistent with previous studies that indicate the methods are capable of quantitatively characterizing morphological differences in microvessel network structures. Among the parameters for the GLCM analysis, it was shown that homogeneity and contrast were the two most indicative of vessel structure. Among the parameters for the GLRLM analysis, it was concluded that gray-level non-uniformity (GLNU) was best suited for characterizing texture. The algorithms can be implemented through a stand-alone graphical user interface to facilitate rapid analysis of large volumes of data, and provide 3D vessel network and image projection capabilities.

Shear wave dispersion in lean versus steatotic rat livers

Christopher T. Barry, MD, Christopher Hazard, PhD, Zaegyoo Hah, PhD, Gang Chen, PhD, Alexander Partin, PhD, Robert A. Mooney, PhD, Kuang-Hsiang Chuang, PhD, Wenjing Cao, PhD, Deborah J. Rubens, MD, Kevin J. Parker, PhD

The precise measurement of fat accumulation in the liver, or steatosis, is an important clinical goal. This RCU team’s previous studies in pigs and mouse livers support the hypothesis that, starting with a normal liver, increasing accumulations of microsteatosis and macrosteatosis will increase the lossy viscoelastic properties of shear waves in a medium. This increase results in an increased dispersion (or slope) of the shear wave speed in the steatotic liver. In a recent paper (JUM 34:1123-1129; 2015), the team moved to a larger animal model, investigated lean versus obese rat liver ex vivo, and employed a higher-frequency imaging system to estimate the shear wave speed from crawling waves. The results of their investigations showed elevated dispersion in obese rats and a separation of the lean versus obese liver parameters in a 2-dimensional parameter space of the dispersion (slope) and shear wave speed at a reference frequency of 150 Hz. The team has confirmed in 3 separate studies the validity of their dispersion hypothesis in animal models.

US strain mapping of the Achilles tendon

Michael S. Richards, PhD, Mark R. Buckley, PhD, Ruth L. Chimienti, PhD, Meghan Kelly, MD, A. Samuel Flemister, MD, John Katz, MD, Mary Bucklin, BS

The laboratories of Professor Michael Richards and Professor Mark Buckley are collaborating in ongoing investigations focused on improving our understanding of mechanical properties of tendon tissues and changes in tissue mechanical properties associated with diseases such as tendinopathy. One of the most frequent sites of tendon pathology is the Achilles, and pathologies that involve tendon insertion are termed insertional Achilles tendinopathy (IAT). Professor Buckley’s lab is dedicated to understanding the role of mechanics in the onset, progression, and treatment of several diseases, including those that affect tendon and cartilage, while Professor Richards’ lab is focused on developing and implementing new elastography techniques for clinical diagnoses. Together, the team is advancing new applications of ultrasound elastography to noninvasively image and measure tendon mechanical properties to provide clinicians with new diagnostic information.

The clinical portion of their work involves patients, previously diagnosed with IAT, who are undergoing therapy to improve the condition of the disease and prevent the need for more invasive treatments (i.e. surgery). To improve clinical outcomes for IAT patients, there is a need to develop new and effective conservative treatments for IAT, and the team hypothesizes that understanding the role of tendon compression will aid in the development of these therapies. In recent work, the team quantified tendon compression using ultrasound to examine the effects of heel lifts on tendon compression during dorsiflexion, and assessed the compensatory strain of the Achilles tendon in individuals with IAT during dorsiflexion compared to healthy subjects. Regional strains within and around the Achilles tendon were measured during exercise in patients with and without IAT (Fig. 1A). Preliminary findings suggest that IAT tendons experience lower compression due to biomechanical stiffening induced within the tendon, that may be transferred to compression in the surrounding tissues thereby causing pain during dorsiflexion.

Remotely accessible microscope

Megan LaFratzi, BS, Rose Rustowicz, BS, Maria Helguera, PhD

Professor Maria Helguera and undergraduate students in her laboratory have designed and built a portable, low cost, WiFi accessible microscope (20x to 200x) that fits inside an incubator for microscopic cell visualization in real time. The system is based on a Raspberry Pi microcomputer and can hold two cell culture plates for simultaneous scanning and time-lapse studies. The system can be adapted to perform 2D or 3D scans, still images or video, gray scale or color. The system facilitates remote microscopic visualization, minimizes manipulation and removal of samples from an incubator, and decreases risk of contamination.

Control and image processing software have been created in Python. The control graphical user interface (GUI) provides an image of the cell culture plates on which the user selects the desired well position by click of the mouse. Motors move the microscope/camera unit to the desired position while a window displays the field of view. Fine position adjustments can be done using the arrows in the keyboard. The GUI also controls the illumination system, mounted on the microscope/camera unit. Image processing algorithms to enhance, segment and count cells are available through another GUI. Other quantitative analyses protocols may include gray-scale textural and volumetric analyses, cell tracking, etc. The system is easily customized for different applications. This project won both the 2014-2015 CS Faculty Award Celebrat- ing Excellence, and the 2015 UNYTE-Hitting the Accelerator.
Crawling waves speed estimation and the dominant component analysis paradigm

Renan Rojas, MS, EE, Juvenal Ormachea, MS, Arthur Salo, MS, Paul Rodrigues, PhD, Kevin J. Parker, PhD, Benjamin Castaneda, PhD

A novel method for estimating the shear wave speed from crawling waves based on the amplitude modulation frequency. The method is compared with the traditional method of examining the channel of the maximum modulus and approaches and approximation methods. Experimental results on phantoms with different compositions and operating frequencies show coherent speed estimates and accurate inclusion locations.

ElasticityLab: A GPU-accelerated simulation tool for ARFI-based viscoelastic shear wave elastography

Jonathan H. Langdon, PhD, Stephen A. McAleavey, PhD

Development and validation of imaging techniques requires testing with targets of known properties, as in phantoms and resolution test objects. Viscoelastic phantoms for ultrasound elastography are challenging to fabricate and limited in general purpose computing on graphics cards (GPU), which is impractical and risky, however, to biopsy every lesion that may be found in a computed tomography (CT) scan. To mitigate this risk, longitudinal scans are collected to determine the growth rates of individual lesions in order to determine if they are consistent with growth rates of known types of malignancies. Maria Helguera, Ph.D., in collaboration with Kitware, Inc and the University of North Carolina, is advancing new imaging process and registration techniques to quantify longitudinal lung nodule deformations. Ground glass opacity (GGO) is especially difficult to analyze, as they feature a variety of non-solid components that may be influenced by lung deformation. Compensating for background lung deformation across longitudinal scans (via image registration) is vital to enable accurate estimation of lesion growth rate. Recent work from the Helguera lab tested four clinical cases and demonstrated that registration over a region of interest (ROI) centered around the lesion yielded lower target registration errors (TRE) than registration over the entire lung. In 3 of 4 cases for lesion ROIs, the median TRE was less than 1 mm. Registration based on lesion ROIs had better performance in 3 of 4 cases, suggesting that a limited ROI enables registration algorithms to converge to the correct global minimum. It was found that affine registration outperformed rigid registration in all four cases, both when lung and lesion ROIs were used.
Experimental evaluations of the microchannel flow model
Kevin J. Parker, PhD
Recent advances have enabled a new wave of biomechanics measurements, and have renewed interest in selecting appropriate rheological models for soft tissues such as the liver, thyroid, and prostate. The microchannel flow model was recently introduced to describe the linear response of tissue to stimuli such as stress relaxation or shear wave propagation. This model postulates a power law relaxation spectrum that results from a branching distribution of vessels and channels in normal and soft tissue such as liver. In a recent article by Professor Kevin Parker (Phys Med Biol 60(1):4227-4242, 2015), the derivation is extended to determine the explicit link between the distribution of vessels and the relaxation spectrum. In addition, liver tissue is modulated by temperature and salinity, and the resulting changes in tissue responses (by factors of 1.5 or greater) are reasonably predicted from the microchannel flow model, simply by considering the changes in fluid flow through the modified samples. The 2-4 parameter versions of the model were considered, and shown that in some cases the maximum time constant (corresponding to the minimum vessel diameters), could be altered in a way that has major impact on the observed tissue response. This could explain why an inflamed region is palpat-ed as harder compared to surrounding normal tissue.

Obstetrics & Gynecology Ultrasound Unit
Loralei L. Thornburg, MD
The UR OB/GYN Ultrasound Unit provides clinical services at multiple sites including Strong Memorial Hospital (SMH), Highland Hospital (HH), and FF Thompson Hospital (FFT).

The physicians of the UR OB/GYN Ultrasound Unit also provide ultrasound interpretation services at Rochester General Hospital (RGH), Newark Wayne Hospital (NWH), FF Thompson Hospital and Nicholas Noyes Hospital (new this year) utilizing a combination of telemedicine and onsite services.

The total number of examinations in 2015 from Strong Memorial Hospital sites (SMH, SMH, FFT, Noyes) included 11,057 abdominal and 3086 vaginal obstetric scans, and 2424 abdominal and 2148 vaginal gynecologic scans. Invasive procedures performed included 94 genetic amniocenteses for karyotype or lung maturity, 48 chorionic villus samplings, 68 sonohysterograms, 40 OR guidance for minor gynecologic procedures, and 38 invasive pregnancy procedures including intrauterine shunt insertions, transfusions, pleurocenteses and other fetal procedures. Additionally, 5011 obstetric and 1,878 gynecologic scans were completed at RGH/NWH.

The unit has 16 ultrasound machines within SMH and HH hospitals, all with 3D and 4D capability, plus additional portable scanners. There are 17 sonographers at HH and SMH, all of whom are CLEAR certified, and 5 of whom are fetal echocardiography certified. SMH remains an active member of NAFNET (North American Fetal Therapy Network). Some examples of recent research projects are provided below.

Prediction of macromosia newborn from ultrasound biometry and maternal characteristics
L Gray, MD, M Mongelli, MB, BS, DM, LL Thornburg, MD, LM Mack, RDMF, MPH, JC Glantz, MD MPH, EK Pressman, MD, TO Ozcan, MD

The objective of this work was to predict macromosia >4000 g from ultrasound biometry and maternal characteristics taken before delivery. The dataset included all term vaginal deliveries from 2004-2013 at a single U.S. institution with an ultrasound ≤ 4 weeks from delivery. Maternal characteristics included age, weight, height, prepregnancy body mass index (BMI), weight gain, and parity. Femur length (FL), placental area, biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), and chest circumference (CC), estimated fetal weight (EFW), gender, and birth weight were included. EFW, biometry measurements, and ratios including HC/FL, AC/FL, AC/FL, and AC/FL were used in the model. EFW was included in the model to improve the prediction of macromosia newborns.
The latest collaborative research by Diane Dalecki (BME) and Denise Hocking (Pharmacology and Physiology) was recognized with the Best Paper Award at the Micro- and Nanotechnology Sensors, Systems, and Applications Conference of the SPIE Defense + Security Symposium held in Baltimore MD in April 2015. Their invited paper, titled “Guiding tissue regeneration with ultrasound in vitro and in vivo” detailed three biomedical ultrasound technologies under development in their laboratories to stimulate tissue formation and regeneration. Co-authors of the paper included RCBU members Sally Child and Carol Raemen, and BME graduate students Eric Comeau and Laura Hobbs. These ultrasound technologies offer new solutions to key challenges currently facing the fields of tissue engineering, biomaterials fabrication, and regenerative medicine.

Jonathan Langdon was awarded First Place in the Best Student Paper Competition at the Bioacoustics Acoustics Section at the 169th Meeting of the Acoustical Society of America held in Pittsburgh PA in May 2015. Jonathan was recognized for his presentation titled “Compensating for Scholte waves in single tracking location shear wave elasticity imaging,” with co-authors Karla Mercado, Diane Dalecki, and Stephen McAleavey. Jonathan is an MD/PhD trainee in the laboratory of Professor McAleavey.

Emma Grygotis was awarded the Outstanding Presentation Award at the Therapeutic Ultrasound Winter School held at Ecole de Physique des Houches in Les Houches France in March 2015. Emma presented an overview of her studies focused on developing ultrasound technologies to fabricate bioactive collagen hydrogels for wound repair. Emma is a Ph.D. candidate in the Department of Pharmacology and Physiology, and her research is supervised by Professor Denise Hocking and Professor Diane Dalecki.

Sohit Nayak was awarded the Best Graduate Student Poster at the University of Rochester Center for AIDS Research World AIDS Day Symposium in December 2015. Rohit is a Ph.D. candidate in Electrical and Computer Engineering working in the laboratory of Professor Marvin Doyley. Rohit was recognized for his presentation titled “Visualizing principal strains of the carotid artery using plane wave imaging.” Co-authors were Marvin Doyley (ECE), Rifat Ahmed (ECE), Prashant Verma (Physics & Astronomy), Nancy Carson (Imaging Sciences), Vikram Dogra (Imaging Sciences), Meera Singh (Microbiology & Immunology), Sanjay Maggiwar (Microbiology & Immunology), and Giovanni Schifitto (Neurology).

Emma Grygotis was awarded the Outstanding Presentation Award at the Therapeutic Ultrasound Winter School held at Ecole de Physique des Houches in Les Houches France in March 2015. Emma presented an overview of her studies focused on developing ultrasound technologies to fabricate bioactive collagen hydrogels for wound repair. Emma is a Ph.D. candidate in the Department of Pharmacology and Physiology, and her research is supervised by Professor Denise Hocking and Professor Diane Dalecki.
The University of Rochester has a long-standing tradition of being at the forefront of innovation and scientific research. In 2015, 151 invention disclosures were received from 253 inventors from 56 University departments and divisions. Fifty-eight external collaborators from 31 institutions, agencies, and corporations were also named as inventors. Eight copyright registrations and 241 patent applications were filed in FY 2015. Of the patent filings, 76 were new matter filings, while 165 were continuations of applications filed in previous years. In FY 2015, the UR was granted 53 U.S. patents and 21 foreign patents. These 74 patents cover 61 different technologies. In FY 2015, the UR also executed 24 new license and options agreements and monitored 120 active agreements.

The University of Rochester is one of only eight universities nationwide to rank in the top 20 each year over the last decade in licensing revenue. The University of Rochester is consistently rated as one of the best educational institutions in the nation for patent licensing and revenue, according to the Association for University Technology Managers (AUTM). The AUTM U.S. Licensing Activity Survey is an annual report of the technology transfer activity of top universities, research institutions, and teaching hospitals across the nation. The technological advances of members of the Rochester Center for Biomedical Ultrasound continue to contribute to the UR’s success.

New Patents Issued for RCBU Member Inventions

The patent titled “Chimeric Fibronectin Matrix Mimetics and Uses Thereof” (US 9,072,706) has recently been assigned to the UR with inventors Denise C. Hocking, Ph.D. and Daniel Roy, Ph.D. The patent relates to a series of recombinant fibronectin peptide mimetics developed to promote wound repair. The technology falls under a new and exciting class of therapies known as wound biologics. The primary commercial application for this technology is to promote the healing of chronic wounds, including diabetic, venous, and pressure ulcers, which impose a significant health care burden worldwide.

Professor Thomas Foster and colleagues were inventors on a new patent assigned to the UR titled “Photodynamic Therapy with Spatially Resolved Dual Spectroscopic Monitoring” (US 9,044,140). This patent describes an apparatus and method to determine photodynamic therapy dosimetry in real-time in vivo.

U.S. PATENTS

Chimeric Fibronectin Matrix Mimetics and Uses Thereof
U.S. Patent No. 9,072,706
Denise C. Hocking and Daniel Roy
July 7, 2015

Photodynamic Therapy with Spatially Resolved Dual Spectroscopic Monitoring, U.S. Patent No. 9,044,140
Thomas H. Foster, et al.
June 2, 2015

Methods and Systems for Spatially Modulated Ultrasound Radiation Force Imaging, U.S. Patent No. 8,753,277
Stephen McAlavey
June 17, 2014

Vikram S. Dogra and Navalgund Rao
2013

Sonoelastographic Shear Velocity Imaging using Crawling Wave Excitation, U.S. Patent No. 8,267,865
Kenneth Hoyt and Kevin J. Parker
September 18, 2012

Statistical Estimation of Ultrasonic Propagation Parameters for Aberration Correction, U.S. Patent No. 7,867,166
Robert C. Waag and Jeffrey P. Astheimer
January 11, 2011

Ultrasonic Imaging of Tissue Stiffness by Spatially Modulated Acoustic Radiation Force Impulse (SM-ARFI), U.S. Patent No. 8,225,666
Stephen McAlavey
May 9, 2008

Zhe Wu and Kevin J. Parker
November 4, 2008

Method of Treating Neurodegenerative Disease Using Ultrasound, U.S. Patent No. 7,211,054
Charles W. Francis and Valentina Suchkova
May 1, 2007

Finite Amplitude Distortion-Based Inhomogeneous Pulse Echo Ultrasonic Imaging, U.S. Patent No. 7,104,956
Ted Christopher
September 12, 2006

Ultrasonic Distortion Compensation using Blind System Identification, U.S. Patent No. 6,699,189
Feng Lin and Robert C. Waag
March 2, 2004

System and Method for 4D Reconstruction and Visualization, U.S. Patent No. 6,169,817
Kevin J. Parker, Saara Totteman, Jose Tamez-Pena
January 2, 2001

System for Model-Based Compression of Speckle Images, U.S. Patent No. 5,734,754
Kevin J. Parker
March 31, 1998

Thin-Film Phantoms and Phantom Systems, U.S. Patent No. 5,756,875
Daniel B. Phillips and Kevin J. Parker
May 26, 1998

Smart Endotracheal Tube, U.S. Patent No. 5,785,051
Jack Motley and Randy Lipscher
July 29, 1998

Kevin J. Parker and Theophano Mitsa

Michael R. Violante and Kevin J. Parker

Multiple Function Infant Monitor, U.S. Patent No. 5,479,932
Joseph Higgins, E. Carr Everbach, Kevin J. Parker
January 2, 1996

Butterfly Search Technique, U.S. Patent No. 5,419,331
S. Kaisar Alam and Kevin J. Parker
May 30, 1995

The RCBU is continually advancing novel concepts in ultrasound technology. For more information, visit the UR Ventures website at www.rochester.edu/ventures/
RCBU FUNDING NEWS & NEW APPOINTMENTS

Mark Buckley has been promoted to Professor of Radiology in Medicine and Biology. He has been elected as the new Chair of the Department of Radiology in Medicine and Biology. Professor Buckley joined the RCBU and the Department of Biomedical Engineering at the University of Rochester in 2015.

Denise C. Hocking has been promoted to Professor of Pharmacology and Physiology, and of Biomedical Engineering at the University of Rochester. Professor Hocking’s research lab is dedicated to understanding mechanisms by which extracellular matrix proteins affect cell and tissue functions that are critical for wound repair. Areas of focus in her lab include developing novel ultrasound technologies for tissue engineering, and therapeutic approaches to promote tissue regeneration in chronic wounds.

Robert C. Waag Retires after 45-Year Career in Biomedical Ultrasound Research

Robert C. Waag, the Arthur Gould Yates Professor of Engineering, professor of electrical and computer engineering, and professor of imaging sciences, retired on June 30, 2015.

Born in Pennsylvania, Professor Waag attended Cornell University, where he received BEE and MS degrees in electrical engineering and a PhD degree in communications engineering in 1963, 1965, and 1969, respectively. After being awarded his doctoral degree, he served as an officer in the United States Air Force.

In 1969, Professor Waag joined the faculty at the University of Rochester as assistant professor of electrical engineering. His academic career continued here with a joint appointment in the Department of Radiology in 1973 and promotions to associate professor in 1975, professor in 1985, and the Arthur Gould Yates Professor of Engineering in 1994. During his early years at Rochester, Professor Waag was introduced to the field of ultrasonic imaging, which was to be the major field of his academic work for decades to come.

For more than 45 years, Professor Waag worked at the leading edge of biomedical ultrasound research. For more than 45 years, Professor Waag worked at the leading edge of biomedical ultrasound research. He has been a leader in the development of new technologies for tissue characterization, wave propagation in inhomogeneous tissue, and aberration correction for imaging. He has authored or coauthored many publications in premier peer-reviewed archival journals in the ultrasound field, Cardiac Ultrasound, Clinical Ultrasound, and Journal of Ultrasound in Medicine. He has served on editorial boards of the Journal of Clinical Ultrasound, Journal of Ultrasound in Medicine, Journal of Ultrasound in Medicine and Biology, and IEEE Transactions on Biomedical Engineering. In 1997, he coedited, with Raymond Gramiak, the seminal textbook, Diagnostic Ultrasound in Medicine, which is currently in its third edition.

Through his work, he made seminal contributions to the field and is a member of many professional organizations. He is a fellow of the Acoustical Society of America, the Institute of Electrical and Electronics Engineers, and the American Institute of Ultrasound in Medicine. He is also a member of the Sigma Xi, Tau Beta Pi, Phi Kappa Phi, and Sigma Xi.

Professor Waag served on the editorial boards of the Journal of Clinical Ultrasound, Journal of Ultrasound in Medicine, Journal of Ultrasound in Medicine and Biology, and IEEE Transactions on Biomedical Engineering. In 1973, he coedited, with Raymond Gramiak, the seminal textbook, Diagnostic Ultrasound in Medicine, which is currently in its third edition.

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ME seniors gain real-world experience with solving biomedical engineering problems through the two-semester Senior Design course taught by RCBU member Amy Lerner and Scott Sedman. In the 2015-2016 academic year, one team of seniors embarked on a project to develop techniques to monitor sonographer position and posture during typical ultrasound imaging procedures. The senior design team consisted of BME students Mary Bucklin, Gregory Palis, Megan Routzong, and Yanwen Zhai. In the 2014-2015 academic year, another senior design team undertook a project to develop an ultrasound-based technique to detect dental cracks in teeth. RCBU Director Diane Dalecki supervised these projects.

The UR Biomedical Engineering Department was ranked 16th on the Graduate Programs Fall 2015 Rankings of Top Biomedical Engineering Graduate Programs. This list highlights the best graduate programs in the country in a variety of disciplines based solely on the ratings and reviews from current or recent graduate students posted on graduateprograms.com. The rankings encompass reviews posted by more than 75,000 students participating in over 1,600 graduate programs nationwide.

SUMMER ACOUSTICS COURSE

David Blackstock again offered his popular summer acoustic course at the UR for students with wide-ranging interests in acoustics and biomedical ultrasound. Dr. Blackstock, from the University of Texas at Austin, is a long-standing RCBU member. He is an expert in acoustics and author of leading textbooks in physical acoustics and nonlinear acoustics. For over 20 years, this course has provided a unique opportunity for RCBU students to learn from one of the world’s leading experts in acoustics.

UR RANKED AMONG BEST BME GRADUATE PROGRAMS ACCORDING TO STUDENT REVIEWS

David Narrow, an alumnus of the University of Rochester Biomedical Engineering program (2012) and co-founder and CEO of Sonovex, was named one of Forbes’s Magazine’s “30 under 30” entrepreneurs in the health care industry in 2015. Sonovex has developed its EchoSure system to facilitate ultrasound monitoring of clot formation in arteries or veins after reconstructive, transplant, or vascular surgery procedures. The EchoSure system combines a bioabsorbable polymeric implant (EchoMark) placed underneath at-risk blood vessels at the time of surgery, and ultrasound software (EchoFind) to quantify blood flow within the target vessels. Blood flow information provided by the EchoSure system assists in early clot detection. Narrow also runs MonoMano Cycling, a company that makes bikes suited for stroke survivors, amputees and others with disabilities.

Steven Huntzicker received his Ph.D. in Electrical and Computer Engineering from the University of Rochester. His thesis, titled “Quantitative Vascular Elastography: Stiffness and Stress Estimation for Identifying Rupture-Prone Plaques,” was supervised by Professor Marvin Doyley.

Jonathan Langdon received his Ph.D. in Biomedical Engineering from the University of Rochester. His thesis, titled “Development of Single Track Location Shear Wave Viscoelasticity Imaging for Real-Time Characterization of Biological Tissues,” was supervised by Professor Stephen McAlevey.

Alex Partin received his Ph.D. in Electrical and Computer Engineering from the University of Rochester. His thesis, titled “Shear Wave Imaging and Tissue Characterization using Vibration Elastographic Techniques,” was supervised by Professor Kevin Parker.

Alexander Bensch received his M.S. in Computer Engineering from the Rochester Institute of Technology. His thesis, titled “Toward Real-Time Video-Enhanced Augmented Reality for Medical Visualization and Simulation,” was supervised by Professor Cristian Linte.

Ying-Ju Chu received her M.S. in Biomedical Engineering from the University of Rochester. Her thesis, titled “Development of Crawling Wave Optical Coherence Elastography,” was co-supervised by Professor Kevin Parker and Professor Jannick Rolland.

Aditya Daryanani received his M.S. in Computer Engineering from the Rochester Institute of Technology. His thesis, titled “Left Ventricles Myocardium Segmentation from 3D Cardiac MR Images using Combined Probabilistic Atlas and Graph Cut-based Approaches,” was supervised by Professor Cristian Linte.

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Sonovex CEO
Biomedical Ultrasound  
(BME 451) Presents the physical basis for the use of high-frequency sound in medicine. Topics include acoustic properties of tissue, sound propagation (both linear and nonlinear) in tissues, interaction of ultrasound with gas bodies (acoustic cavitation and contrast agents), thermal and non-thermal biological effects, ultrasonography, dosimetry, hyperthermia, and lithotripsy.

Ultrasound Imaging  
(BME 452) Investigates the imaging techniques applied in state-of-the-art ultrasound imaging and their theoretical bases. Topics include linear acoustic systems, spatial impulse responses, the k-space formulation, methods of acoustic field calculation, dynamic focusing and apodization, scattering, the statistics of acoustic speckle, speckle correlation, compounding techniques, phase aberration, velocity estimation, and flow imaging.

Medical Imaging - Theory & Implementation  
(ECE 452) Provides an introduction to the principles of X-ray, CT, PET, MRI, and ultrasound imaging. The emphasis is on providing linear models of each modality, which allows linear systems and Fourier transform techniques to be applied to analysis problems.

Fundamentals of Acoustical Waves  
(ECE 432) Introduces acoustical waves. Topics include acoustic wave equation; plane, spherical, and cylindrical wave propagation; reflection and transmission at boundaries; normal modes; absorption and dispersion; radiation from points, spheres, cylinders, pistons, and arrays; diffraction; and nonlinear acoustics.

Digital Image Processing  

Viscoelasticity in Biological Tissues  
(BME 412) Viscoelastic materials have the capacity to both store and dissipate energy. As a result, properly describing their mechanical behavior lies outside the scope of both solid mechanics and fluid mechanics. This course will develop constitutive relations and strategies for solving boundary value problems in linear viscoelastic materials. In addition, the closely-related biphasic theory for fluid-filled porous solids will be introduced. An emphasis will be placed on applications to cartilage, tendon, ligament, muscle, blood vessels, and other biological tissues. Advanced topics including non-linear viscoelasticity, composite viscoelasticity and physical mechanisms of viscoelasticity will be surveyed.

Biosolid Mechanics  
(BME 483) This course examines the application of engineering mechanics to biological tissues, including bone, soft tissue, cell membranes, and muscle. Other topics include realistic modeling of biological structures, including musculoskeletal joints and tissues, investigations of the responses of biological tissues to mechanical factors, and experimental methods and material models.

Elasticity  
(ME 449) Presents an analysis of stress and strain, equilibrium, compatibility, elastic stress-strain relations, and material symmetries. Additional topics include torsion and bending of bars, plane stress and plane strain, stress functions, applications to half-plane and half-space problems, wedges, notches, and 3D problems via potentials.

Biomedical Optics  
(BME 492) Introduces the major diagnostic methods in biomedical optics. The course emphasizes spectroscopy (absorption, fluorescence, Raman, elastic scattering), photon migration techniques (steady-state and time-resolved), and high-resolution subsurface imaging (confocal, multi-photon, optical coherence tomography). Essential methods of multivariate data analysis are taught in the context of spectroscopy.

Applied Vibration Analysis  
(ME 443) Vibrations of both discrete (one, two, and many degrees of freedom systems) and continuous (strings, beams, membranes, and plates) will be studied. Focus is on free and forced vibration of undamped and damped structures. Analytical, numerical, and experimental methods will be covered. Approximate methods (Rayleigh, Rayleigh-Ritz) for obtaining natural frequencies and mode shapes will also be introduced.

Nonlinear Finite Element Analysis  
(BME 487) The theory and application of nonlinear FE methods in solid and structural mechanics, and biomechanics. Topics: review and generalization of linear FE concepts; review of solid mechanics, nonlinear incremental analysis, FE formulations for large displacements and large strains, nonlinear constitutive relations, incompressibility and contact conditions, hyperelastic materials, damage plasticity formulation, solution methods, explicit dynamic formulation.

Computational Methods  
(ECE 492) Covers computational techniques for the solution of numerical problems with applications of the techniques in acoustic and electromagnetic wave propagation and scattering.

Eric Comeau was the recipient of an American Heart Association Pre-Doctoral Fellowship. This prestigious two-year fellowship will support Eric’s research focused on developing new ultrasound-based technologies for cell patterning and microvesSEL network formation within three-dimensional, engineered tissue constructs. Eric is a Ph.D. candidate in the Department of Biomedical Engineering, and his research is co-mentored by Professor Cristian Linte and Professor Denise Dalecki.

Tristan Ford was the recipient of a Xerox Undergraduate Research Fellowship. Tristan is a BME undergraduate student working in the laboratory of Professor Diane Dalecki on a project focused on acoustic streaming. The Xerox Undergraduate Fellowship is a highly selective program that provides research experience for undergraduates during the summer and continuing through the academic year.

Alexander Dawson-Elli received an SPIE Medical Imaging Undergraduate Student Fellowship from the International Society of Optics and Photonics–SPIE Medical Imaging Symposium. Alexander’s research was supervised by Professor Cristian Linte.


Comeau ES, Hocking DC, Dalecki D. Designing ultrasound fields to control the morphology of engineered microvascular networks. 169th Meeting of the Acoustical Society of America, Pittsburgh, PA, May 2015.

Comeau ES, Vander Horst M, Raeman CH, Hocking DC, Dalecki D. Using acoustic fields to pattern cells or microparticles in collagen hydrogels in situ. Annual Meeting of the Biomedical Engineering Society, Tampa, FL, October 2015.


Gray L, Mongelli M, Thornburg LL, Mack L, Glantz JC, Pressman EK, Ozcan TO. Prediction of macrosomic newborn from ultrasound biometry and maternal characteristics. ISOUG, October 2015.

Gray L, Mongelli M, Thornburg LL, Mack L, Glantz JC, Pressman EK, Ozcan TO. Prediction of small for gestational age (SGA) newborn from ultrasound biometry and maternal characteristics. ISOUG, October 2015.


Hocking DC, Dalecki D. Ultrasound technologies for the fabrication of artificial microvascular networks. 44th Annual Symposium of the Ultrasonic Industry Association, Washington, DC, April 2015.


Langdon J, Osapoetra L, Ford T, Elegee E, McAlavey S. Comparison and analysis of multiple tracking location and single tracking location shear wave elasticity imaging in a rat model of liver fibrosis. BMES Annual Meeting, Tampa, FL, October 2015.


McAlavey SA, Langdon JH. Simulation of shear wave elasticity imaging including speckle and refraction effects. 170th Meeting of the Acoustical Society of America, Jacksonville, FL, November 2015.


Parker KJ. What do we know about shear wave dispersion in normal and steatotic livers? American Institute of Ultrasound in Medicine Annual Convention, Orlando, FL, March 2015.

## Graduate Training Opportunities at the RCBU

The Rochester Center for Biomedical Ultrasound (RCBU) provides exciting opportunities for graduate and post-graduate research and training in the field of biomedical ultrasound. Research at the RCBU spans a wide range of topics in diagnostic imaging and therapeutic applications of ultrasound. With access to RCBU laboratories at the University of Rochester’s River Campus, Hajim School of Engineering and Applied Sciences, UR Medical Center, and Rochester Institute of Technology, students can tailor their own interdisciplinary training experiences.

Students can pursue advanced degrees (M.S. and Ph.D.) through various departments of engineering and basic science with a research focus in biomedical ultrasound. A wide range of relevant course offerings complement the rich research environment. Students tailor their formal coursework individually to complement their research focus and meet requirements of their home department.

The RCBU has a long history of innovation in biomedical ultrasound. Research of student members of the RCBU has led to numerous patents in ultrasound imaging and therapy.

Students have access to state-of-the-art research facilities to engage in leading-edge research in ultrasound. Core facilities in the new Goergen Hall include an ultrasound teaching laboratory, imaging and bioinstrumentation equipment, cell and tissue culture facilities, and biomedical microscopy equipment, and mechanical testing apparatus. For more information, contact Diane Dalecki at ddalecki@ur.rochester.edu.

### University of Rochester

**Anesthesiology**
- Paul Bogenes, M.D.
- Janine Shapiro, M.D.
- David Stern, M.D.
- Jack Wojtczak, M.D.

**Biomedical Engineering**
- Mark Buckley, Ph.D.
- Sally Child, M.S.
- Ruth Chimenti, Ph.D.
- Eric Comeau, M.S.
- Diane Dalecki, Ph.D.
- Jonathan Langdon, Ph.D.
- Amy Lerner, Ph.D.
- Stephen McAleavey, Ph.D.
- Renato Perucchio, Ph.D.
- Zhe Wu, Ph.D.

**Cardiology Unit**
- James Eichelberger, M.D.

**Center for Vaccine Biology & Immunology**
- Mitra Azadniv, Ph.D.

**Center for Imaging Sciences**
- Thomas Foster, Ph.D.
- Nina Kioletsosky, M.D.
- Deborah Rubens, M.D.
- John Strang, M.D.

**Dermatology**
- Alice Pentland, M.D.

**Earth & Environmental Sciences**
- Asish Basu, Ph.D.

**Electrical & Computer Engineering**
- Rifat Ahmed, M.S.
- Edwin Carstensen, Ph.D.
- Yong Thung Cho, Ph.D.
- Aaref ElOUS, Ph.D.
- Andrew Hesford, Ph.D.
- Steven Huntzicker, Ph.D.

**Engineering Sciences**
- Asish Basu, Ph.D.

**Emergency Medicine**
- Jefferson Sengsouk, M.D.

**Imaging Sciences**
- Mark James Adams, M.D.
- Shweta Bhatt, M.D.
- Vikram Dogra, M.D.
- Nina Kioletsosky, M.D.
- Susan Voci, M.D.

**Immunology/Rheumatology**
- Ralf Thiele, M.D.

**Mechanical Engineering**
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- Alfred Clark, Jr., Ph.D.
- Sheryl Gracweiz, Ph.D.
- Renato Perucchio, Ph.D.

**Obstetrics & Gynecology**
- Morton Miller, Ph.D.
- Richard Miller, M.D.
- Tulin Ozcan, M.D.

**Pathology**
- P. Anthony di Sant’Agnese, M.D.

**Pharmacology & Physiology**
- Emma Grygotis, B.S.
- Denise Hocking, Ph.D.

**Radiation Oncology**
- Paul Okunieff, M.D.

**Surgery**
- Christopher Barry, M.D.
- Michael Richards, Ph.D.

**Urology**
- Robert Davis, M.D.
- Erald Ertuk, M.D.
- Irwin Frank, M.D.
- Jean Joseph, M.D.
- Robert Mayer, M.D.

**Vascular Medicine**
- Charles Francis, M.D.

### Rochester General Hospital

**Radiology**
- Robert Lerner, M.D., Ph.D.

### Rochester Institute of Technology

**Biomedical Engineering**
- Stephen Burns, Ph.D.
- Alfred Clark, Jr., Ph.D.
- Sheryl Gracweiz, Ph.D.
- Renato Perucchio, Ph.D.

**Biophysics/Biochemistry**
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- Robert Mayer, M.D.

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- Charles Francis, M.D.

### Visiting Scientists

- Daniel Phillips, Ph.D.
- Cristian Linte, Ph.D.

### Research Areas

- Lithotripsy
- Acoustic cavitation
- Harmonic imaging
- Nonlinear acoustics
- Diagnostic imaging
- Doppler ultrasound
- Tissue characterization
- High-frequency imaging
- Ultrasound contrast agents
- 3D and 4D ultrasound imaging
- Acoustic radiation force imaging
- Novel therapeutic applications
- Multi-modal imaging techniques
- Biological effects of ultrasound fields
- Sonomicroscopy and elasticity imaging
- Acoustic scattering and wave propagation in tissue
- High intensity focused ultrasound (HIFU) techniques
- Ultrasound technologies for cell & tissue engineering