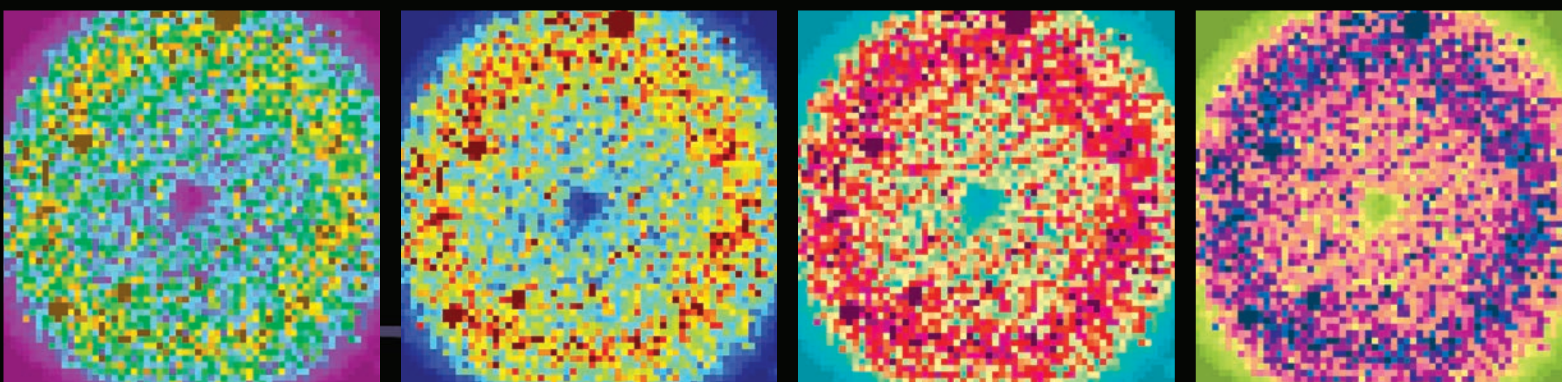


RCBU

Rochester Center for Biomedical Ultrasound

2014 | Annual Report

RCBU
Rochester Center for Biomedical Ultrasound

Layout and Design
Heather Deal

Rochester Center for Biomedical Ultrasound
University of Rochester
311 Goergen Hall, PO Box 270168
Rochester, New York 14627

(585) 275-9542
rcbu@seas.rochester.edu
www.urmc.rochester.edu/rcbu

On the cover: High-frequency, quantitative ultrasound images of the integrated backscatter coefficient from cell-embedded engineered tissue constructs (see related stories on pages 7 & 12).

TABLE OF CONTENTS

MEET THE DIRECTORS

Diane Dalecki, Ph.D., Director

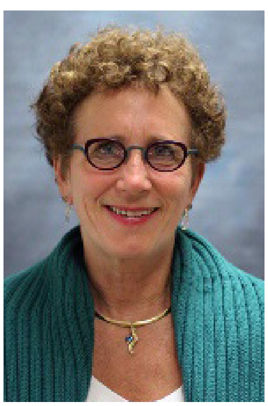
This year's annual report summarizes progress in research, education, and innovation from the RCBU. Recent scientific advances from RCBU laboratories across diverse topics in biomedical ultrasound imaging and therapy are included within this report. RCBU members continue to advance the development of novel elastography techniques, nonlinear and contrast imaging, quantitative ultrasound tissue characterization, and new therapeutic applications of ultrasound.

This year, Kevin Parker, PhD (Dean Emeritus of the School of Engineering and Applied Sciences, and Past-Director of the RCBU) was awarded the Eastman Medal, one of the University's most prestigious awards. The Eastman Medal recognizes individuals whose achievements and service embody the University's highest ideals. Dr. Parker and his former graduate student, Theophano Mitsa, PhD, were awarded Eastman Medals for their Blue Noise Mask invention.

On a more reflective note, the RCBU and the broader ultrasound community recently lost one of its most important pioneers, Floyd Dunn. Floyd was a Charter Honorary Member of the RCBU and colleague of many RCBU members. His body of scientific work provides foundation for our understanding of the propagation of ultrasound in tissues and biological effects 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. This year, RCBU members were inventors on two new patents assigned to the University of Rochester (UR). Stephen McAleavey, PhD was the inventor of a novel ultrasound elastography technique, and Vikram Dogra, MD and Navalgund Rao, PhD were inventors of a new, low-cost photoacoustic imaging approach. The UR is consistently rated as one of the best educational institutions in the nation for patent licensing and revenue, and a list of selected patents by RCBU members 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.

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 research. 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 reports.



Deborah J. Rubens, M.D., Associate Director

Ultrasound continues to grow at the University of Rochester Medical Center, up 20% from 2011, now at 29,700 exams for Imaging Sciences in 2014. Our clinical enterprise now includes Strong West and outpatient sites at University Imaging at Science Park as well as at Penfield. Our affiliate hospitals, Highland Hospital and F.F. Thompson in Canandaigua 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 65,796 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. Susan Voci was appointed the Medical Director of the Diagnostic Medical Sonography Program at RIT in addition to her roles as Councilor at the American College of Radiology (ACR) and member of the ACR Ultrasound Section for the diagnostic Radiology In-training examination. Dr. Rubens represented the UR elastography research team in a two day consensus conference on liver elasticity sponsored by the Society of Radiologists in Ultrasound. 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 Asia Pacific Congress of Cardiovascular and Interventional Radiology in Singapore. Dr. Bhatt presented at the Ruta del Sol Radiology meeting in Mexico, Dr. Sidhu lectured in India and Dr. Dogra spoke in Dubai, Israel, India and Turkey in addition to examining radiology trainees for the Aga Khan University in Kenya.

Dr. Dogra is investigating photoacoustic imaging of the prostate and the thyroid, and Dr. Rubens continues her collaboration with Professor Kevin Parker and General Electric on liver elasticity and steatosis. New collaborations underway involve investigations of carotid elastography with Drs. Marvin Doyley and Giovanni Schiffito.

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 over the years to nearly 100 members, with several visiting scientists from locations around the world.

THE RCBU MISSION

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.

The RCBU 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 and closely related fields.

RCBU laboratories offer opportunities for post-doctoral research in ultrasound and collaborations with other areas of biomedical engineering.

Throughout its history, the RCBU has offered 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. The University of Rochester is a leader in technology revenue income among all higher education institutions in the nation.

RCBU innovations have produced steady progress in new imaging modalities and therapeutic applications of ultrasound.

2014 RESEARCH

Research laboratories of RCBU members are advancing the use of ultrasound for diagnosis and therapy. The following pages highlight research accomplishments in 2014. Selected publications and presentations can be found on pages 25-28.

Acoustic patterning for microvascular tissue engineering

Diane Dalecki,PhD, Denise C. Hocking, PhD, Eric Comeau, MS, and Sally Z. Child, MS

Creating artificial microvessel networks that structurally and functionally mimic native microvasculature is critical for the fabrication and survival of a wide range of bioengineered tissues. Engineered microvascular constructs would also provide realistic cost-effective in vitro models for drug discovery, product testing and toxicology screening.

The Dalecki and Hocking labs have developed an innovative, non-invasive ultrasound-based method to spatially pattern cells within 3D hydrogels, and have demonstrated the feasibility of translating this ultrasound technology to microvascular tissue engineering. The research team has shown that acoustic radiation forces associated with ultrasound standing wave fields (USWF) can rapidly organize a variety of cell types into distinct multicellular planar bands within 3D collagen hydrogels. USWF-induced patterning of endothelial cells rapidly initiates the assembly of complex, branching vessel networks throughout the volume of the hydrogel. Importantly, the morphology of the resultant microvessel networks can be controlled by design of the acoustic field employed during fabrication. Specifically, by tuning the acoustic intensity and/or frequency employed for the initial spatial patterning of endothelial cells, the technology can produce microvascular networks having two distinct, physiologically relevant morphologies; one composed of a tortuous, capillary-like network (Figure 1, left), and one composed of hierarchical branching vessels (arteriole/venule-like) (Figure 1, right).

Recent efforts from the Hocking and Dalecki labs have focused on optimizing acoustic exposure parameters to control microvessel morphology, and producing multilayered composite constructs with complex, physiologically-relevant vascular morphologies. Non-invasive ultrasound-based technologies that can rapidly organize endothelial cells into distinct geometric patterns and initiate rapid, volumetric microvascular network development are expected to provide new clinical tools for a variety of tissue engineering and regenerative medicine applications.

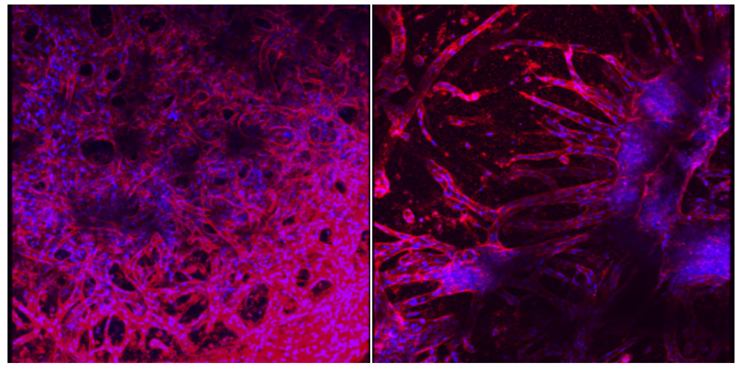


Figure 1. Complex microvessel network morphologies created within 3D engineered tissues using USWFs. Multiphoton microscopy images show vascular network morphology (red, vessel walls; blue, cell nuclei) as either dense and tortuous (left) or hierarchical branching (right) microvessels.

Shear wave arrival time estimates correlate with local speckle pattern

Stephen McAleavey, PhD, Jonathan Langdon, MS, Laurentius Osapoetra, MS

Quantitative Shear Wave Elastography (SWE) techniques estimate the velocity of shear waves by tracking tissue motion at one or more locations with ultrasound beams of width comparable to the dimensions of the shear wave. The displacements involved in Acoustic Radiation Force Impulse (ARFI) SWE are small, with associated high echo correlation. Yet shear wave arrival time estimates are known to be noisy even at high echo SNR. The McAleavey lab hypothesized that the observed arrival time variations are largely due to the underlying speckle pattern, and call the effect speckle bias.

A simulation study was performed modeling imaging of both diffuse and point targets subject to shear wave motion. A 5.3 MHz linear array with transmit apertures of f/2-8 and receive apertures of f/2-4 was modeled, with a range of shear wave amplitudes (5-20 μm) and profiles simulated. The local speckle pattern was determined through swept-receive-aperture imaging of the transmit beam (Figure 1, next page).

Arrival time bias was found to be strongly correlated (r = 0.7) with the location of the lateral peak of the swept-receive speckle pattern (Figure 2). The results suggest that high RF echo correlation does not equate to an accurate shear wave arrival time estimate, and that RF echo correlation is weakly related to arrival time accuracy. The variation in shear wave arrival time bias at a given location over the range of shear wave amplitudes considered is an order of magnitude smaller than the variation with different speckle realizations obtained along a given tracking vector.

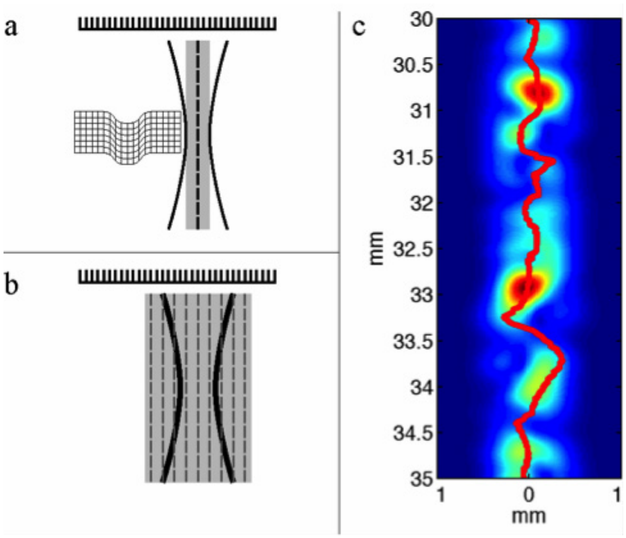


Figure 1. Tracking of shear wave displacements is depicted in (a), with the transmit beam profile is indicated by the solid arcs, while dashed line indicates the axis of the dynamically focused receive beam, and the gray region the finite width of the beam. In swept-receive imaging (b), the transmit beam remains stationary, while the receive aperture is translated over the region of interest. The estimated shear wave arrival time for this speckle realization, scaled by the shear wave speed, is plotted over the swept receive image in (c).

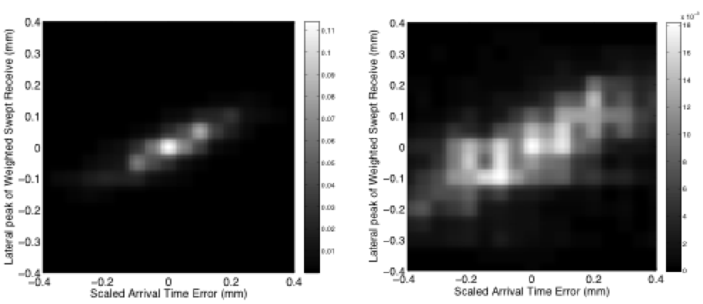


Fig 2. Representative two-dimensional histograms of speckle lateral peak location and TTP scaled by shear wave speed, for Tx f/3, Rx f/2 (left), and Tx f/8, Rx f/4 (right).

Quantitative sparse array vascular elastography: the impact of tissue attenuation and modulus contrast on performance

Steve Huntzicker, MS, Rohit Nayak, MS, Marvin M. Doyley, PhD

Quantitative sparse array vascular elastography visualizes the shear modulus distribution within vascular tissues, information that clinicians could use to reduce the number of strokes each year. However, the low transmit power sparse array (SA) imaging could hamper the clinical usefulness of the resulting elastograms.

In a recent study, the Doyley lab evaluated the performance of modulus elastograms recovered from simulated and physical vessel phantoms with varying attenuation coefficients (0.6, 1.5, and 3.5 cm^{-1}) and modulus contrasts (−12.04, −6.02, and −2.5 dB) using SA imaging relative to those obtained with conventional linear array (CLA) and plane-wave (PW) imaging techniques. Plaques were visible in all modulus elastograms, but those produced using SA and PW contained less artifacts. The modulus contrast-to-noise ratio decreased rapidly with increasing modulus contrast and attenuation coefficient, but more quickly when SA imaging was performed than for CLA or PW. The errors incurred varied from 10.9% to 24% (CLA), 1.8% to 12% (SA), and ~4% (PW). Modulus elastograms produced with SA and PW imaging were not significantly different ($p > 0.05$). Despite the low transmit power, SA imaging can produce useful modulus elastograms in superficial organs, such as the carotid artery.

Gaussian shear wave in a dispersive medium

Kevin J. Parker, PhD, Natalie Baddour, PhD

A number of approaches analyze shear wave propagation initiated by a short radiation force push in order to generate images of the biomechanical properties of tissues. Unfortunately, it has been experimentally observed that the displacement-versus-time curves for lossy tissues are rapidly damped and distorted in ways that can confound simple tracking approaches.

A recent article by Kevin Parker, PhD (UMB 40:675-684; 2014) addresses the propagation, decay and distortion of pulses in lossy and dispersive media, to derive closed-form analytic expressions for the propagating pulses. The theory identifies key terms that drive the distortion and broadening of the pulse. Furthermore, the approach taken is not dependent on any particular viscoelastic model of tissue, but instead takes a general first-order approach to dispersion. Examples with a Gaussian beam pattern and realistic dispersion parameters are given along with general guidelines for identifying the features of the distorting wave that are the most compact.

Quantitative ultrasound imaging of collagen microstructure

Karla P. Mercado, PhD, Maria Helguera, PhD, Denise C. Hocking, PhD, Diane Dalecki, PhD

Collagen-based biomaterials are widely investigated as scaffolds for tissue engineering and regenerative medicine applications. The physical and biological properties of fibrillar collagens are strongly tied to variations in collagen fiber microstructure. Structural properties of collagen scaffolds can influence cell behaviors key to tissue regeneration, including cell migration, differentiation, and proliferation. Thus, the development of non-destructive, quantitative technologies capable of visualizing spatial differences in collagen fiber microstructure under various fabrication conditions will provide critical tools to facilitate the development of functional engineered tissues. The goal of a recent collaborative project among RCBU members was to develop the use of high-frequency quantitative ultrasound to assess collagen microstructure within three-dimensional (3-D) hydrogels noninvasively and nondestructively.

The integrated backscatter coefficient (IBC) was employed as a quantitative ultrasound parameter to detect, image, and quantify spatial variations in collagen fiber density and diameter. Collagen fiber microstructure was varied by fabricating hydrogels with different collagen concentrations or polymerization temperatures. IBC values were computed from measurements of the backscattered radio-frequency (RF) ultrasound signals collected using a single-element transducer (38-MHz center frequency, 13–47 MHz bandwidth). The IBC increased linearly with increasing collagen concentration and decreasing polymerization temperature. Parametric 3-D images of the IBC were generated to visualize and quantify regional variations in collagen microstructure throughout the volume of hydrogels fabricated in standard tissue culture plates (Figure 1, top). IBC parametric images of corresponding cell-embedded collagen gels showed cell accumulation within regions having elevated collagen IBC values (Figure 1, bottom). Furthermore, the technique provided quantitative visualization of collagen microstructure throughout the entire volume of collagen hydrogels that were on the order of 1-cm thick. The capability of this ultrasound technique to noninvasively detect and quantify spatial differences in collagen microstructure offers a valuable tool to monitor the structural properties of collagen scaffolds during fabrication, to detect functional differences in collagen microstructure, and to guide fundamental research on the interactions of cells and collagen matrices.

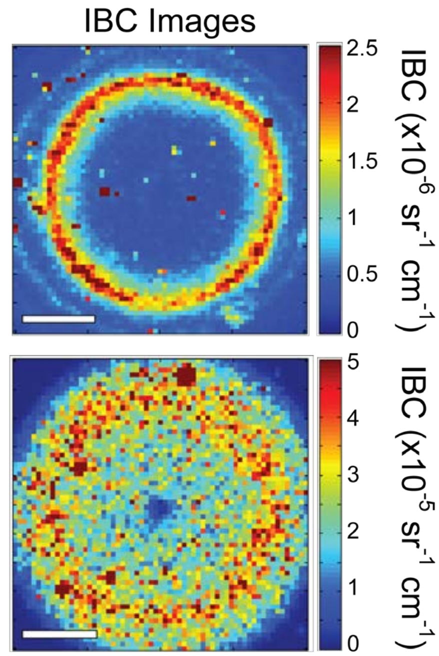


Figure 1. IBC parametric images of collagen hydrogels fabricated in the absence (top) and presence (bottom) of cells. Regional variations in collagen microstructure are evident in acellular gels (top). Cell-embedded gels (bottom) showed cell accumulation within regions having elevated collagen IBC values. Scale bar = 5 mm.

Multi-element synthetic aperture vascular elastography for carotid imaging

Rohit Nayak, MS, Marvin M. Doyley, PhD

Plaque rupture may trigger myocardial or cerebral infarctions. Synthetic aperture vascular elastography (SAVE) can be employed to visualize the strain distribution within vascular tissues with high precision. However, there are concerns that the low transmit power of SAVE will degrade clinical utility. Recent work from the Doyley lab hypothesized that increasing the number of transmission elements would overcome this limitation. More specifically, they proposed to use parabolic defocussing delays to produce a virtual source with a spherical beam pattern.

To test this hypothesis, simulation studies were performed on two groups of vessels with attenuation coefficients of (a) 0 dB/cm/MHz (to represent the ideal case, where power is not a limiting factor) and (b) 1.5 dB/cm/MHz (at diagnostic level of attenuation). The simulated vessels had inner radius of 1.5 mm, outer radius of 6 mm, elastic modulus of 45 kPa, and a Poisson's ratio of 0.495. The inner vessel wall was subjected to an intra-luminal pressure of 5 mm of Hg. A linear array was simulated with 128 elements, each with size of 0.2 mm (width) x 4 mm (height), pitch of 0.03 mm, and center frequency of 5 MHz. Sparse array imaging was performed by transmitting an acoustic signal from 16 groups of elements (subaperture) sequentially. The transmit subapertures were uniformly distributed over the entire aperture of the transducer. The size of the subaperture was varied from 1 to 21 elements. For all cases, the virtual source was placed 1 mm behind the transducer. The delay- and-sum technique was used to beamform the RF echo frames. Displacement elastograms were computed by applying a 2D cross-correlation-based echo-tracking technique to the pre- and post-dilated RF echo frames. The elastographic signal to noise ratio (SNRe) and the root mean square error (RMSE) were used to evaluate the quality of the strain elastograms. The RMSE metric was normalized over the full range of applied strain.

For both radial and circumferential strain elastograms, SNRe improved with increased subaperture size up to 7 elements, and then degraded with further increase. In the RMSE, the smallest error occurred for transmit with 7 elements. For the non-attenuating vessel, the peak SNRe (radial strain) of SAVE (1 element) and multi-element SAVE (7 elements) were comparable. For 1.5 dB/cm/MHz attenuation, the peak SNRe (radial strain) of SAVE and multi-element SAVE (mSAVE) reduced to 7.33 dB and 11.41 dB, respectively. Similarly, for the non-attenuating vessels, the peak RMSE (radial strain) of SAVE and mSAVE were 13.4% and 13%, respectively. On increasing attenuation to 1.5 dB/cm/MHz, the peak RMSE (radial strain) for SAVE and mSAVE increased to 32.58% and 17.70%, respectively.

These results suggest that mSAVE can produce useful strain elastograms at diagnostic levels of attenuation. These simulation results encourage further development of the proposed technique. Future work will involve ex vivo study using excised carotid artery, and subsequent in vivo validation on human subjects.

Quantifying the passive stretching response of human tibialis anterior muscle using shear wave elastography

Terry K. Koo, PhD, Jing-Yi Guo, PhD, Jeffrey H. Cohen, DC, Kevin J. Parker, PhD

Quantifying passive stretching responses of individual muscles helps the diagnosis of muscle disorders and aids the evaluation of surgical/rehabilitation treatments. Utilizing an animal model, the Parker lab demonstrated that shear elastic modulus measured by supersonic shear wave elastography increases linearly with passive muscle force. A recent study aimed to use this state-of-the-art technology to study the relationship between shear elastic modulus and ankle dorsi–plantarflexion angle of resting tibialis anterior muscles and extract physiologically meaningful parameters from the elasticity–angle curve to better quantify passive stretching responses.

Elasticity measurements were made at resting tibialis anterior of 20 healthy subjects with the ankle positioned from 50° plantarflexion to up to 15° dorsiflexion at every 5° for two cycles. Elasticity–angle data were curve-fitted by optimizing slack angle, slack elasticity, and rate of increase in elasticity within a piecewise exponential model. Elasticity–angle data of all subjects were well fitted by the piecewise exponential model with coefficients of determination ranging between 0.973 and 0.995. Mean (SD) of slack angle, slack elasticity, and rate of increase in elasticity were 10.9° (6.3°), 5.8 (1.9) kPa, and 0.0347 (0.0082) respectively. Intraclass correlation coefficients of each parameter were 0.852, 0.942, and 0.936 respectively, indicating excellent test–retest reliability.

This study demonstrated the feasibility of using supersonic shear wave elastography to quantify passive stretching characteristics of individual muscle and provided preliminary normative values of slack angle, slack elasticity, and rate of increase in elasticity for human tibialis anterior muscles. Future studies will investigate diagnostic values of these parameters in clinical applications.

Experimental demonstration of reduced variance shear wave speed estimation using single-tracking-location ARFI shear wave elastography

Stephen McAleavey, PhD, Jonathan Langdon, MS, Laurentius Osapoetra, MS

Acoustic Radiation Force Impulse (ARFI) based shear wave elastography imaging (SWEI) methods use ARFI to generate shear waves and ultrasonic tracking methods to monitor tissue motion and estimate shear wave speed (SWS). Most methods excite a shear wave at a single spatial location and estimate its speed by measuring its arrival time at multiple tracking locations (MTL). The flexibility of electronic beamforming allows a "dual" method, wherein tissue motion is observed at a single tracking location (STL) and the arrival times of shear waves from sources of known location are used to estimate the SWS. The McAleavey lab has previously shown that ultrasound speckle can be a significant source of variance in estimation of shear wave velocity and shear modulus.

Professor McAleavey and his team have recently completed a comparison of STL and MTL shear wave elastography in uniform and point-target phantoms (Figures 1 & 2). These new results demonstrate that speckle noise can manifest itself as noise in ARFI-SWEI derived shear wave speed images, and that STL ARFI SWEI greatly reduces noise in the shear wave speed estimates associated with speckle, up to a factor of 5 for the range of beam spacings considered (Figure 3). The STL method also avoids artifacts due to isolated bright targets (Figure 2). Suppression of speckle noise without the need for spatial averaging can enable higher resolution shear wave speed imaging for a given ultrasound imaging frequency, potentially leading to improved diagnostic capability.

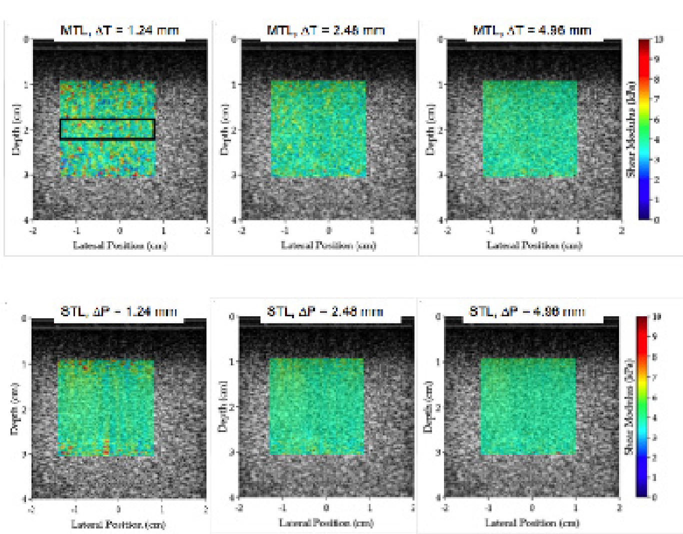


Figure 1. Representative images of the uniform gelatin phantom using MTL (top row) and STL (bottom row). The transducer was kept in the same position for all six images so that the speckle realization is identical in each. Lateral spacing of the tracking (MTL) or push (STL) beams was 1.24 mm (left column), 2.48 mm (center column), and 4.96 mm (right column). No median or other spatial filtering was applied to the estimated values.

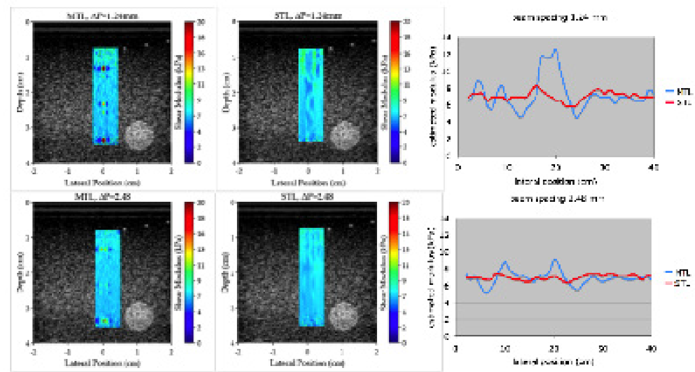


Figure 2. Matched STL and MTL images of nylon monofilaments in a region of otherwise uniform shear modulus in the CIRS 049GSE phantom. In the top row, a lateral spacing of 1.24 mm for tracking (MTL) or push (STL) beams, while a 2.48 mm separation was used in the bottom row. The left column presents the MTL images, with the characteristic artifact visible at the location of each three wires. Matched STL images of the same region do not exhibit the same artifact and are comparatively uniform. Estimated modulus values obtained along a lateral cross section through the central wire are plotted in the right column, with the MTL data exhibiting the characteristic bias. In the 1.24 mm case the tracking beam separation is sufficiently close that the estimate does not return to the baseline value, but the overestimation peaks merge into a single peak.

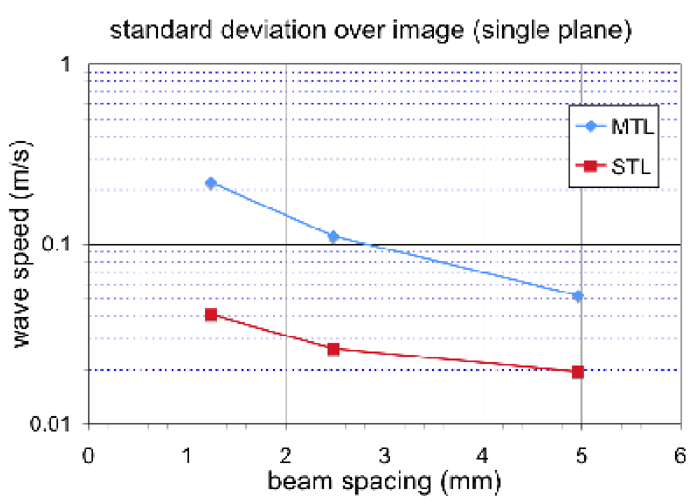


Figure 3. Standard deviation as a function of beam spacing of the pixel-by-pixel shear wave speed estimates within the region denoted by the black rectangle in Figure 1. The greater image uniformity of the STL images in Figure 1 for a given beam spacing are reflected in the correspondingly lower standard deviations.

Elasticity estimates from images of crawling waves generated by miniature surface sources

Alexander Partin, MS, Zaegyoo Hah, PhD, Christopher T. Barry, MD, Deborah J. Rubens, MD, Kevin J. Parker, PhD

A team of RCBU researchers led by Professor Kevin Parker recently investigated a surface-based approach to generate shear wave interference patterns, called crawling waves (CrW), within a medium and derive local estimates of biomechanical properties of tissue.

In previous experiments, elongated bars operating as vibration sources were used to generate CrW propagation in samples. In the present study, however, a pair of miniature circular vibration sources was applied to the overlying skin to generate the CrW within the medium. The shape and position of the miniature sources make this configuration more applicable for in vivo implementation. A modified ultrasound imaging system was used to display the CrW propagation. A shear speed mapping algorithm was developed using a detailed analysis of the CrW. The setup was applied to several biomaterials including a homogeneous phantom, an inhomogeneous phantom and an ex vivo human liver. The data were analyzed using the mapping algorithm to reveal the biomechanical properties of the biomaterials.

Nonlinear intravascular ultrasound contrast imaging with a modified clinical system

Himanshu Shekhar, PhD, Ivy Awuor, BS, Sahar Hashemgeloogerdi, MS, Marvin M. Doyley, PhD

An intravascular ultrasound system capable of visualizing microbubble contrast agents could provide functional information for assessing atherosclerotic plaques. The goal of a recent study from the Doyley lab was to investigate the feasibility of contrast-enhanced imaging with a modified commercial intravascular ultrasound system. An iLab™ system (Boston Scientific/Scimed, Natick, MA) equipped with an Atlantis™ PV imaging catheter (15-MHz center frequency, 26% fractional bandwidth) was employed to image tissue mimicking phantoms that had contrast agent (Targestar-P®, Targeson Inc., CA) flowing inside channels parallel to the center lumen. Chirp-coded pulses were employed with transmit frequency of 12 MHz and peak pressures ranging from 1–2 MPa. The ultraharmonic response (18 MHz) was isolated from the backscattered radiofrequency using pulse inversion and matched filtering to produce contrast specific images. The detection sensitivity of the agent was evaluated as a function of microbubble concentration and transmit pulse parameters. Example images are shown in Figure 1. The results revealed that side channels with diameters ranging from 500 μm to 2 mm could be visualized for a wide range of concentrations.

These results demonstrate that functional imaging of plaque neovascularization is feasible with commercially available intravascular catheters. Further development of such systems can facilitate the widespread use of contrast-enhanced intravascular ultrasound for preclinical research and clinical imaging.

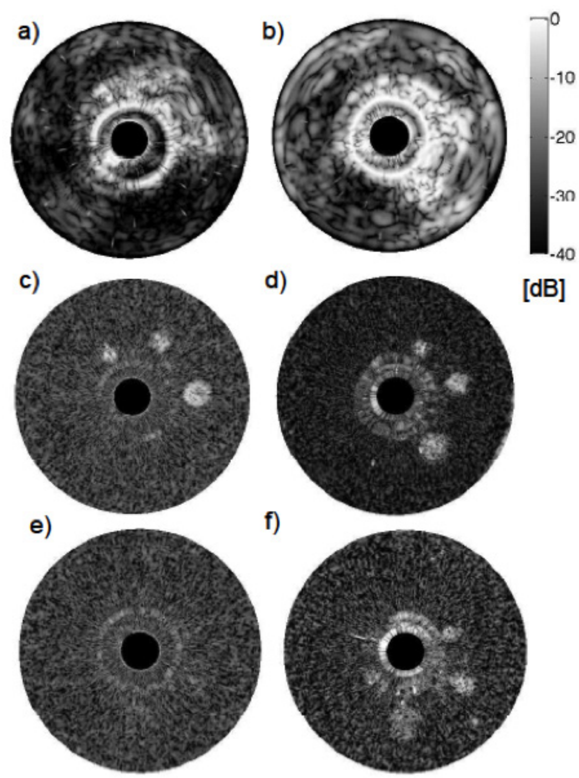


Figure 1. Fundamental and nonlinear contrast-enhanced intravascular ultrasound (CE-IVUS) images acquired with a phantom at 1:1000 agent concentration. (a) 18 MHz fundamental; (b) 12 MHz fundamental; (c) subharmonic image corresponding to 18 MHz fundamental; (d) ultraharmonic image corresponding to 12 MHz fundamental; (e) Subharmonic and (f) ultraharmonic image acquired at an agent concentration of 1:16,000, respectively.

Synthetic aperture elastography: a GPU based approach

Prashant Verma, MS, Marvin M. Doyley, PhD

Synthetic aperture (SA) ultrasound imaging systems produce highly accurate axial and lateral displacement estimates; however, low frame rates and large data volumes can hamper its clinical use. Recent efforts in the Doyley lab investigated a real-time SA imaging based ultrasound elastography system recently developed to overcome this limitation.

In this system, both beamforming and 2D cross-correlation echo tracking were implemented on Nvidia GTX 480 graphics processing unit (GPU). One thread per pixel for beamforming was used, whereas one block per pixel was used for echo tracking. The quality of elastograms computed with the real-time system was compared relative to those computed using a standard single threaded elastographic imaging methodology.

In all studies, conventional measures of image quality were used such as elastographic signal to noise ratio (SNRe). Specifically, SNRe of axial and lateral strain elastograms computed with the real-time system were 36 dB and 23 dB, respectively, which was numerically-equal to those computed with the standard approach. A frame rate of 6 frames per second was achieved using the GPU based approach for 16 transmits and kernel size of 60 × 60 pixels, which was 400 times faster than that achieved using the standard protocol.

Delayed onset of subharmonic and ultraharmonic emissions from microbubble contrast agents

Himanshu Shekhar, PhD, Ivy Awuor, BS, Keri Thomas, PhD, Joshua Rychak, PhD, Marvin M. Doyley PhD

Characterizing the non-linear response of microbubble contrast agents is important for their efficacious use in imaging and therapy. In recent work from the Doyley lab (UMB 40:727-738;2014), the team reported that the subharmonic and ultraharmonic response of lipid-shelled microbubble contrast agents exhibits a strong temporal dependence. Non-linear emissions from Targestar-p microbubbles (Targeson Inc., San Diego, CA, USA) were characterized periodically for 60 min, at 10 MHz excitation frequency. The results revealed a considerable increase in the subharmonic and ultraharmonic response (nearly 12-15 and 5-8 dB) after 5-10 min of agent preparation. However, the fundamental and the harmonic response remained almost unchanged in this period. During the next 50 min, the subharmonic, fundamental, ultraharmonic, and harmonic responses decreased steadily by 2-5 dB. The temporal changes in the non-linear behavior of the agent appeared to be primarily mediated by gas-exchange through the microbubble shell; temperature and prior acoustic excitation based mechanisms were ruled out. Further, there was no measurable change in the agent size distribution by static diffusion.

These findings will help obtain reproducible measurements from agent characterization, non-linear imaging, and fluid-pressure sensing. The results also suggest the possibility for improving non-linear imaging by careful design of ultrasound contrast agents.

Measurement of blood flow velocity in vivo video sequences with motion estimation methods

María Helguera, PhD, Yansong Liu, MS, Angela Glading, PhD

During her appointment as the Wedd Visiting Professor in Pharmacology and Physiology (see related story on page 20), Maria Helguera, PhD developed a new collaboration with Angela Glading, PhD. Dr. Glading, an Assistant Professor in the UR Department of Pharmacology and Physiology, is an expert in endothelial cell biology with a research focus on angiogenesis and the microvascular in normal and diseased tissues. Measurement of blood flow velocity using in vivo microscopy video is an approach to study microcirculation systems in the Glading lab. Dr. Helguera, and her student Yansong Liu, applied their expertise in image/video processing to analyze blood flow direction in the microvasculature with this video technique. The video sequences investigated in this project utilize a CCD camera with frame rate of 30 frames/s. The team compared current optical flow algorithms (OF) and particle image velocimetry (PIV) techniques based on cross-correlation by testing them with simulated vessel images and in vivo microscopy video sequences. The estimated results from different in vivo video sequences were influenced by several factors such as the width of the vessels, vascular structures, and noise. The accuracy was evaluated by applying OF and PIV to simulated vessel image sequences and calculating the mean square root based on ground truth. The issue of erroneous motion generated by microscopy video noise was addressed. A temporal post-processing scheme was employed to reduce erroneous vectors in the velocity field. By incorporating the iterative PIV algorithm with optical flow method, a dense velocity field can be obtained. Subsequently, a new approach of adaptive window cross-correlation (AWCC) method was proposed for overcoming the drawbacks of using fixed interrogation window (Figure 1). This work demonstrated that both optical flow and PIV techniques using cross-correlation have their limitations when determining motion vector field in complicated vessel structures. Optical flow provides smoother vector fields in thicker vessels, while cross-correlation is more robust to noise but suffers from the fixed size of the interrogation window. However, the performance of the cross-correlation method was superior to optical flow in relatively thinner vessels.

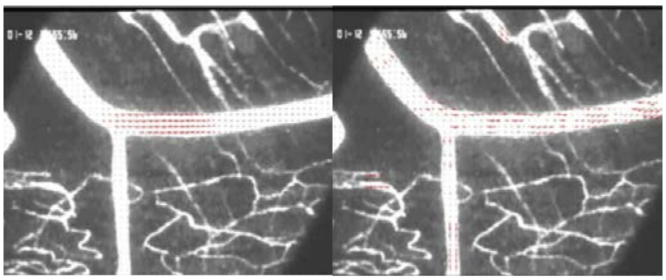


Figure 1. Comparison of vector maps of 15 averaged frames for OF (left) and AWCC (right). Note that OF does not detect flow in smaller vessels.

Estimating cell concentration in engineered tissue constructs using high frequency ultrasound

Karla P. Mercado, PhD, Maria Helguera, PhD, Denise C. Hocking, PhD, Diane Dalecki, PhD

Monitoring the structural and biological properties of engineered tissue constructs during fabrication is critical for the development of functional engineered tissues. Histology and biochemical assays are standard techniques for estimating cell concentration in engineered tissues. However, these techniques are destructive and cannot be used for longitudinal monitoring of engineered tissues during fabrication processes. RCBU members Diane Dalecki, Maria Helguera, and Denise Hocking have developed a productive collaboration focused on developing non-destructive ultrasound technologies to quantitatively image and characterize the structural, biological, and material properties of engineered tissues. The goal of a recent study from BME graduate student Karla Mercado and this research team was to develop high-frequency quantitative ultrasound techniques to nondestructively estimate cell concentration in three-dimensional (3D) engineered tissue constructs. High-frequency ultrasound backscatter measurements were obtained from cell-embedded, 3D agarose hydrogels. Two broadband single-element transducers (center frequencies of 30 and 38 MHz) were employed over the frequency range of 13 to 47 MHz. Agarose gels with cell concentrations ranging from 1×10^4 to 1×10^6 cells mL^{-1} were investigated. The quantitative ultrasound parameter known as the integrated backscatter coefficient (IBC) was employed in this work. The IBC is an estimate of the backscatter strength of sub-resolution scatterers per unit volume over the transducer bandwidth, and provides an approximation of the scatterer number density. A series of experiments demonstrated that the IBC can provide estimates of fibroblast concentrations in 3D agarose constructs. The IBC increased linearly with increasing cell concentration. Accuracy and precision of this technique were analyzed by calculating the percent error and coefficient of variation of cell concentration estimates. Accuracy and precision improved with increasing dimensions of the region of interest of IBC estimation, and with increasing cell concentration. Axial and lateral dimensions of regions of interest that resulted in errors of less than 20% were determined. Images of cell concentration estimates were employed to visualize quantitatively regional differences in cell concentrations (Figure 1) within 3D cell-embedded agarose hydrogels. This ultrasound technique provides the capability to rapidly quantify cell concentration within 3D tissue constructs noninvasively and nondestructively.

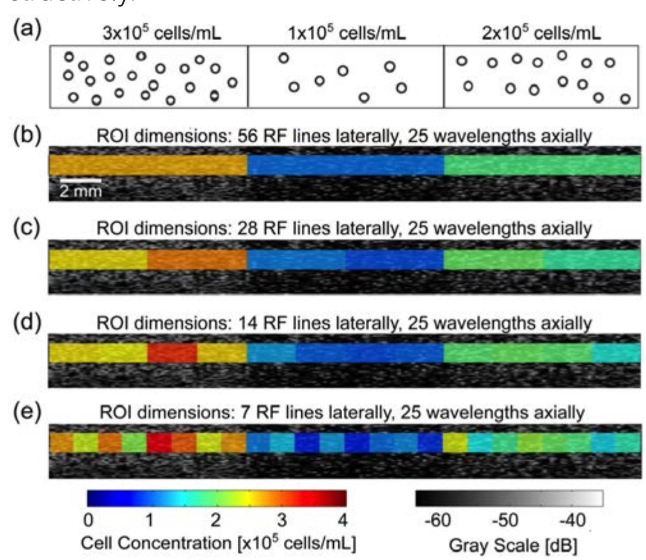


Figure 1 . (a) Schematic of agarose gel with three regions of homogeneous cell concentrations. Representative B-scans and overlaid color images of cell concentrations estimated from the IBC in regions of interest (ROI) that have (b) 56, (c) 28, (d) 14, and (e) 7 RF lines.

Analysis and visualization of 3D microvessel networks in engineered tissues

María Helguera, PhD, Mohammed YousefHussien, MS, Denise C. Hocking, PhD, Diane Dalecki, PhD

The Dalecki and Hocking laboratories have demonstrated that acoustic radiation forces associated with ultrasound standing wave fields provide a rapid, non-invasive approach to spatially pattern cells in three dimensions without affecting cell viability. Furthermore, ultrasound-patterning of endothelial cells leads to rapid and extensive microvessel network formation in 3D collagen-based constructs. Both the rate of formation and morphology of the resultant vascular networks are dependent upon the ultrasound field parameters used to produce the cellular alignment (see related story on page 5).

This collaborative multidisciplinary project also draws upon the expertise of Maria Helguera, PhD, to develop image processing approaches to visualize and quantify properties of engineered microvessel networks produced by ultrasound. Together, Dr. Helguera and RIT graduate student Mohammed YousefHussein designed a tool to provide quantitative textural and morphometric analyses of multi-photon microscopy images of ultrasound-induced microvasculature in 3D engineered tissues. The tool also provides the capability for fast 3D volume rendering of microvessel network structure and morphology.

Multi-photon immunofluorescence z-stack images were first pre-processed to suppress noise, and then a 3D connected component analysis was used for volume segmentation. Two different textural analysis techniques (gray level co-occurrence matrix, GLCM, and gray level run length matrix, GLRLM) were combined to provide a comprehensive quantification of microvessel network structure. GLCM textural parameters were computed in nine spatial orientations and include entropy, energy, contrast, and homogeneity. GLRLM methods provide quantification of vessel length and branching, and volumetric analyses techniques are used to quantify vessel growth direction and volume percentage. The team utilized MATVTK, a 3D volume rendering technique running on MATLAB with faster volume reconstruction time compared to MATLAB built-in tools (Figure 1). Results indicated the methods are capable of quantitatively characterizing morphological differences in microvessel network structures. Texture feature analyses (particularly entropy, energy, and homogeneity) of connected component images supported the observed differences in vascular network morphologies produced by different USWF parameters. The algorithms can be implemented through a stand-alone graphical user interface to facilitate rapid analyses of large volumes of data, and provide 3D vessel network visualization and image projection capabilities.

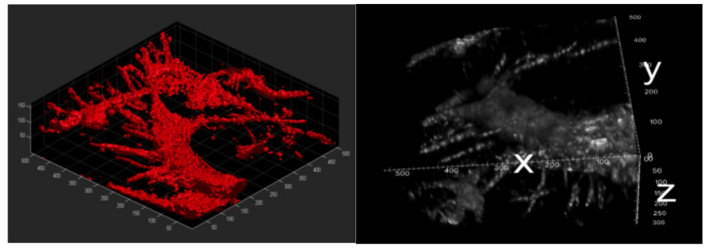


Figure 1. (a) Isosurface rendering by MATLAB functions (~ 1 hour). (b) MATVTK volume rendering through MATLAB (~10 sec).

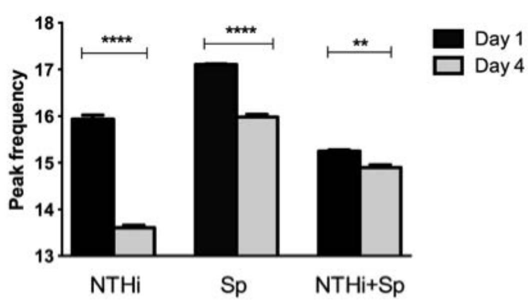
Multimodal imaging and characterization of biofilms

Kunal Vaidya, PhD, Michael Pichichero, MD, María Helguera, PhD

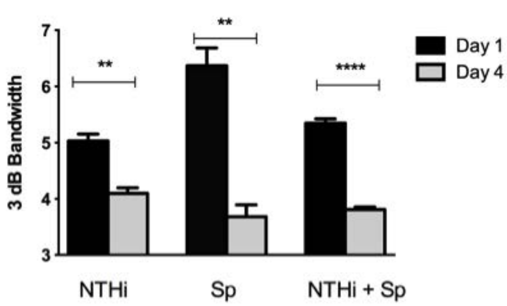
Bacterial infection is a rampant problem faced by the medical community. The bacteria gene pool is capable of adapting itself to changing conditions building biofilms to ensure the survival of progeny. This capability reduces the efficiency of antibiotics and protects the bacteria from immune system eradication, prompting the need for a technology capable of early detection of biofilms. The ability to non-invasively image and characterize bacterial biofilms in children during nasopharyngeal colonization with potential otopathogens and during acute otitis media would represent a significant advance. Recently, a team of engineers and clinicians in the Helguera lab investigated whether quantitative high-frequency ultrasound techniques could be used to achieve that goal.

Systematic time studies of bacterial biofilm formation were performed in vitro on three preparations of an isolated Haemophilus influenzae (NTHi) strain, a Streptococcus pneumoniae (Sp) strain and a combination of H. influenzae and S. pneumoniae (NTHi + Sp). The process of ultrasound characterization included first conditioning the acquired radiofrequency data obtained with a 15-MHz focused, piston transducer by using a seven-level wavelet decomposition scheme to de-noise the individual A-lines. All subsequent spectral parameter estimations were done on the wavelet de-noised radiofrequency data. Various spectral parameters were investigated, including peak frequency shift, bandwidth reduction and integrated backscatter coefficient. These parameters were successfully used to map the progression of the biofilms in time and to differentiate between single- and multiple-species biofilms. Results were compared with those from confocal microscopy and theoretical evaluation of form factor.

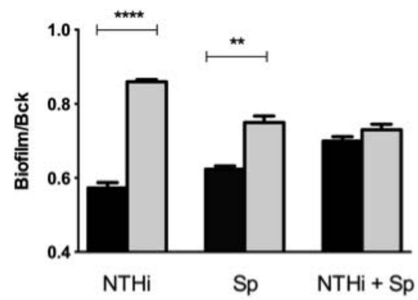
Figure 1 presents the peak frequency shift (Fig. 1a), the 3 dB bandwidth (Fig. 1b) and the biofilm to background ratio (Fig. 1c) for each strain at Day 1 and Day 4. Results were analyzed using Prism 6, where unpaired t-tests with a 95% confidence interval were performed. Further, results from the two independent imaging modalities (high-frequency ultrasound and confocal microscopy) confirmed that as biofilms matured they became thicker and denser regardless of the strain, although the rate of growth varied among the strains. Results based on the spectral fit model are shown in Figure 2. It can be seen that the effective scatterer size is consistently larger for NTHi than for Sp and NTHi + Sp. Furthermore, the trend shown in these estimates confirmed the findings of an increase in the integrated backscatter as a function of biofilm maturity. In conclusion, results of this investigation indicate that high-frequency ultrasound may provide a useful modality to detect and characterize bacterial biofilms in humans as they form on tissues and plastic materials.



[a]



[b]



[c]

Figure 1: (a) Peak frequency; (b) 3 dB Bandwidth; and (c) Biofilm to background ratio demonstrate the ability of these parameters to differentiate biofilms as they mature.

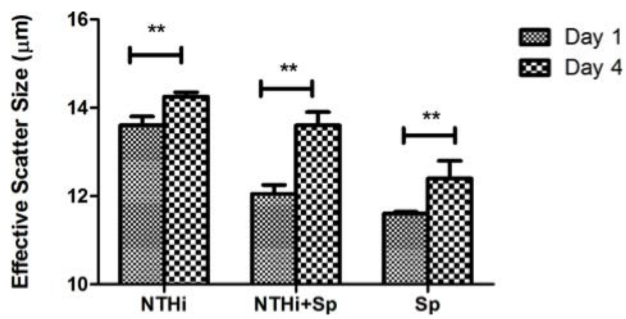


Figure 2. Effective scatterer size within samples as a function of biofilm maturity.

Physical models of tissue in shear fields

Edwin L. Carstensen, PhD, Kevin J. Parker, PhD

A recent review paper (UMB, 40:655-674; 2014) by RCBU Founding Director, Edwin Carstensen, and Kevin Parker (Past RCBU Director) considers three general classes of physical as opposed to phenomenological models of the shear elasticity of tissues.

The first is simple viscoelasticity. This model has a special role in elastography because it is the language in which experimental and clinical data are communicated. The second class of models involves acoustic relaxation, in which the medium contains inner time-dependent systems that are driven through the external bulk medium. Hysteresis, the phenomenon characterizing the third class of models, involves losses that are related to strain rather than time rate of change of strain.

In contrast to the vast efforts given to tissue characterization through their bulk moduli over the last half-century, similar research using low-frequency shear data is in its infancy. Rather than a neat summary of existing facts, this essay is a framework for hypothesis generation—guessing what physical mechanisms give tissues their shear properties.

Mouse liver dispersion for the diagnosis of fatty liver disease

Christopher T. Barry, MD, Zaegyoo Hah, PhD, Alexander Partin, MS, Robert A. Mooney, PhD, Kuang-Hsiang Chuang, PhD, Alicia Augustine, PhD, Anthony Almudevar, PhD, Wenqing Cao, BMed, Deborah J. Rubens, MD, Kevin J. Parker, PhD

The accumulation of fat droplets within the liver is an important marker of liver disease. A recent study from the lab of Professor Kevin Parker assessed gradations of steatosis in mouse livers using crawling waves, which are interfering patterns of shear waves introduced into the liver by external sources. The crawling waves were detected by Doppler ultrasound imaging techniques, and were used to analyze and to estimate the shear wave speed as a function of frequency between 200 and 360 Hz. In a study of 70 mice with progressive increases in steatosis from 0% to 60%, increases in steatosis are found to increase the dispersion, or frequency dependence, of shear wave speed. This finding confirms an earlier, smaller study and points to the potential of a scoring system for steatosis based on shear wave dispersion.

Obstetrics & Gynecology Ultrasound Unit

Tulin Ozcan, MD

The UR OB/GYN Ultrasound Unit provided clinical service at multiple sites including Strong Memorial Hospital (SMH), Highland Hospital, Rochester General Hospital, and FF Thompson Hospital.

The total number of examinations in 2014 from SMH sites included 11,321 obstetric, and 2,096 gynecological scans. Invasive procedures included 107 amniocenteses for karyotype or lung maturity, 53 chorionic villus samplings, 69 sonohysterograms, 212 OR guidance for minor gynecological procedures, and 36 invasive procedures that include intracardiac KCL injections, intrauterine shunt insertions, pleurocenteses or cyst aspirations. Interpretation of ultrasound examinations at FF Thompson Hospital continued utilizing a combination of telemedicine and onsite service.

The Unit also continued to provide ultrasound and consulting services to Rochester General Hospital OB/GYN Department. The Unit has many ultrasound scanners within SMH, all with 3D and 4D capability, plus additional portable scanners. Examples of recent research projects are provided below.

Do clinical practitioners demonstrate compliance with biosafety recommendations?

B Bromley, MD, J Spitz, MPH, RDMS, K Fuchs, MD, LL Thornburg, MD

The aim of this study was to evaluate compliance with the ALARA (as low as reasonably achievable) principle by practitioners seeking credentialing for nuchal translucency (NT) measurement between 11 and 14 weeks gestation. Nuchal Translucency Quality Review Program credentialing requires quantitative scoring of 5 NT measurements from 5 different fetuses. Images submitted by 100 consecutive practitioners were retrospectively evaluated for the output display standard (ODS). The thermal index (TI) type (bone [TIb] or soft tissue [TIs]) and numeric value of the index were recorded. The TIb was considered the correct index for this study. Compliance with the numeric value was evaluated in several ways. Collectively, a TIb lower than 0.5 was considered optimal, lower than 0.7 compliant, and 1.0 or lower satisfactory. An ODS was present in at least 1 image submitted by 77 practitioners. The TIb was used exclusively by 15 (19.5%), the TIs by 37 (48.1%), and 25 used a combination of the TIb and TIs. Only 4 of 77 providers (5%) used the correct TI type (TIb) at lower than 0.5 for all submitted images, 5 of 77 (6%) at lower than 0.7, and 9 of 77 (12%) at 1.0 or lower. A TI (TIb or TIs) higher than 1.0 was used by 15 of 77 providers (19.5%). Proficiency in NT measurement and educational background (physician or sonographer) did not influence compliance with ALARA. In conclusion, clinicians seeking credentialing in NT did not demonstrate compliance with the recommended use of the TIb in monitoring acoustic output.

Limitations of aneuploidy and anomaly detection in the obese patient

P Zozzaro-Smith, MD, L Gray, MD, S Bacak, DO, LL Thornburg, MD

Obesity is a worldwide epidemic and can have a profound effect on pregnancy risks. Obese patients tend to be older and are at increased risk for structural fetal anomalies and aneuploidy, making screening options critically important for these women. Failure rates for first-trimester nuchal translucency (NT) screening increase with obesity, while the ability to detect soft-markers declines, limiting ultrasound-based screening options. Obesity also decreases the chances of completing the anatomy survey and increases the residual risk of undetected anomalies. Additionally, non-invasive prenatal testing (NIPT) is less likely to provide an informative result in obese patients. Understanding the limitations and diagnostic accuracy of aneuploidy and anomaly screening in obese patients can help guide clinicians in counseling patients on the screening options.

HIGHLIGHTS FROM THE 2014 ITEC

Pictured above: Group photo of 2014 ITEC attendees in Utah

The Thirteenth Annual International Tissue Elasticity Conference was held in Snowbird, Utah from September 7-10, 2014. David Cosgrove opened up ITEC 2014 with a lecture that discussed the medical applications where elastography is able to make a genuine clinical difference, and explored possible applications where it can be expected to make a difference in the future. RCBU member **Marvin Doyley** gave a tutorial on the rapidly developing technological area of ultrasonic beam forming, a hot topic in ultrasound in general for the last few years, and one which is now having a substantial impact on performance and capability of elastography. RCBU members **Rohit Nayak**, **Prashant Verma**, **Marvin Doyley**, **Steve McAleavey**, and **Jonathan Langdon** all had abstracts that were featured at this year's conference.

SELECTED RCBU MEMBER ABSTRACTS

"Multi-element Synthetic Aperture Vascular Elastography for Carotid Imaging"
Rohit Nayak, **Prashant Verma**, and **Marvin M. Doyley**

"Development of Open-source Tools to Validate Shear Wave Imaging: An Integrated QIBA Effort"
Jingfeng Jiang, **Steve McAleavey**, **Jonathan Langdon**, and Mark Palmeri

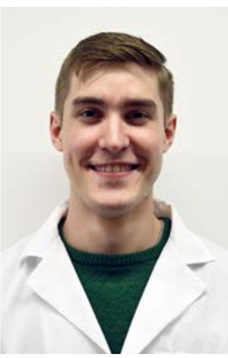
"Beam-forming Choices: What are they, how do they work, and what is their impact for elastography"
Marvin M. Doyley

The International Tissue Elasticity Conference was co-founded by RCBU Past-Director **Kevin Parker** in 2001. The goal of this scientific conference is to provide an international forum for the advancement of knowledge and methods for the measurement and imaging of the elastic attributes of soft tissues by ultrasound. The conference provides a unique and unified forum that brings together researchers from several countries and disciplines.

International
Tissue Elasticity Conference™

STUDENT FELLOWSHIPS

Raquel (Ivy) Awuor, an undergraduate student in Electrical and Computer Engineering at the UR was awarded the American Heart Association (AHA) Founders Affiliate Undergraduate Student Summer Fellowship. The fellowship was awarded for her proposal titled, "Development of a Nonlinear Intravascular Ultrasound System for Imaging the Vasa Vasorum in Coronary Arteries." Ivy will spend the summer conducting this exciting research in Professor Marvin Doyley's Parametric Imaging Research Lab.



Jonathan Macoskey was the recipient of a UR Reach Internship for the summer of 2014. The Reach Internship provided an opportunity for Jonathan to begin research in biomedical ultrasound in the laboratory of Professor Diane Dalecki.

Melinda Vander Horst was the recipient of a Xerox Undergraduate Research Fellowship. Melinda is a BME undergraduate student working in the laboratory of Professor Diane Dalecki. The Xerox Undergraduate Fellowship is a highly selective program that provides research experience for undergraduates during the summer preceding their senior year and continuing through the senior academic year.

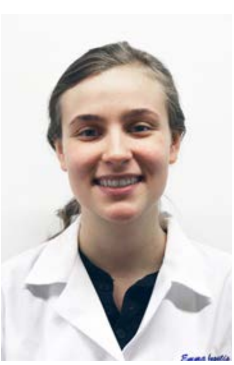
IN MEMORIAM

In Memoriam: Floyd Dunn

The biomedical ultrasound community sadly lost one of its important pioneers. Floyd Dunn passed away on January 24, 2015 at the age of 90. Floyd was a member of the Electrical and Computer Engineering Department at the University of Illinois at Urbana-Champaign for over 50 years. Following the death of Bill Fry in 1968, Floyd became director of the Department's Bioacoustics Research Laboratory and made it a world leader in the field of biomedical ultrasound. Founding RCBU Director Ed Carstensen writes, "It is hard to believe today, but in the mid-1960s, research in this field had dwindled to the point that progress could be reported in biannual sessions at meetings of the Acoustical Society. Floyd and Wesley Nyborg organized those special sessions and we are uniquely indebted to them for keeping the field alive."

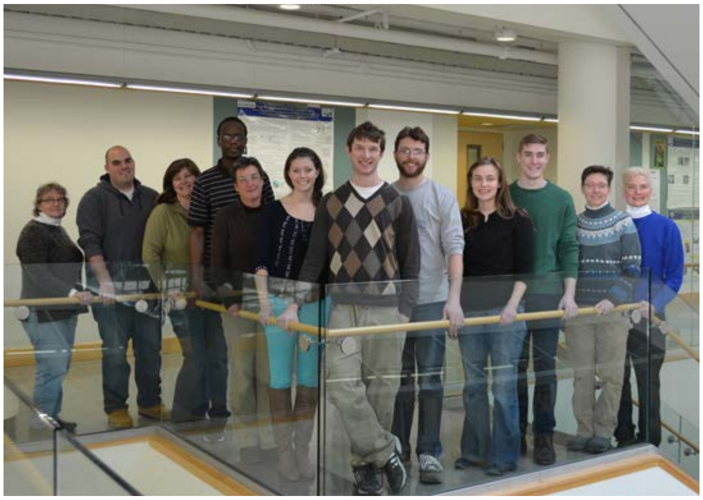
Floyd's body of scientific work provides foundation for our understanding of the propagation of ultrasound in tissues and the biological effects of ultrasound. He was a member of both the National Academy of Sciences and the National Academy of Engineering, and served as President of the Acoustical Society America. He was recognized with the highest awards from numerous scientific societies, including the IEEE Edison Award, the ASA Gold and Silver Medal Awards, and the AIUM Joseph P. Holmes Basic Science Pioneer Award. He served on many FDA, NIH, AIUM, and ASA committees, and was a member of Committee 66 of the National Council on Radiation Protection.

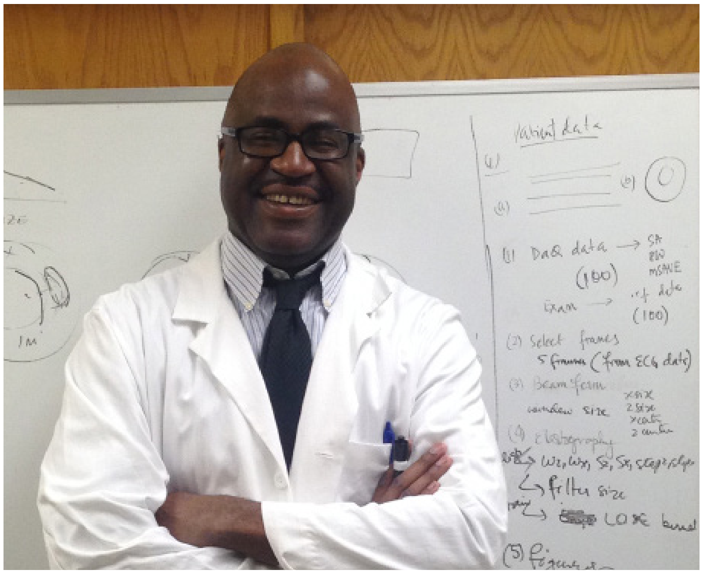
Floyd was a Charter Honorary Member of the RCBU and was a long-time friend and colleague for many of us. The RCBU and the wider biomedical ultrasound community will miss Floyd dearly.

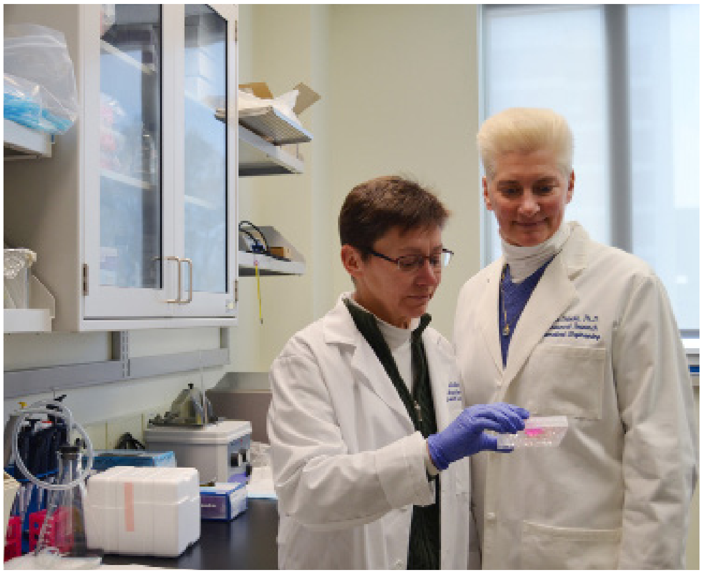


Emma Grygotis and **Prashant Verma** were each awarded a Howard Hughes Medical Institute (HHMI) Med-into-Grad Fellowship in Cardiovascular Science. This prestigious HHMI sponsored UR Medical Center graduate Fellowship augments traditional Ph.D. training with clinical rotations, a clinical co-mentor, a weekly Cardiovascular Research Institute seminar series, and translational cardiovascular coursework to train the next generation of bench-to-bedside cardiovascular scientists. Emma Grygotis is a Ph.D. candidate in Pharmacology and Physiology working with Professor Densie Hocking and Professor Diane Dalecki. Prashant is a Ph.D candidate in Physics supervised by Professor Marvin Doyley.

RCBU FUNDING NEWS







Denise Hocking (Pharmacology and Physiology) and **Diane Dalecki** (BME) are multi-PIs on a new NIH R01 grant from the NIH NIBIB titled "Ultrasound Standing Wave Fields for Vascular Tissue Engineering." The overall goal of this project is to advance a novel ultrasound technology to fabricate complex, functional microvessel networks within three-dimensional engineered constructs. Collaborators on this project are **Maria Helguera** (Imaging Sciences, RIT), Ingrid Sarelius (Pharmacology and Physiology), and Angela Glading (Pharmacology and Physiology).

Marvin Doyley (ECE) is a co-investigator on a new NIH R01 award titled "cART Accelerates Vascular Aging in HIV Infected Patients" with Principal Investigator, Giovanni Schifitto, M.D. of the UR Department of Neurology. The goal of this project is to develop a sparse array vascular elastography system to measure the mechanical properties of carotid arteries in individuals infected with HIV. This approach will test the hypothesis that older HIV-infected individuals are at increased risk of developing measurable changes in markers of atherosclerosis.

Diane Dalecki (BME) and **Denise Hocking** (Pharmacology and Physiology) were the recipients of a UR Pump Primer Award for their project titled "Engineering Lymphatic Vessel Networks". The goal of this funding was to test the feasibility of developing an ultrasound-based technique to fabricate lymphatic vessel networks in engineered constructs.

Marvin Doyley (ECE) and Dr. Giovanni Schifitto (Neurology) received a University Research Award for their project titled "Carotid Disease, Elastography, and Inflammatory Markers." The goal of the project was to develop a novel elastography method to assess carotid artery stiffness.

Pictured from top: Dalecki and Hocking lab members in Goergen Hall, Professor Doyley in the lab, and Dr. Hocking and Dr. Dalecki in the lab.

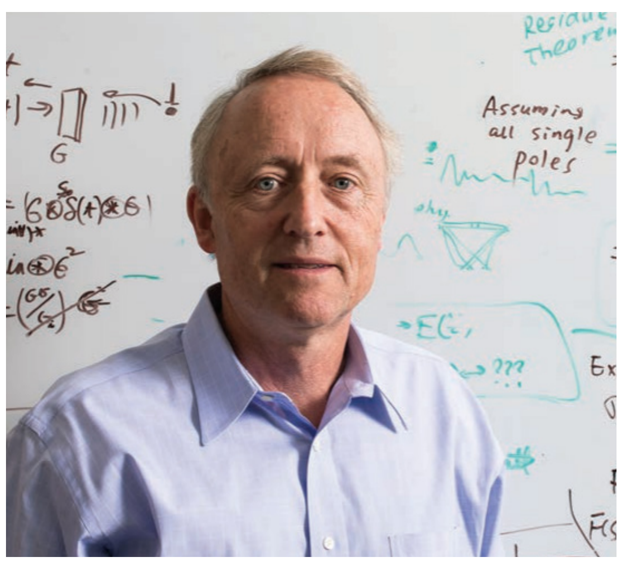
2014 AWARDS

Kevin Parker Receives Eastman Medal

Kevin Parker, Ph.D., Dean Emeritus of the School of Engineering and Applied Sciences and RCBU Director from 1990-2006 was awarded an Eastman Medal for his work on the Blue Noise Mask. The virtuous cycle of research, invention and funding that the Blue Noise Mask set in motion was celebrated when Parker and Theophano Mitsa, Ph.D., were awarded Eastman Medals by the University for their invention. The Eastman Medal recognizes individuals whose achievements and service embody the University's highest ideals. The Medal is named for George Eastman, the UR's major benefactor and one of the nation's greatest inventors and champions of higher education.

University President Joel Seligman said Dr. Parker and Dr. Mitsa exemplify "what we hope to accomplish as we go further in Data Science, as we go further in clinical and translational science across Elmwood (at the University's Medical Center), and as we continue to amplify the significance of the Hajim School of Engineering and Applied Sciences. They are an illustration of the highest quality of research that one can envision, research that really has touched the world."

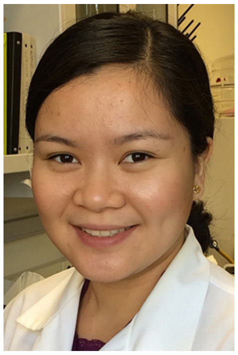
Blue Noise Mask is a widely adopted half-toning technique that prints shades of gray in less time and at a higher quality than traditional methods; it has been licensed by more than a dozen companies, including Hewlett Packard. And it has generated in excess of $30 million in royalties for the University of Rochester.



Counterclockwise from top: UR President Joel Seligman presenting the Eastman Medal to Kevin Parker, Theophano Mitsa, Ph.D., graduate of the Parker lab, and Kevin Parker, Ph.D.

Maria Helguera, Ph.D. was appointed the Wedd Visiting Professor in Pharmacology and Physiology for the 2013-2014 academic year. Dr. Helguera is an Associate Professor in the Chester Carlson Center for Imaging Sciences at RIT, and a long-standing member of the RCBU. Her research is dedicated to biomedical and materials multimodal imaging. During this visiting professorship, Dr. Helgeura collaborated with Professors Denise Hocking and Diane Dalecki to develop novel image processing techniques to quantitatively characterize vascular morphology in three-dimensional engineered constructs (see story on page 13). Dr. Helguera also developed a new collaboration with Professor Angela Glading in the UR Department of Pharmacology & Physiology. Dr. Glading and Dr. Helguera worked toward developing new imaging techniques to characterize normal and abnormal vasculature in vivo (see page 11).

Rohit Nayak was awarded Second Place in the Best Student Oral Presentation Awards at the 2014 International Tissue Elasticity Conference that took place in Snowbird, UT in September 2014. Rohit is a Ph.D. candidate working in the laboratory of Professor Marvin Doyley. Rohit was recognized for his presentation titled "Multi-element synthetic aperture vascular elastography for carotid imaging."



Karla Mercado was awarded Second Place in the Best Student Paper Competition in Biomedical Acoustics at the 167th Meeting of the Acoustical Society of America, held in Providence, Rhode Island in May 2014. Karla was recognized for her research titled "Characterizing collagen microstructure using high frequency ultrasound."

Himanshu Shekhar was awarded the prestigious Frederick V. Hunt Postdoctoral Research Fellowship in Acoustics from the Acoustical Society of America. Himanshu completed his doctoral work (May 2014) in Professor Marvin Doyley's lab, working in the area of high-frequency ultrasound imaging. The Hunt Fellowship was established by the Acoustical Society of America to honor the legacy of the late Professor Frederick Vinton Hunt of Harvard University. Himanshu received the Hunt Fellowship for his proposal titled "Ultrasound-enhanced drug delivery for treating vascular disease." He will complete this research as a Post-doctoral Fellow in the laboratory of Professor Christy Holland in the Department of Internal Medicine at the University of Cincinnati.

Himanshu also won the Best Student Paper Award in Biomedical Acoustics at the 167th Meeting of the Acoustical Society of America, held in Providence, Rhode Island in May 2014. Himanshu was recognized for his research titled, "Nonlinear intravascular ultrasound contrast imaging with a modified clinical system," with co-author Professor Marvin Doyley.

Jonathan Macoskey was the recipient of the 2014 Robert W. Young Award for Undergraduate Student Research in Acoustics from the Acoustical Society of America. The Robert W. Young Award will allow Jonathan to complete his proposed research project focused on developing a high-frequency ultrasound technique to visualize and quantify the material properties of engineered tissue constructs. Jonathan is an undergraduate in the UR Biomedical Engineering program working with Professor Diane Dalecki and Professor Denise Hocking.

INNOVATION

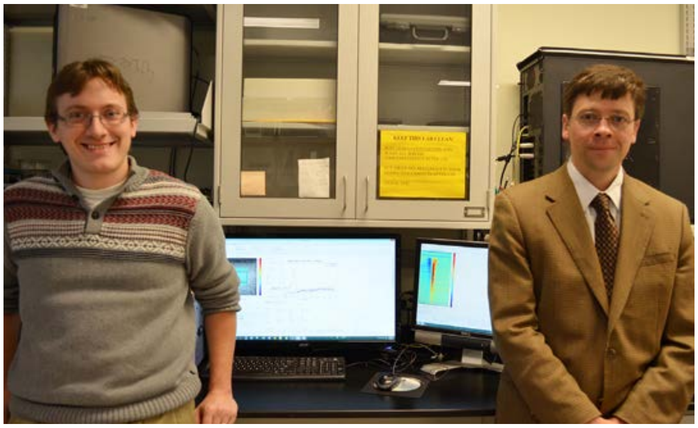
The RCBU is continually advancing novel concepts in ultrasound technology. For more information visit the UR Ventures website at http://www.rochester.edu/ventures/.

UR: A Leader in Technology Commercialization

The University of Rochester has a long-standing tradition of being at the forefront of innovation and scientific research. In 2014, 155 invention disclosures were received from 250 inventors from 51 University departments and divisions. Fifty-one external collaborators from 28 institutions, agencies, and corporations were also named as inventors. This is more than a 10% increase over disclosures received in FY 2013. Fifteen copyright registrations and 205 patent applications were filed in FY 2014. Of the patent filings, 64 were new matter filings, while 141 were continuations of applications filed in previous years. In FY 2014, the University of Rochester was granted 49 U.S. patents and 20 foreign patents. These 69 patents cover 63 different technologies.

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.

Two New Patents Issued for RCBU Member Inventions



The patent titled "Methods and Systems for Spatially Modulated Ultrasound Radiation Force Imaging" (US 8753277) has recently been assigned to the UR with inventor Stephen A. McAleavey. The patent describes a new method for using ultrasound to determine the shear modulus of a tissue noninvasively. Changes in shear modulus of tissues can be associated with certain pathologies, such as cancer and liver fibrosis. Thus, Professor McAleavey's new ultrasound technology holds great promise for increasing early detection and diagnosis of disease in patients.

RCBU members Vikram Dogra, M.D., and Navalgund Rau, Ph.D., were inventors on a new patent assigned to the UR titled "Low-cost Device for C-scan Acoustic Wave Imaging" (US 8870770). The patent describes a new technique to generate C-scan images of tissues using photoacoustic and/or acoustic waves. This photoacoustic technique can be applied for prostate imaging and detecting and diagnosing in other tissue types. *Pictured: Graduate student Jonathan Langdon and Professor Stephen McAleavey in the lab.*

U.S. PATENTS

Methods and Systems for Spatially Modulated Ultrasound Radiation Force Imaging U.S. Patent No. 8,753,277	Stephen McAleavey | June 17, 2014
Low-cost device for C-scan acoustic wave imaging U.S. Patent Nos. 8,870,770 (2014) and 8,353,833 (2013)	Vikram S. Dogra, Navalgund Rao

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, Jeffrey P. Astheimer | January 11, 2011
Ultrasound Imaging of Tissue Stiffness by Spatially Modulated Acoustic Radiation Force Impulse (SM-ARFI) U.S. Patent No. 8,225,666	Stephen McAleavey | May 9, 2008
Real Time Visualization of Shear Wave Propagation in Soft Materials with Sonoelastography U.S. Patent No. 7,444,875	Zhe Wu and Kevin J. Parker | November 4, 2008
Finite Amplitude Distortion-Based Inhomogeneous Pulse Echo Ultrasonic Imaging U.S. Patent No. 7,104,956	Ted Christopher | September 12, 2006
Ultrasound Distortion Compensation using Blind System Identification U.S. Patent No. 6,699,189	Feng Lin, 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 Totterman, and Jose Tamez-Pena January 2, 2001
Blue Noise Mask U.S. Patent Nos. 5,111,310 (1992); 5,477,305 (1995); 5,543, 941 (1996); 5,708,518 (1998); and 5,726,772 (1998)	Kevin J. Parker and Theophano Mitsa
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 Mottley and Randy Lipscher | July 29, 1998
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 Acoustic Filter U.S. Patent No. 5,334,136	Karl Schwarz, Richard Meltzer, and Charles Church August 2, 1994
Sonoelasticity Imaging Estimators U.S. Patent No. 5,086,775	Ron Huang, Robert Lerner, and Kevin Parker February 11, 1992

EDUCATION

Maria Helguera Teaches in Peru

Maria Helguera, Ph.D. was a Visiting Professor at the Pontifica Catholic University of Peru (PUCP) in the Department of Electrical Engineering. While at PUCP she taught a course titled Introduction to Medical Imaging Systems, and collaborated on research with RCBU member Professor **Benjamín Castañeda** and other PUCP faculty. "The course was taught in English as part of an effort by PUCP to expand the offerings of elective courses. I designed the course in close collaboration with Drs. Benjamín Castañeda and Roberto Lavarello, principal investigators in the Laboratory of Medical Images. The students taking the course were undergraduates, mostly EE, with specialization in biomedical engineering. It was extremely well received." said Helguera.

Summer Acoustics Course

David Blackstock again offered his popular summer acoustics course at the UR for students with various 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. 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 physical acoustics.

Dr. Voci Appointed Medical Director

Dr. Susan Voci was appointed the Medical Director of the Diagnostic Medical Sonography Program at RIT in addition to her roles as Councilor at the American College of Radiology (ACR) and member of the ACR Ultrasound Section for the diagnostic Radiology In-training examination.

TRAINING COMPLETED

Etana Elegbe received her Ph.D. in Biomedical Engineering from the University of Rochester. Her thesis, titled "Development of Single Tracking Location Acoustic Radiation Force Imaging for the Assessment of Liver Fibrosis Progression", was supervised by Professor Stephen McAleavey.

JoHannah Kohl completed her M.S. degree in Electrical and Computer Engineering at the UR. Her M.S. thesis, titled "Beamforming Technique for Non-invasive Vascular Elastography", was supervised by Professor Marvin Doyley.

Karla Mercado completed her Ph.D. degree in Biomedical Engineering from the UR. Her thesis, titled "Developing High-Frequency Quantitative Ultrasound Techniques to Characterize Three-Dimensional Engineered Tissues", was supervised by Professor Diane Dalecki.

Himanshu Shekhar received his Ph.D. in Electrical and Computer Engineering from the UR in May 2014. His thesis, titled "Acoustic Characterization and Nonlinear Imaging of Ultrasound Contrast Agents for Intravascular Assessment of Atherosclerosis", was supervised by Profesor Marvin Doyley.

Kunal Vaidya received his Ph.D. in Imaging Sciences from RIT. His thesis, titled "Multimodal Imaging and Characterization of Biofilms", was supervised by Professor Maria Helguera.

BME Senior Design Team Focuses on Ultrasound Project

BME seniors help real-life customers solve biomedical engineering problems through the two-semester Senior Design course taught by RCBU member **Amy Lerner** and Scott Seidman. In the 2014-2015 academic year, one team of BME seniors is embarking on a project to develop an ultrasound-based technique to detect dentinal cracks in teeth. The team will focus on detection of cracks in mandibular molars as these are the teeth that exhibit cracks often. The senior design team consists of BME students Alexa Kuenstler, **Jonathan Macoskey**, Jacob Hyatt, Tek Gautum, and Jenny Won. The problem was brought to the team by long-standing RCBU member **Robert Lerner, MD, PhD,** who serves as the customer for this project. **Diane Dalecki, PhD** is the senior design team supervisor for this project.

RELATED COURSES

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.

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.

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.

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.

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.

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.

Digital Image Processing

(ECE 447) Digital image fundamentals. Intensity transformation functions, histogram processing, fundamentals of spatial filtering. Filtering the frequency domain. Image restoration and reconstruction. Multi-resolution processing. Morphological image processing. Image segmentation.

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.

SELECTED PUBLICATIONS

Barry CT, **Hah Z**, **Partin A**, Mooney RA, Chuang K, Augustine A, Almudevar A, Cao W, **Rubens DJ**, **Parker KJ**. Mouse liver dispersion for the diagnosis of fatty liver disease: A 70-sample study. Ultrasound Med Biol 40: 704-713; 2014.

Bromley B, Spitz J, Fuchs K, **Thornburg LL**. Do clinical practitioners seeking credentialing for nuchal translucency measurement demonstrate compliance with biosafety recommendations? Experience of the nuchal translucency quality review program. J Ultrasound Med. 33: 1209-1214; 2014.

Carstensen EL, **Parker KJ**. Physical models of tissue in shear fields. Ultrasound Med Biol. 40: 655-674; 2014.

Cuckle H, Platt LD, **Thornburg LL**, Bromley B, Fuchs K, Abuhamad A, Benacerraf B, Copel JA, Depp R, D'Alton M, Goldberg J, Okeeffe D, Spitz J, Toland G, Wapner R; the Nuchal Translucency Quality Review Program of the Perinatal Quality Foundation. Nuchal translucency quality review (NTQR) program: first one and half million results. Ultrasound Obstet Gynecol. 45: 199-204; 2014.

Dogra VS, Chinni BK, Valluru KS, Moalem J, Giampoli EJ, Evans K, **Rao NA**. Preliminary results of ex vivo multispectral photoacoustic imaging in the management of thyroid cancer. Am J Roentgenol. 202: W552-8; 2014.

Doyley M, Jadamba B, Khan AA, Sama M, Winkler B. A new energy inversion for parameter identification in saddle point problems with an application to the elasticity imaging inverse problem of predicting tumor location. Numerical Functional Analysis and Optimization. 35: 984-1017; 2014.

Doyley MM, **Parker KJ**. Elastography: general principles and clinical applications. Ultrasound Clinics. 9: 1-11; 2014.

Hah Z, **Partin A**, **Parker KJ**. Shear wave speed and dispersion measurements using crawling wave chirps. Ultrasonic Imaging. 36: 277-290; 2014.

Hesford AJ, **Tillett JC**, **Astheimer JP**, **Waag RC**. Comparison of temporal and spectral scattering methods using acoustically large breast models derived from magnetic resonance images. J Acoust Soc Am. 136: 682-92; 2014.

Huntzicker S, **Nayak R**, **Doyley MM**. Quantitative sparse array vascular elastography: the impact of tissue attenuation and modulus contrast on performance. Journal of Medical Imaging. 1: 027001-1 – 027001-13; 2014.

Kaproth-Joslin KA, **Bhatt S**,Scoutt LM, **Rubens DJ**. The essentials of extracranial carotid ultrasonographic imaging. Radiol Clin North Am. 52: 1325-42; 2014.

Khorana AA, **Rubens D**, **Francis CW**. Screening high-risk cancer patients for VTE: a prospective observational study. Thromb Res. 134: 1205-7; 2014.

Koo TK, Guo J, Cohen JH, **Parker KJ**. Quantifying the passive stretching response of human tibialis anterior muscle using shear wave elastography. Clinical Biomechanics. 29: 33-39; 2014.

McAleavey SA. Analysis and measurement of the modulation transfer function of harmonic shear wave induced phase encoding imaging. J Acoust Soc Am. 135: 2836-46; 2014.

Mercado KP, **Helguera M**, **Hocking DC**, **Dalecki D**. Estimating cell concentration in three-dimensional engineered tissue constructs using high frequency quantitative ultrasound. Annals of Biomedical Engineering. 42:1292-1304; 2014.

Nicola R, **Carson N**, **Dogra VS**. Imaging of traumatic injuries to the scrotum and penis. Am J Roentgenol. 202: W512-20; 2014.

Parker KJ. A microchannel flow model for soft tissue elasticity. Physics Med Biol. 59: 4443-4457; 2014.

Parker KJ. Apodization and windowing eigenfunctions. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 61: 1575-1579; 2014.

Parker KJ. Real and causal hysteresis elements. J Acoust Soc Am. 135: 3381-3389; 2014.

Parker KJ, N Baddour. The Gaussian shear wave in a dispersive medium. Ultrasound Med Biol. 40: 675-684; 2014.

Partin A, **Hah Z**, **Barry CT**, **Rubens DJ**, **Parker KJ**. Elasticity estimates from images of crawling waves generated by miniature surface sources. Ultrasound Med Biol. 40: 685-694; 2014.

Ravines P, Baum KG, Cox N, Welch S, **Helguera M**. Multimodality imaging of daguerreotypes and development of a registration program for image evaluation. American Institute of Conservation, 53: 19-32; 2014.

Shekhar H, **Awuor I**, Thomas K, Rychak JJ, **Doyley MM**. The delayed onset of subharmonic and ultraharmonic emissions from a phospholipid-shelled microbubble contrast agent. Ultrasound Med Biol. 40: 727-738; 2014.

Sinha S, **Rao N**, Valluru KS, Chinni BK, **Dogra VS**, **Helguera M**. Frequency analysis of multispectral photoacoustic images for differentiating malignant region from the normal region in excised human prostate. Proceedings of SPIE, 9040: 90400P -1-9; 2014.

Vaidya K, Osgood R, Ren D, Pichichero M, **Helguera M**. Ultrasound imaging and characterization of biofilms based on wavelet denoised RF data. Ultrasound Med. Biol. 40: 583–595; 2014.

Zozzaro-Smith P, Gray L, Bacak S, **Thornburg L**. Limitations of aneuploidy and anomaly detection in the obese patient. Clin Med, 3: 795-808; 2014.

SELECTED PRESENTATIONS

Barry CT, Hazard C, Cheng G, Hah Z, Chuang K, **Partin A**, Mooney RA, Cao W, **Rubens DJ**, **Parker KJ**. Detection of steatosis through shear speed dispersion. 2014 IEEE International Ultrasonics Symposium, Chicago, IL, September 2014.

Barry CT, Hazard C, Cheng G, **Hah Z**, **Partin A**, Chuang K, Mooney RA, Cao W, **Rubens DJ**, **Parker KJ**. Detection of steatosis through shear speed dispersion: A rat study. American Institute of Ultrasound in Medicine Annual Convention, Las Vegas, NV, April 2014.

Dalecki D, **Hocking DC**. Ultrasound for microvascular tissue engineering. The 167th Meeting of the Acoustical Society of America, Providence, RI, May 2014.

Doyley MM. Beam-forming choices: what are they, how do they work, and what is their impact for elastography. International Tissue Elasticity Conference, Snowbird, UT, September 2014.

Doyley MM. Can we use elastography to visualize the stress distribution within vascular tissues? 7th World Congress on Biomechanics, Boston, MA, July 2014.

Glantz JC, Sheth T, Gray L. Third-trimester fetal biometry and neonatal outcome in term deliveries. American Institute of Ultrasound in Medicine Annual Convention, Las Vegas, NV, 2014.

Harris GR, Church CC, **Dalecki D**, Ziskin MC, Bagley JE. A comparison of thermal safety guidelines for diagnostic ultrasound exposures. Annual Convention of the American Institute of Ultrasound in Medicine, Las Vegas, NV, March 2014.

Hocking DC, **Raeman C**, **Dalecki D**. Investigation of effects of ultrasound on dermal wound healing in diabetic mice. 167th Meeting of the Acoustical Society of America, Providence, RI, May 2014.

Huntzicker S, **Doyley MM**. Can quantitative synthetic aperture vascular elastography predict the stress distribution within the fibrous cap non-invasively. 167th Meeting of the Acoustical Society of America, Providence, RI, May 2014.

Huntzicker S, **Doyley M**. Non-invasive estimation of the stress distribution within the fibrous cap. 7th World Congress on Biomechanics, Boston, MA, July 2014.

Koo TK, Guo J, Cohen JH, **Parker KJ**. Direct measurement of muscle forces using supersonic shear wave elastography. 7th World Congress of Biomechanics, Boston, MA, July 2014.

Liu Y, Glading A, Saber E, **Helguera M**. Measurement of blood flow velocity in vivo video sequences with motion estimation methods. SPIE Medical Imaging, San Diego, CA, February 2014.

Mack L, Gray L, Dolan J, Rich J, Glantz JC, **Thornburg L**. Head circumference-to-abdominal circumference ratio: A predictor of shoulder dystocia? Annual Convention of the American Institute of Ultrasound in Medicine, Las Vegas, NV, March 2014.

Mercado KP, **Helguera M**, **Hocking DC**, **Dalecki D**. Characterizing collagen microstructure using high frequency ultrasound. The 167th Meeting of the Acoustical Society of America, Providence, RI, May 2014.

Nayak R, **Doyley MM**. Multi-element synthetic aperture vascular elastography for carotid imaging. International Tissue Elasticity Conference, Snowbird, UT, September 2014.

Ohayon J, Bouvier A, Le'Floch S, Finet G, **Doyley MM**, Pettigrew RI, Cloutier G. Intravascular ultrasound coronary plaque elasticity reconstruction methods based on in vivo strain imaging. 7th World Congress on Biomechanics, Boston, MA, July 2014.

Ormachea J, Rojas R, Rodriguez P, Lavarello R, **Parker KJ**, **Castaneda B**. Shear wave speed estimation from crawling wave sonoelastography: A comparison between AM-FM dominant component analysis and phase derivation methods. 2014 IEEE International Ultrasonics Symposium, Chicago, IL, September 2014.

Parker KJ. A microchannel flow model of liver viscoelasticity. 2014 IEEE International Ultrasonics Symposium, Chicago, IL, September 2014.

Parker KJ. A microchannel flow model for soft tissue elasticity. 7th World Congress of Biomechanics, Boston, MA, July 2014.

Parker KJ, Chen S. Asymmetric focal beam patterns enable supersonic resolution. American Institute of Ultrasound in Medicine Annual Convention, Las Vegas, NV, April 2014.

Shekhar H, **Awuor I**, Hashemgeloogerdi S, **Doyley MM**. Nonlinear intravascular ultrasound contrast imaging with a modified clinical system. 167th Meeting of the Acoustical Society of America, Providence, RI, May 2014.

Verma P, **Kohl J**, **Huntzicker S**, **Nayak R**, **Doyley MM**. Beam-forming strategies for plane-wave vascular elastography. IEEE Ultrasonics Symposium, Chicago, IL, September 2014.

Verma P, **Doyley MM**. Synthetic aperture elastography: a GPU based approach. SPIE Medical Imaging, San Diego, CA, February 2014.

RCBU MEMBERS

University of Rochester

Anesthesiology
Paul Bigeleisen, M.D.
Janine Shapiro, M.D.
David Stern, M.D.
Jacek Wojtczak, M.D.

Biomedical Engineering
Sally Child, M.S.
Ruth Chimenti, Ph.D.
Eric Comeau, M.S.
Diane Dalecki, Ph.D.
Jonathan Langdon, M.S.
Amy Lerner, Ph.D.
Stephen McAleavey, Ph.D.
Karla Mercado, Ph.D.
Laurentius Osapoetra, B.S.
Carol Raeman, A.A.S.
Richard Waugh, Ph.D.

Biophysics/Biochemistry
Scott Kennedy, Ph.D.

Cardiology Unit
James Eichelberger, M.D.
Karl Schwarz, M.D.
Sherry Steinmetz, R.D.M.S.

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

Dermatology
Alice Pentland, M.D.

Earth & Environmental Sciences
Asish Basu, Ph.D.

Electrical & Computer Engineering
Edwin Carstensen, Ph.D.
Yong Thung Cho, Ph.D.
Marvin Doyley, Ph.D.
Zaegyoo Hah, Ph.D.
Andrew Hesford, Ph.D.
Steven Huntzicker, M.S.
Jack Mottley, Ph.D.
Rohit Nayak, M.S.
Prashant Verma, M.S.
Kevin Parker, Ph.D.
Alexander Partin, Ph.D.
Michael Richards, Ph.D.
Himanshu Shekhar, Ph.D.
Jason Tillett, Ph.D.
Robert Waag, Ph.D.

Emergency Medicine
Jefferson Svengsouk, M.D.

Imaging Sciences
Mark James Adams, M.D.
Shweta Bhatt, M.D.
Vikram Dogra, M.D.
Thomas Foster, Ph.D.
Nina Klionsky, M.D.
Deborah Rubens, M.D.
John Strang, M.D.
Susan Voci, M.D.
Eric Weinberg, M.D.
Jianhui Zhong, Ph.D.

Immunology/Rheumatology
Ralf Thiele, M.D.

Mechanical Engineering
Stephen Burns, Ph.D.
Alfred Clark, Jr., Ph.D.
Sheryl Gracewski, Ph.D.
Renato Perucchio, Ph.D.

Obstetrics & Gynecology
Morton Miller, Ph.D.
Richard Miller, M.D.
Tulin Ozcan, M.D.
Eva Pressman, M.D.
James Woods, 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.

Urology
Robert Davis, M.D.
Erdal Erturk, M.D.
Irwin Frank, M.D.
Jean Joseph, M.D.
Robert Mayer, M.D.
Jeanne O'Brien, M.D.

Vascular Medicine
Charles Francis, M.D.

Rochester General Hospital

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

Rochester Institute of Technology

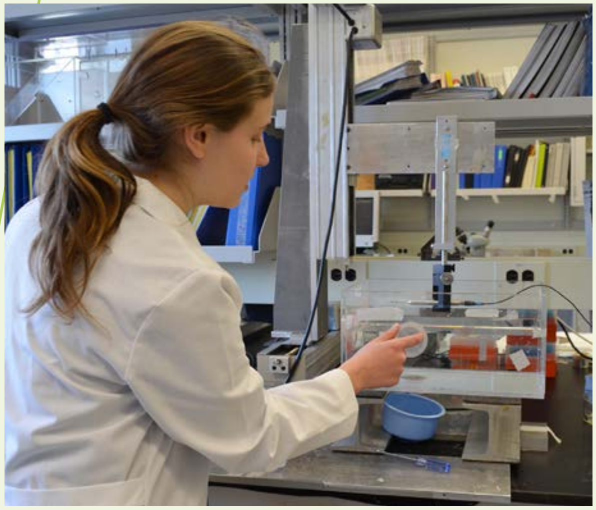
Center for Imaging Sciences
Maria Helguera, Ph.D.
Navalgund Rao, Ph.D.

Biomedical Engineering
Cristian Linte, Ph.D.
Daniel Phillips, Ph.D.

Visiting Scientists

David Blackstock, Ph.D.
University of Texas at Austin
Benjamín Castañeda, Ph.D.
Pontificia Universidad Catolica del Peru
E. Carr Everbach, Ph.D.
Swarthmore College
Zhe Wu, Ph.D.
University of California, San Diego

Graduate Training Opportunities in Biomedical Ultrasound 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 complements the rich research environment. Students tailor their formal coursework individually to complement their research focus and meet requirements of their home department.

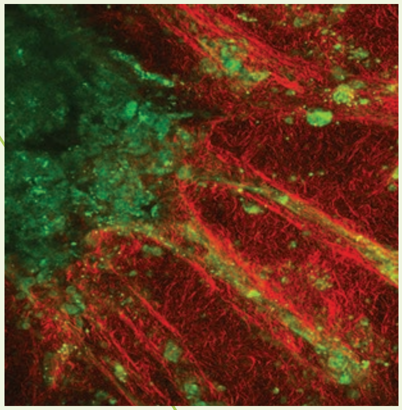
The Ultrasound Journal Club is attended by an interdisciplinary group of students and faculty interested in biomedical applications of ultrasound.

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, biomedical microscopy equipment, and mechanical testing apparatus.

Research Areas and Graduate Training Opportunities

RCBU laboratories are advancing the use of ultrasound in diagnosis and discovering new therapeutic applications of ultrasound, including:



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

UNIVERSITY of ROCHESTER

Rochester Center for Biomedical Ultrasound
University of Rochester
PO Box 270168
Rochester, NY 14627

Nonprofit
U.S. Postage Paid
Rochester, NY
Permit No. 780

RCBU

Rochester Center for Biomedical Ultrasound

2014 | Annual Report