Rochester Center for Biomedical Ultrasound

2007 Annual Report

On the cover

The Robert B. Goergen Hall for Biomedical Engineering and Optics officially opened in the spring of 2007. The collages on the front cover and inside back cover illustrate the building's architecture and the research and educational activities supported by this state-of-the-art building. A full story and "tour" of Goergen Hall can be found on pages 6-7.

Rochester Center for Biomedical Ultrasound

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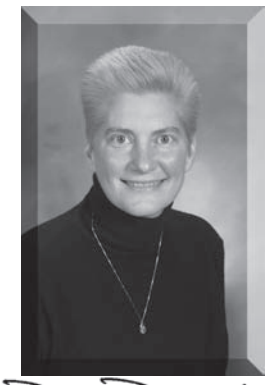
Table of Contents

FROM THE DIRECTORS

Diane Dalecki, PhD, Director



Diane Dalecki

This year marked the opening of the Robert B. Goergen Hall for Biomedical Engineering and Optics. This state-of-the-art educational and research facility was designed to stimulate cross-disciplinary learning and scientific discoveries. The RCBU main office and several RCBU faculty laboratories are now housed in Goergen Hall. The architecture and atmosphere of Georgen Hall reflect the RCBU's core mission of collaborative research, education, and innovation. The images and text on pages 6-7 of this report provide a tour of this remarkable new facility.

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. Elasticity imaging continues to expand and The Sixth International Conference on Ultrasonic Measurement and Imaging of Tissue Elasticity is reviewed in this report.

Collaborative projects between RCBU clinicians, engineers, and scientists continue to advance novel diagnostic and therapeutic applications of ultrasound. This year's annual report details progress from RCBU laboratories on diverse topics in biomedical ultrasound, including sonoelastography, acoustic radiation force imaging, multimodal imaging, ultrasound scattering, acoustic cavitation, and bioeffects. This annual report also highlights special awards and achievements by RCBU members. We welcome your comments on any of the enclosed reports.

Deborah J. Rubens, MD, Associate Director

2007 brought a new focus to ultrasound in Imaging Sciences. In June, we acquired the vascular lab for the Medical Center. Under the direction of Dr. Vikram Dogra, Director of Ultrasound, Chief Sonographer, Nancy Carson, and several vascular and interventional radiologists, the lab came up to speed; offering a full spectrum of vascular examinations from arterial-brachial indices to graft studies, carotid and vertebral Dopplers, as well as the full range of venous examinations already in our armamentarium. Many sonographers put in extra time and effort to learn the new techniques and procedures, and Nancy did a heroic job consolidating and streamlining all the studies, protocols and personnel. As a result, our vascular examinations now comprise nearly 50% of our entire studies, which total over 19,000 annually. Our Sonographer team continues to expand to meet growing clinical demands. We now total ten full-time and six part-time people, with increased staffing on evenings and weekends.

The department has recently signed a single vendor agreement with General Electric and the entire fleet of ultrasound equipment will be state-of-the-art with continuous upgrades to GE's newest platform. In addition to equipping the six examination rooms, there will be additional portable machines and a new brachytherapy machine to better serve the Medical Center population. We anticipate testing the CT/US fusion software GE is currently trialing, as well as their 3D workstation capabilities.

The University of Rochester Medical Center was represented by sonographers and physicians in education nationally and internationally. Dr. Dogra lectured on various ultrasound topics at the Singapore National Ultrasound Society, the Mumbai Ultrasound course in India, and at the Turkish Radiological Society meeting in Antalya, Turkey. Dr. Rubens, as Distinguished Scientist for Armed Forces Institute of Pathology, gave courses on liver Doppler, testis, and scrotal Doppler at the annual Radiologic-Pathology course, as well as talks on liver, gallbladder, renal, venous, and testicular ultrasound at AFIP courses in Brazil, Austria, Spain, Portugal, and Argentina. She also spoke on 3D Ultrasound representing the RCBU in Lima, Peru and at the University of Maryland. Center member Benjamin Castaneda lectured on sonoelasticity in Lima, Peru as well. Dr. Dogra was the international visiting RSNA professor to Uganda, Africa and spoke at the World Federation of Ultrasound meeting in Kampala and also at the Pan African Radiological Society meeting. In addition, he taught ultrasound at Mulago and Mengo hospitals in Kampala. Dr. Dogra was also the guest editor of Ultrasound Clinics of Genito-Urinary Tract and Ultrasound Clinics on Emergency Imaging published by Elsevier Science. He was also guest editor of Radiologic Clinics of North America on Emergency Cross-Sectional Imaging. Drs. Bhatt, Rubens, and Strang participated nationally teaching at AIUM, SRU, RSNA, and ARRS. Dr. Dogra also lectured at RSNA's annual meeting as a refresher course faculty member. Publications in the ultrasound field from members in the department of Imaging Sciences totaled over 19.

Deborah Rubens MD.

ABOUT THE ROCHESTER CENTER FOR BIOMEDICAL ULTRASOUND

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 country.

The Center provides a unique collaborative environment where researchers can join together to investigate the use of very 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 monthly 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 UR 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 imaging.
- 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 innovations have produced steady progress in new imaging modalities and therapeutic applications of ultrasound.
- RCBU members hold numerous patents in ultrasound and imaging. The UR ranks 9th in technology revenue income among all higher education institutions in the nation.

About the University of Rochester

The University of Rochester (www.rochester.edu) is one of the nation's leading private research universities. Located in Rochester, N.Y., the University's environment gives students exceptional opportunities for interdisciplinary study and close collaboration with faculty. Its College of Arts, Sciences, and Engineering is complemented by the Eastman School of Music, Simon School of Business, Warner School of Education, Laboratory for Laser Energetics, and Schools of Medicine and Nursing.

Collaborative Research, Education, and Innovation

Goergen Hall Opening

The Robert B. Goergen Hall for Biomedical Engineering and Optics officially opened in the spring of 2007. Dedication ceremonies for Goergen Hall were held on May 17, 2007 and included a scientific symposium by faculty researchers, guest speakers, a ribbon-cutting ceremony, tours, and many festivities. The 100,000 square foot facility is a home for the Biomedical Engineering (BME) department and provides state-of-the art research and teaching facilities for biomedical engineering and optics. The Rochester Center for Biomedical Ultrasound administrative office and research laboratories of several RCBU members are also now located in Goergen Hall.

The building is named after Robert B. Goergen in recognition of his long history of strategic support for the University of Rochester. Goergen, a UR alumnus and entrepreneur, has been a University Trustee since 1982 and served as chair from 1991-2003. Goergen pledged a gift of $10 million toward construction of this state-of-the-art research and educational facility. In the building dedication, Goergen states "It is my hope that these labs, classrooms, and common spaces will continue to foster groundbreaking research, education, and collaboration across disciplines for many generations to come."

A Tour of Goergen Hall

The Robert B. Goergen Hall for Biomedical Engineering and Optics is a $40-million, five-story building that contains state-of-the art research facilities, classrooms, and teaching laboratories. The first floor is dedicated to teaching spaces. The second and third floors house the BME department, RCBU main office, and BME faculty research and teaching labs. Optics research and teaching facilities are located on the fourth and fifth floors. The Center for Institute Ventures, also housed on the fifth floor, helps faculty members commercialize their research and innovations.

The building is located on the edge of the River Campus closest to the UR Medical Center. Its location facilitates multi-disciplinary collaborations between biomedical engineers in Goergen Hall and basic scientists and physicians in the Medical Center. The Millennium Bridge is an enclosed walkway that connects the second floor of Goergen Hall to the Carlson Science and Engineering Library, and to the Computer Studies Building. Each floor of Goergen Hall is also connected to the Institute of Optics in the Wilmot Building.

Entrance into the building opens to Munnerlyn Atrium (named after UR alumnus Charles R. Munnerlyn). The atrium is the centerpiece of Goergen Hall. Its skylights above the fifth floor fill the building with natural light. The first floor of Goergen Hall is dedicated to teaching facilities. A coffee-shop off the atrium is an active gathering spot for students, faculty, and staff.

Teaching Facilities: Sloan Auditorium (named for UR alumnus Thomas R. Sloan) is a 150-seat, lecture hall with state-of-the-art video, audio and networking capabilities. There are also smaller lecture halls and classrooms on the first floor, and conference/ meeting spaces throughout the building.

BME teaching laboratories, including wet-lab space and facilities for bioinstrumentation labs, are housed on the first floor. The second floor contains dedicated space for BME Senior Design projects and shop facilities. There are also teaching laboratories for cell and tissue engineering, biomaterials testing, ultrasound, and microscopy.

The administrative offices of the BME department are housed in a glass-enclosed suite on the second floor. The RCBU main office is located on the third floor of Goergen Hall, above the BME departmental offices.

Research space in Goergen Hall is uniquely designed for faculty members in biomedical engineering and optics. Research laboratories and offices of RCBU members Diane Dalecki, Stephen McAleavey, Amy Lerner, and Richard Waugh, are all now located in Goergen Hall.

The open floor plan of Goergen Hall allows clear views to all floors of the building. Each floor contains an open lounge area. These common spaces are often utilized for student study groups and informal meetings among researchers. The environment is ideal for stimulating cross-disciplinary learning and research.

2007 RESEARCH

Research laboratories of RCBU members are advancing the use of ultrasound for diagnosis and treatment. The pages that follow highlight research accomplishments in 2007. Publications and presentations of this year can be found on pages 28–29.

Semi-automatic measurement of thermal ablated lesions in sonoelastography images

Benjamin Castaneda, MS, Maggie Zhang, PhD, Kevin Bylund, MD, Jared Christensen, MD, Wael Saad, MD, Deborah J. Rubens, MD, Kevin J. Parker, PhD

In order to process the large amount of images generated in sonoelastography, an accurate and fast method for measuring the size and shape of the lesions is needed. Recent work by Castaneda et al. employs a semi-automatic segmentation algorithm for sonoelastography data. The aim of the algorithm is to reduce the variability and processing time involved in manual segmentation while keeping comparable results.

Radiofrequency ablation was used to create 11 lesions in 5 porcine livers. Sonoelastography images were acquired in vivo. The animal was sacrificed after imaging and lesions were harvested and measured. These measurements were considered ground truth and ranged from 20 mm^2 to 250 mm^2. Three independent observers manually measured the lesions in the sonoelastography images. The images were also processed by the semi-automatic algorithm. The algorithm requires an initialization step in which the user selects the center of the lesion. This initialization was performed by three different observers. Based on the user's input, a region-growing technique based on initial watershed segmentation is applied to define an estimate of the area of the lesion. Then, level-set methods are used to refine the final shape of the lesion.

Measurements of lesion size (area) were analyzed. Table 1 summarizes the results for manual and semi-automatic methods. The correlation coefficients and average and maximum errors were computed with respect to ground truth. Results showed that the semi-automatic algorithm outperformed manual segmentation. Inter-observer coefficients of variation indicated that the algorithm increases repeatability. The processing time was reduced more than 15 times. These results suggest that measurement of lesions in sonoelastography images can be processed in real-time with minimal human intervention.

Table 1. *Comparison between manual and semi-automatic segmentations.*

	Correlation Coefficient (%)	Average Error (mm^2)	Max Error (mm^2)	Coefficient of Variation (%)	Average Segmentation time per lesion (min)
Manual Segmentation	88.3	-8.7	57.6	3.9	3.8
Algorithm	95.5	6.1	33.2	1.1	0.2

Real-time shear velocity imaging using sonoelastographic techniques

Kenneth Hoyt, PhD, Kevin J. Parker, PhD, Deborah J. Rubens, MD

Recently, it was shown by RCBU members in Dr. Parker's lab that interfering shear waves can produce slowly propagating interference patterns with an apparent velocity much less than (but proportional to) the underlying true shear velocity. Termed crawling waves, they are generated using a pair of mechanical sources vibrating at slightly offset frequencies or by continuously phase shifting one of the source excitation signals. The resultant shear wave interference patterns can be visualized in real-time using sonoelastographic imaging techniques. In general, crawling wave images describe shear wave propagation patterns and allow local estimation of shear velocity distributions. Assuming that the local shear velocity values are proportional to the square root of the shear modulus, spatial mapping of either parameter allows production of quantitative tissue elasticity images.

A real-time sonoelastographic technique for estimating local shear velocities from crawling wave images was introduced by Hoyt et al. (Ultrasound Med. Biol. 33: 1086-1097, 2007). A relationship between the local crawling wave phase derivatives and shear wave velocity was derived with phase derivatives estimated using a one-dimensional (1D) autocorrelation-based technique. Results from homogeneous phantoms demonstrated the ability of sonoelastographic shear velocity imaging to quantify the true underlying shear velocity distributions as verified using time-of-flight measurements. Heterogeneous phantom results revealed the capacity for lesion detection and shear velocity quantification as validated from mechanical measurements on phantom samples. Experimental results obtained from a prostate specimen illustrated feasibility for shear velocity imaging in tissue. More importantly, high-contrast visualization of focal carcinomas was demonstrated introducing the clinical potential of this novel sonoelastographic imaging technique.

Subsequent work by Hoyt et al. (Proceeding of the SPIE 6513: 65130L, 2007), assessed lesion contrast and detection using sonoelastographic shear velocity imaging. Shear wave interference patterns for a two phase medium were simulated assuming plane wave conditions. Shear velocity estimates were computed using a spatial autocorrelation algorithm that operates in the direction of shear wave propagation for a given (1D) kernel size. Contrast was determined by analyzing the shear velocity estimate transition between the two disparate elastic mediums. Experimental results were obtained using heterogeneous phantoms with spherical inclusions (5 or 10 mm in diameter) characterized by elevated shear velocities. Two vibration sources were applied to opposing phantom edges and scanned (orthogonal to shear wave propagation) with an ultrasound scanner equipped for sonoelastography. Demodulated data were saved and transferred to an external computer for processing shear velocity images. Simulation results demonstrate the shear velocity transition between contrasting mediums is governed by both estimator kernel size and source vibration frequency. Experimental results from phantom materials further indicate that decreasing the estimator kernel size produces a corresponding decrease in shear velocity estimate transitions between background and inclusion materials albeit with an increase in estimation noise. Overall, results demonstrate the ability to generate high contrast shear velocity images using sonoelastographic techniques and detect millimeter-sized lesions.

An eigenfunction method for reconstruction of large-scale and high-contrast objects

Robert C. Waag, PhD, Feng Lin, PhD, Trond K. Varslot, PhD, Jeffrey P. Astheimer, PhD

In recent work from the laboratory of Professor Waag, a multiple-frequency inverse scattering method, that uses eigenfunctions of a scattering operator, was extended to image large-scale and high-contrast objects. The extension uses an estimate of the scattering object to form the difference between the scattering by the object and the scattering by the estimate of the object. The scattering potential defined by this difference is expanded in a basis of products of acoustic fields. These fields are defined by eigenfunctions of the scattering operator associated with the estimates. In the case of scattering objects for which the estimate is radial, symmetries in the expressions used to reconstruct the scattering potential greatly reduce the amount of computation. The method was applied to experimental data from a 48-mm diameter scattering object with tissue-like properties. The image reconstructed from measurements has, relative to conventional B-scan formed using a low f-number at the same center frequency, significantly higher resolution and less speckle, implying that small, high-contrast structures can be demonstrated clearly using the extended method.

Enhancement of elasticity images using locally adaptive Gaussian filtering

Kenneth Hoyt, PhD, Kevin J. Parker, PhD

The purpose of this research was to introduce and analyze a technique for enhancing elasticity image quality using locally adaptive Gaussian filtering (Proceedings of the SPIE 6513: 65131F, 2007). To assess the performance of this filtering method for reconstructing images with missing or degraded data, heterogeneous images were simulated with circular regions of intensity twice that of the surrounding material. Missing pixel data were introduced by thresholding a uniformly distributed noise matrix. Results demonstrate locally adaptive Gaussian filtering (AGF) accurately reconstructs the original image while preserving boundary detail. To further analyze the performance of this filtering technique, multiple local image regions were suppressed and normally distributed noise superimposed. Consequently, locally adaptive Gaussian filtering is capable of reconstructing local missing data whereas both median (MF) and conventional Gaussian filtering (GF) fail, Figure 1. Using compressional elastographic experimental data, results illustrate that locally adaptive Gaussian filtering is capable of minimizing decorrelation noise artifacts while preserving lesion boundaries. Additionally, results obtained using vibrational shear velocity sonoelastography further illustrate the ability of locally adaptive Gaussian filtering to enhance image quality by minimizing estimator noise degradation in comparison to conventional spatial filtering techniques. Overall, results indicate the feasibility of employing this spatial filtering technique for improving elasticity image quality while preserving lesion boundaries.

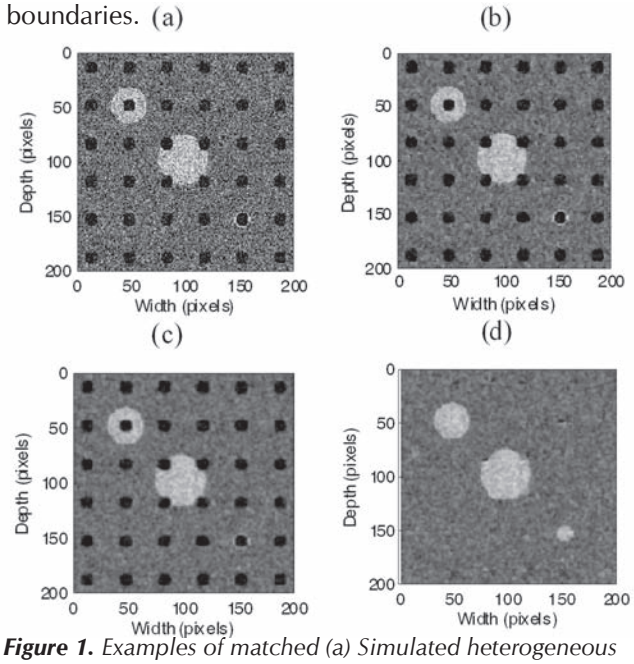


Figure 1. *Examples of matched (a) Simulated heterogeneous image with localized regions of missing data (black "holes") superimposed with white noise, (b) MF image using a 3-by-3 pixel kernel, (c) GF image and (d) AGF image.*

Interactions of underwater sound fields and mammalian lung

Diane Dalecki, PhD, Sally Z. Child, MS, Carol H. Raeman, AAS

The Dalecki lab continues to investigate the interaction of underwater sound fields with biological tissues. The U.S. Navy and the Naval Submarine Medical Research Laboratory (NSMRL) in Groton, CT support our projects in this area. Underwater sound over a broad frequency range can be produced from a variety of sources including sonar systems and underwater blasts. An understanding of the interaction of underwater sound fields with biological systems is necessary to develop safe exposure guidelines for humans, marine mammals, and fish exposed to these acoustic fields. Tissues containing gas are particularly sensitive to underwater sound exposure. Over the years, our laboratory has been working to quantify the thresholds for sound-induced damage to tissues containing gas and identify the physical mechanisms for tissue damage.

The air-filled lung is particularly sensitive to underwater sound exposure. We have investigated the response of murine lung to underwater sound exposure for frequencies spanning over four orders of magnitude (i.e., ~100 Hz to 1000 kHz). To generate low frequency underwater sound fields, we have used a G40 inertial calibrator (~100-500 Hz) and a specially designed traveling wave tube (~100–6000 Hz), Figure 1. At higher frequencies (i.e., ≥ 10 kHz), we employ either horn transducers or single element piezoceramic transducers as acoustic sources. All systems are designed to easily accommodate exposure of small lab animals to the sound fields in vivo. Professor Sheryl Gracewski has developed both analytical and computational models to predict the acoustic fields within the exposure chambers of our experimental acoustic systems.

When the intact, air-filled lung is exposed to sound at frequencies where the wavelength is much greater than the radius of the lung, we have demonstrated that the whole lung oscillates radially in response to exposure to this spatially uniform sound field. Using both an acoustic scattering technique and a pulse-echo ranging technique, we have shown that the response of the lung is maximized for exposure at the resonance frequency of the lung. At the resonance frequency of the lung, the threshold for damage to the lung and surrounding tissues is lowest. In the adult mouse, the resonance frequency of the lung is ~325 Hz and the threshold for lung damage at the resonance frequency is ~2 kPa. Mammalian lung can also be damaged by exposure to low frequency sound above resonance frequency. Our lab determined the thresholds for murine lung hemorrhage from exposure to continuous wave underwater sound at frequencies ranging from ~2.5–1000 kHz. The equation $P_{thresh} = 0.01f^{0.64}$, where P_{thresh} is the threshold pressure in MPa and f is the acoustic exposure frequency in kHz, represents a best-fit to our experimental lung threshold data over the 2.5–1000 kHz range.

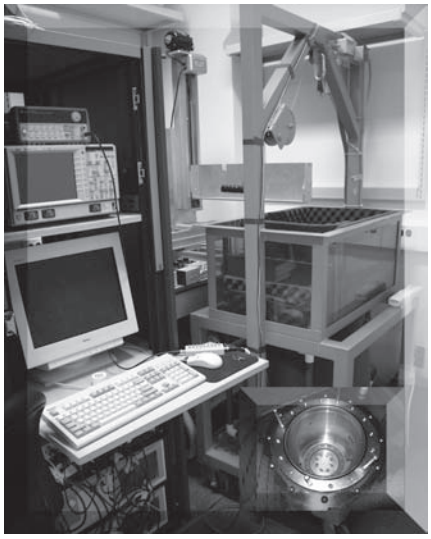


Figure 1. *Low-frequency sound exposure system.*

Progress this year focused on investigations of the response of lung to sound exposure at and near lung resonance frequency. We have determined the threshold for lung hemorrhage from exposure to acoustic fields at 500 Hz, and investigated the response of lung to 200-Hz sound fields. Results of both investigations indicate that the threshold or lung damage increases significantly for frequencies above and below lung resonance. A series of experiments were performed to determine the roles of exposure timing parameters on sound-induced lung damage for exposure at the lung resonance frequency. Through several experimental tests, we have demonstrated that sound-induced lung hemorrhage can occur for exposure durations as short as 1 s. The pressure threshold for lung hemorrhage does not differ greatly for exposure durations of 10 s, 1 min and 3 min. However, for a given pressure amplitude, the extent of damage increases with increasing exposure duration. Further studies in our lab continue to characterize the response of lung to continuous wave sound exposures of short duration over a broad frequency range.

Coded waveforms

Michael Sealander, MS, Edward Titlebaum, PhD, and Stephen McAleavey, PhD

The research we are currently conducting extends over several projects in diagnostic ultrasound including the use of coded waveforms, associated array processing techniques, and the mathematical inversion of wave propagation.

In echo-location systems, replica correlating is an optimum detector in the presence of additive white Gaussian noise, but it does not account for many other types of channel distortion. It is often the case that a received signal has been subject to distortion including nonlinear propagation and frequency dependent absorption. We have developed coding schemes to self-

adaptively account for these types of distortion and are investigating their relative performances. Additionally, when targets are range-extended, we have developed a time-varying adaptive RAKE filter to reintegrate the target's impulse response for superior target detection.

Another project being pursued is the extraction of sound speed profiles of inhomogeneous media given a space-time dataset of a propagating waveform. Using a mathematical model of propagation, we have developed a method of projection onto convex sets (POCS) that inverts the model producing an estimate of the sound speed profile. The technique has applications to elasticity imaging by tracking shear wave propagation.

The Dalecki lab collaborates with Hydroacoustics, Inc. to study the bioeffects of underwater impulses

Diane Dalecki, PhD, Sally Z. Child, MS, Carol H. Raeman, AAS, Sheryl M. Gracewski, PhD

Sponsored by the U.S. Naval Submarine Medical Research Laboratory (NSMRL), the Dalecki lab is investigating the effects of low frequency, underwater sound impulses on biological systems. Underwater impulsive sound fields are employed in the ocean for both commercial and military applications. For our investigations, underwater acoustic impulses are produced with an air gun source system.

To generate and test the bioeffects of these impulsive acoustic fields, the Dalecki lab has developed a collaboration with a Rochester-based company, Hydroacoustics, Inc. (HAI). HAI manufactures and supports unique low frequency, continuous wave and impulsive underwater sound sources. The HAI facility, located a short distance from the UR, includes 12,000 square feet of laboratory space dedicated to acoustic research and testing of underwater sound sources. Air gun technology, water tanks, and measurement facilities at HAI are used to generate underwater acoustic impulses for our bioeffects investigations.

The Dalecki lab and Hydroacoustics, Inc. (HAI) are working together to investigate the effects of underwater acoustic impulses on mammalian lung. Robert De La Croix, Vice President of Engineering at HAI, has been a key collaborator in adapting the HAI exposure apparatus for the Dalecki team's biological experiments. This past year, the team completed a series of investigations to characterize the acoustic impulse fields generated by various air gun systems in the water tanks available at the HAI facility. Professor Sheryl Gracewski and her students used finite element modeling techniques to simulate the acoustic fields under the specific geometries relevant to our experimental field measurements. The Dalecki lab then began investigations to determine the effects of these impulse fields on murine lung in vivo. Using a 10 cubic inch air gun system, we investigated the response of lung to acoustic impulses with peak acoustic pressure amplitudes ranging from ~0-60 kPa. We found that lung hemorrhage could be produced following exposure to five underwater acoustic impulses with pressure amplitudes equal to or greater than 45 kPa. Ongoing studies continue to characterize the response of lung to these underwater impulses. In related upcoming investigations, the Dalecki lab will collaborate with the laboratory of John Olschowka, Ph.D. to study the effects of underwater acoustic impulse fields on the mammalian brain and spinal cord (see related story on page 21).

Non-invasive output measurement of cardiac assist devices using quantitative contrast Doppler echocardiography

Karl Q. Schwarz, MD, Xucai Chen, PhD, Sherry Steinmetz, RDCS

Many implantable ventricular assist devices (VADs) that are currently clinically available have no direct measurement of pump output; instead, they estimate output using calculations based on indirect measures, such as power consumed and pump speed, or VAD rate and stroke volume. Recent work by Dr. Schwarz and colleagues tested the hypothesis that quantitative contrast Doppler echocardiography can be used to accurately measure the output of VAD devices compared to independent flow measurements.

A continuous-flow impeller-style VAD (HeartMate II) was tested in a flow system consisting of plastic tubing and pressurized reservoirs designed to simulate the human circulation. Contrast-enhanced spectral Doppler was used to monitor the flow velocities in the inlet and outlet cannulae of the VAD. The Doppler-measured minute flow rate (Dopp_Q) was calculated as the product of the spectral Doppler flow velocity time integral and the cannula cross-sectional area, normalized to 60-seconds. The actual minute flow rate was simultaneously measured with an ultrasonic flow meter (Q). The VAD rate was adjusted between 6,400 and 12,000 RPM in 13 steps and afterload was adjusted from none (tubing resistance only) to total occlusion in 5 steps. A total of 130 flow measurements were made, half with phasic inflow pressure and half with static inflow pressure.

Q ranged from -0.25 to 6.01 LPM. Dopp_Q in the outflow and inflow cannulae showed an excellent correlation with measured Q (Outlet Dopp_Q = $1.0052*Q+0.048$, $R^2 = 0.9865$, and Inlet Dopp_Q = $1.5043*Q+0.003$, $R^2 = 0.9904$), but the inlet Dopp_Q was 50% higher than the measured Q. This was determined to be due to different velocity profiles

in the HeartMate IIs conical inlet tube compared to the uniform-diameter outflow graft, which showed plug flow. Correcting for the non-linear conical inlet tube's velocity profiles yielded excellent correlation with measured Q (Inlet Dopp_Q = 1.0029*Q+0.002, R^2 = 0.9904). Phasic vs. non-phasic inflow pressure yielded results that were not statistically different.

These recent studies demonstrated that non-invasive Doppler flow techniques can be used to accurately measure VAD flow, but the characteristics of the cannula velocity profiles need to be taken into account.

Obstetrics & Gynecology Ultrasound Unit

Eva K. Pressman, MD and Tulin Ozcan, MD

The OB/GYN Ultrasound Unit continues to be involved in busy clinical practice and multiple research endeavors. OB/Gyn ultrasound services are provided at Strong Memorial Hospital, Highland Hospital, Rochester General Hospital, FF Thompson Hospital and our facilities at Red Creek Drive and West Ridge Road. This year, the medical directorship of OB/Gyn Ultrasound was transferred to Dr. Tulin Ozcan due to her strong clinical skills as well as her academic interests in ultrasound and prenatal Doppler. The volume of patients seen for OB/Gyn ultrasound remains high, with more than 22,000 studies performed including 370 amniocenteses, 120 chorionic villus samplings, 187 sonohysterograms, and 6 fetal blood samplings and transfusions. In addition, the Strong Maternal Fetal Medicine Faculty interpreted almost 2000 obstetrical ultrasound examinations at FF Thompson Hospital utilizing a combination of telemedicine and onsite service. We are hopeful that our services to the entire Finger Lakes Region will continue to increase.

We continue to expand the availability of first trimester screening for aneuploidy and have seen a marked increase in first trimester diagnostic procedures with chorionic villus sampling. Additional equipment has been obtained to increase the utilization of 3-D and 4-D scanning in both obstetrics and gynecology.

Areas of research have expanded to include sonographic markers for fetal aneuploidy, training for ultrasound guided procedures, and the effects of maternal obesity on the diagnostic accuracy of prenatal ultrasound. A sample of recently completed research projects is provided below.

Mitral valve-tricuspid valve distance as sonographic marker of trisomy-21.

Daniel Grace, MD, J. Christopher Glantz, MD, Tulin Ozcan, MD

OBJECTIVE. Pathologic studies suggest decreased mitral valve-tricuspid valve distance (MTD) in trisomy-21 fetuses without cardiac defects. We assessed the feasibility of using MTD as a second trimester sonographic marker for trisomy-21.

STUDY DESIGN. All cases of trisomy-21 at our institution from 1998 to 2006 were reviewed. Cases without cardiac defects and with adequate images from 15 to 26 weeks were assessed. The distance between the medial insertions of the mitral and tricuspid valves (MTD) was obtained. We also obtained the MTD from normal controls. Multiple linear regression analysis using SPSS assessed the independent effects of gestational age and trisomy-21 on MTD.

RESULTS. We identified 53 trisomy-21 fetuses with a measurable MTD and compared these with 123 control fetuses. Multiple linear regression revealed a positive association between MTD and gestational age (coefficient 0.09, $p < 0.001$) and a negative association between MTD and trisomy 21 (coefficient -1.0, $p < 0.001$). Regression R square was .40, with $p < .001$.

CONCLUSION. The MTD increases with gestational age. After adjusting for gestational age, we found the MTD for fetuses with trisomy 21 without cardiac defects is on average 1 mm smaller than controls. The MTD may be useful as a marker for trisomy-21. Larger prospective trials are needed to confirm these findings.

Completion rates for ultrasound anatomic surveys in obese gravid patients compared with non-obese controls

Loralei Thornburg, MD, Kathryn M. Miles, MD, Eva K. Pressman, MD, Monique Ho, MD

OBJECTIVE. Compare the rate and gestational age (GA) of completion of fetal anatomic surveys for obese gravid patients to non-obese controls.

STUDY DESIGN. Retrospective review of anatomic surveys of singletons 15-24 weeks from 1/2004 to 1/2007, at a single institution. Subjects were grouped based on pre-pregnancy BMI into normal weight (BMI 18.5-24.9), overweight (BMI 25-29.9), and obese: Class I (BMI 30-34.9), Class II (BMI 35-40) or Class III (BMI > 40) categories. Complete surveys were defined as adequate visualization of 13 predefined fetal structures, including biometry, intracranial anatomy, 4 chamber heart view, arms, legs, spine, ventral wall, diaphragm, kidneys, bladder, stomach, and 3 vessel cord.

RESULTS. Of 14,353 ultrasound visits reviewed, 7023 patients were eligible for inclusion. The rate of survey completion, number of exams required, and GA at completion differed significantly as BMI increased. The completion rate at the first attempt decreased significantly with increasing BMI, while GA at completion on the first attempt increased (all p-values < 0.00001).

CONCLUSION. As maternal BMI increases, the rate of completion of the anatomic survey decreases, while the number of required exams increases. Delaying the initial anatomic survey until after 20 weeks for patients with BMI > 35 may improve the ability to complete the exam in a single visit.

Dynamic response of constrained bubbles to acoustic excitation

Sheryl M. Gracewski, PhD

Numerous systems, from ultrasound contrast agents to microfluidics, depend on the dynamic response of bubbles whose expansion is constrained by a surrounding tube or channel. For example, ultrasound contrast agents are microbubbles injected intravenously to enhance diagnostic imaging techniques. Furthermore, potential therapeutic uses of biomedical ultrasound, including localized drug delivery and clot dissolution, may be enhanced by the acoustic excitation of targeted microbubbles within the blood stream. The goal of ongoing work in the Gracewski laboratory is to develop an understanding of the complex dynamic interactions between a gas cavity in a liquid and a surrounding compliant solid tube or channel. To model the highly nonlinear interaction of this three-phase system with large deformations and rapidly changing time scales, simulation techniques are being developed using coupled ***boundary element*** and ***finite element methods.*** The description below provides insight into the value of these simulation techniques in understanding the interaction of ultrasound with microbubbles in biological systems.

For numerical simulations, the equilibrium bubble radius, $R_o = 1.5$ μm, was chosen to represent the average size of typical ultrasound contrast agents. A schematic diagram for simulations of a bubble centered in a tube is given in Figure 1. The average inner radius of capillaries is ~ 4 μm. However, to investigate the influence of the vessel inner radius on bubble oscillations, inner tube radii $r_{tube} = 2$ μm, 4 μm, and 8 μm were used. Due to limited computing resources, the tube length L was set equal to 30 μm, ten times the initial bubble diameter. The average thickness of the capillary wall, ~ 1 μm, was used for the tube wall thickness *w*. The Young's modulus, Poisson's ratio, and density of the tube wall material used in the simulations were $E = 10$ MPa, $\nu = 0.49$, and $\rho_s = 1100$ kg/m^3, respectively, to represent a stiff vessel material.

In the simulations, the bubble and the tube were exposed to ultrasound with frequency of 1 MHz and pressure amplitude of 0.2 MPa. The amplitude of 0.2 MPa is just above the inertial cavitation threshold predicted by the Rayleigh-Plesset equation. Other constant parameters used for numerical simulations were: $\rho_l = 1000$ kg/m^3, $p_v = 2300$ Pa, $p_o = 101230$ Pa, $\sigma = 0.0717$ N/m, $\Gamma = 1.4$, where ρ_l is the liquid density, p_v the vapor pressure, p_o the ambient pressure, σ the surface tension of the liquid, and Γ the polytropic exponent of the gas.

In Figure 2, a series of bubble and tube shapes are plotted for a tube radius equal to 4 μm. The maximum tensile hoop stress occurs at $t = 0.189$ μs, well before the bubble reaches its maximum radius. The tube begins to contract even while the bubble is still expanding.

These results support the hypothesis that the tensile acoustic excitation causes tube dilation when a bubble is present. The pressure drop across the tube occurs because the expanding bubble cannot support a tensile force to balance the tensile excitation force on the outer tube surface. Therefore, the tube dilation is much greater in the region near the bubble.

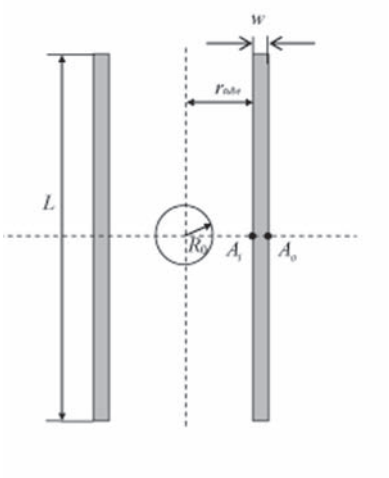


Figure 1. *Schematic illustration of a single bubble in a tube.*

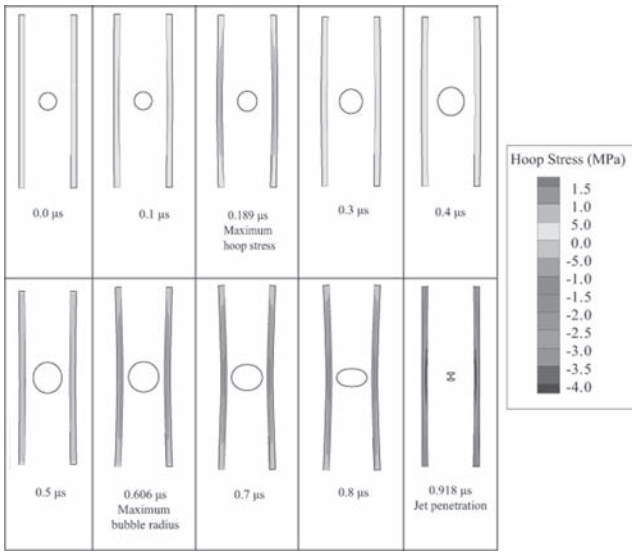


Figure 2. *Bubble and tube shapes and hoop stress distribution within the tube wall at a series of time points for* $r_{tube} = 4$ μm.

Congruence of imaging estimator and mechanical measurements of viscoelastic properties of soft tissues

Man Zhang, PhD, Benjamin Castaneda, MS, Zhe Wu, PhD, Priya Nigwekar, MD, Jean Joseph, MD, Deborah J. Rubens, MD, Kevin J. Parker, PhD

Biomechanical properties of soft tissues are important for a wide range of medical applications, such as surgical simulation and planning and detection of lesions by elasticity imaging modalities. Currently, data in the literature are limited and conflicting. Furthermore, to assess the biomechanical properties of living tissue in vivo, reliable imaging-based estimators must be developed and verified. For these reasons, we developed and compared two independent quantitative methods—crawling wave estimator (CRE) and mechanical measurement (MM) for soft tissue characterization. The CRE method images shear wave interference patterns from which the shear wave velocity can be determined and hence the Young's modulus can be obtained. The MM method provides the complex Young's modulus of the soft tissue from which both elastic and viscous behavior can be extracted. A recent article from this group (Ultrasound in Medicine and Biology 33:1617-31, 2007) presented the systematic comparison between these two techniques on the measurement of gelatin phantom, veal liver, thermal-treated veal liver and human prostate. It was observed that the Young's moduli of liver and prostate tissues slightly increase with frequency. The experimental results of the two methods are highly congruent, suggesting CRE and MM methods can be reliably used to investigate viscoelastic properties of other soft tissues, with CRE having the advantages of operating in nearly real time and in situ.

SMURF: A new method for quantification of tissue stiffness

Stephen McAleavey, PhD

Changes in tissue stiffness have long been associated with disease. Manual palpation and elastography have been used to detect localized changes in stiffness, i.e. the presence of "lumps," and provide a useful contrast mechanism for imaging. In addition to detecting localized tissue changes, there is evidence that quantification of tissue stiffness can be a sensitive indicator of disease. Liver fibrosis staging is a particularly interesting example of an application where tissue stiffness quantification can be used to detect and grade disease. Ultrasound methods for tissue stiffness quantification are especially attractive due to their low cost and non-toxic nature.

We are developing a new method, based on ultrasound acoustic radiation force for tissue stiffness quantification, called Spatially Modulated Ultrasound Radiation Force (SMURF) [McAleavey et al., Ultrasonic Imaging 29:87-104, 2007]. The principle of SMURF imaging is to use acoustic radiation force to generate a shear wave of known wavelength (λ) in a material of uniform unknown shear modulus and measure the temporal frequency of the propagating shear wave to determine the shear modulus of the material. The frequency (f) of this wave, which depends solely on its point of generation and not the surrounding environment, is then measured to determine the shear modulus (G) of the tissue using the relationship $G = (\lambda f)^2 \rho$ where ρ is the tissue density ($\sim 10^3$ kg/m^3). The frequency is estimated from tissue motion tracked ultrasonically using the same transducer that generated the radiation force beam. The pulsed nature of the shear waves avoids interference from standing waves inherent in continuous wave methods, while the use of acoustic radiation force to generate the shear wave at the point of interest eliminates difficulties in propagating a shear wave from the body surface to the region of interest, i.e. attenuation, refraction, and slip boundaries between tissues. Our ability to control the lateral ultrasound beam intensity allows tissue probing at a variety of (shear wave) frequencies, allowing viscoelastic properties of the tissue to be characterized.

Our preliminary in vitro studies have shown that SMURF imaging is capable of providing rapid estimates of shear modulus in good agreement with values obtained through standard mechanical testing methods. Figure 1 (next page) shows a simulated image of tissue velocity as a function of position 4.6 ms after application of a spatially-varying radiation force with 1 cycle/mm intensity variation. The material has a shear modulus of 1 kPa, with a 2-kPa, 1-cm diameter circular lesion at right. The broadening of the shear wave in the higher sound speed lesion is evident.

Figure 2 (next page) is a schematic illustration of SMURF push and track beam arrangements. A spatially varying ultrasound beam intensity (denoted by the gray ellipses) applies a similarly spatially varying, impulsive load to the tissue phantom, inducing a shear wave. The tissue velocity due to the propagating shear wave is tracked at the location indicated by the tracking beam (dashed line). Figure 2 (right) displays an image of measured velocity versus axial position (vertical axis) and time (horizontal axis) in a two layer phantom, with brightness corresponding to velocity. Note the higher frequency of the shear wave induced in the stiffer material, compared to the lower frequency in the softer material. Figure 3 (left) is the mean frequency estimate image in a bi-layer phantom, with softer upper layer and stiffer lower layer. The right panel is the B-mode image of the ame region of the phantom, with no distinct contrast visible.

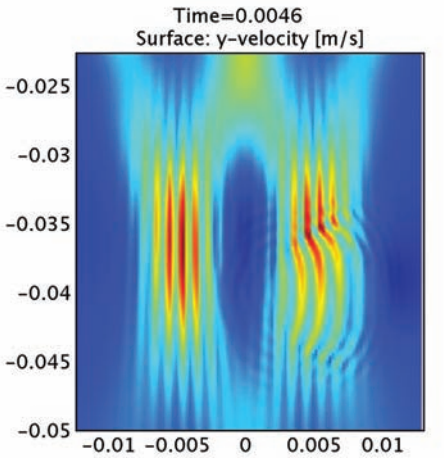
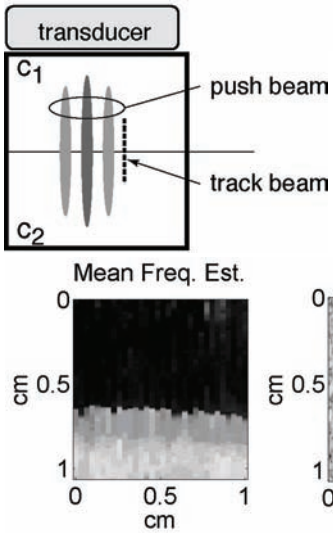


Figure 1. *Simulated image of tissue velocity as a function of position.*



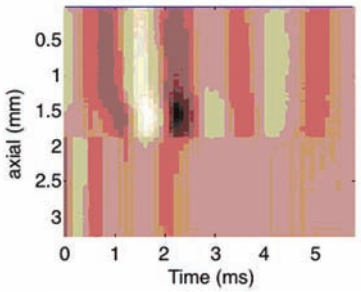


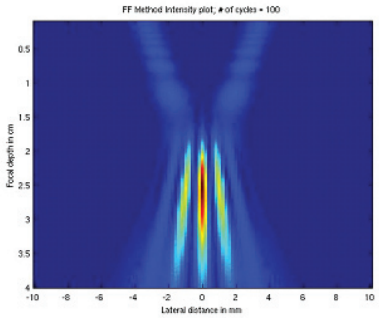
Figure 2. (below) *SMURF push and track beam arrangements.* ***(right)*** *Image of measured velocity vs axial position.*

Figure 3. (left) *Mean frequency estimate image in a bi-layer phantom with softer upper layer and stiffer lower layer.* ***(right)*** *B-mode image of same region of phantom.*

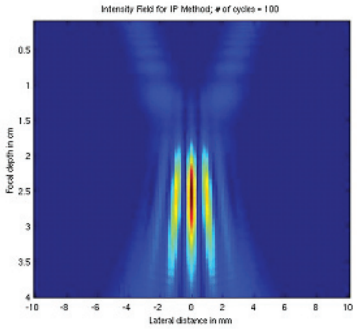
Generating spatially modulated ultrasound radiation forces

Etana Elegbe, BS, Stephen McAleavey, PhD

In the McAleavey lab, Etana Elegbe, BME graduate student, is currently investigating two methods of generating spatially modulated ultrasound radiation forces (SMURF); specifically, the focal Fraunhofer and Gaussian beam/Intersecting plane wave methods. The potential clinical applications of Spatially Modulated Ultrasound Radiation Forces are based on the ability of the radiation forces to determine the shear modulus of a region, which in turn is a means of quantifying the stiffness of that area.The focal Fraunhofer method relies on the knowledge that lateral pressure distribution at a specific focal depth is determined by the Fourier transform of the apodization function. The beam is formed by creating two near impulses with groups of transducer elements a certain distance apart. The method of intersecting plane waves involves two unfocused sources that are directed at an angle θ so as to create plane waves that will intersect at a desired focal point. The goal of this work is to determine which method will generate the greatest intensities, and thus displacements, given a certain area and a limited drive voltage for each transducer element.



1a: Focal Fraunhofer Method of SMURF beam formation



1b: Intersecting Plane Wave Method of SMURF beam formation

Figure 1: *Field II simulation of both methods. [Array centered at (0,0) radiating in the +z direction (downwards); Lateral intensity variation = 1cycle/mm, at a depth of 2.5cm; Lateral envelope given by* $\exp(-x^2/2\sigma^2)$*, with* $\sigma = 1mm$ *].*

Two-dimensional quantitative sonoelastographic imaging

Kenneth Hoyt, PhD, Benjamin Castaneda, MS, Kevin J. Parker, PhD

Despite promising results using a previously developed one-dimensional (1D) shear velocity sonoelastographic imaging technique, a more accurate and robust quantitative estimator was hypothesized, which functions by exploiting shear wave displacement data in neighboring depth regions. Therefore, this study focused on developing and evaluating a two-dimensional (2D) quantitative sonoelastographic technique for estimating local shear velocities from crawling wave images (IEEE Ultrasonics Symposium: 2032-2035, 2007). In our validation experiments comparing the 1D and 2D-based estimation techniques, homogeneous tissue-mimicking phantom results demonstrate the ability of both quantitative sonoelastographic imaging methods to accurately reconstruct the true underlying shear wave speed distributions as verified using mechanical measurements. From heterogeneous phantoms containing a 5 or 10

mm stiff inclusion, contrast-to-noise ratio (CNR) values from quantitative sonoelastograms reveal that the 2D quantitative sonoelastographic imaging technique outperforms the 1D precursor in terms of image noise minimization and contrast enhancement. A representative set of matched crawling wave and quantitative sonoelastograms (processed using the 2D-based estimation method) are depicted in Figure 1. Experimental results from an embedded porcine liver specimen with an induced radiofrequency ablation (RFA) lesion validate 2D quantitative sonoelastographic imaging in tissue. Overall, 2D quantitative sonoelastography was shown to be a promising new imaging method to characterizing the shear velocity distribution in elastic materials.

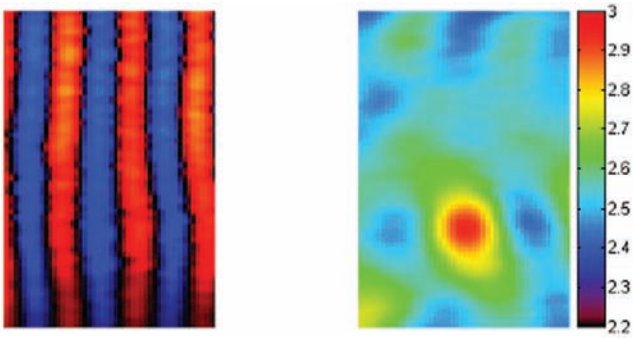


Figure 1. *Crawling wave sonoelastogram* ***(left)*** *depicting shear wave interference patterns in a tissue-mimicking gelatin phantom with an embedded 5 mm diameter spherical inclusion of stiffer gelatin. Shear waves were excited using a vibration frequency of 200 Hz and local image properties (namely spatial wavelength) reflect the material's elastic properties. The quantitative sonoelastogram* ***(right)*** *depicts the shear velocity distribution (unit of m/s) within the heterogeneous phantom material. The estimated shear velocity of the stiff inclusion is approximately 1.5 times higher than the surrounding material.*

Prostate cancer detection based on sonoelastography

Benjamin Castaneda, MS, Kenneth Hoyt, PhD, Maggie Zhang, PhD, David Pasternack, BS, Laurie Baxter, PA (ASPC), Priya Nigwekar, MD, Anthony di Sant'Agnese, MD, Jean Joseph, MD, John Strang, MD, Deborah J. Rubens, MD, Kevin J. Parker, PhD

Research in 2007 focused on advancing sonoelastography for prostate cancer detection. Ben Castaneda processed 3D sonoelastographic data from cancerous prostates and compared the results to histological volumes in terms of size and location. Figure 1 shows a representative result. Histological slides from a whole mount procedure are marked by a pathologist and reconstructed into a volume showing the surface of the prostate and the tumor (Fig. 1a). The imaging results from B-mode and sonoelasticity imaging are combined to obtain the surface of the prostate and the location and size of the suspicious mass (Fig 1b). The volumes are registered using the surface of the gland as a marker. Figure 1c shows the overlap of the tumor found in histology and the suspicious mass from sonoelastography.

In a recent paper (Castaneda, et al., "Prostate cancer detection based on three dimensional sonoelastography", IEEE Ultrasonics Symposium, New York, NY, 2007), we evaluated the performance of sonoelastography for prostate cancer detection. Ultrasound B-mode and sonoelastographic volumes were acquired from five prostate glands ex vivo. Additionally, one more gland was imaged in vivo using a transrectal ultrasound probe. Semi-automatic algorithms were used to segment the surface of the gland from the B-mode volume and the tumors from sonoelastographic data. To assess the detection performance, 3D sonoelastographic findings were compared in size and position to 3D histological data. Sonoelastography detected seven out of nine cancers in the ex vivo prostate glands and two out of three malignant masses in the in vivo experiment. Overall, 3D sonoelastography has shown potential for prostate cancer detection, albeit based on limited data.

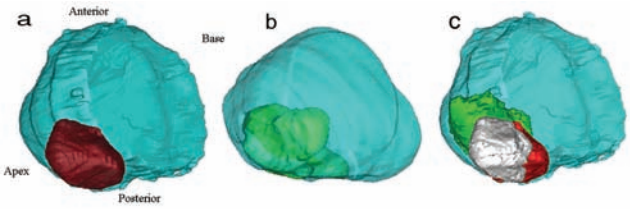


Figure 1. *Volumes reconstructed from* ***(a)*** *histological images and* ***(b)*** *ultrasound images. The tumor found by the pathologist is depicted in red. The deficit found by sonoelastography is shown in green. The fusion of both volumes is illustrated in* ***(c)****. The overlap of the tumors from sonoelastography and histology is presented in white.*

Using sonoelastography for thermally ablated lesions

Benjamin Castaneda, MS, Maggie Zhang, PhD, Kenneth Hoyt, PhD, Kevin Bylund, MD, Jared Christensen, MD, Wael Saad, MD, John Strang, MD, Deborah J. Rubens, MD, Kevin J. Parker, PhD

The Parker lab is using sonoelastography to measure thermally ablated lesions. Radiofrequency ablation (RFA) is a minimally invasive thermal therapy that is under investigation as an alternative to surgery for treating liver tumors. Currently, there is a need to monitor the process of lesion creation to guarantee complete treatment of the diseased tissue. In a previous study, sonoelastography was used to detect and measure RFA lesions during exposed liver experiments in a porcine model in vivo. Manual outlining of these lesions in the sonoelastographic images is challenging due to a lack of boundary definition and artifacts formed by respiratory motion and perfusion.

As a result, measuring the lesions becomes a time-consuming process with high variability.

Recent work by Ben Castaneda focused on implementing two and three-dimensional algorithms to measure thermal ablated lesions from sonoelastographic data. The semi-automatic segmentation algorithm for sonoelastographic data is based on level set methods. This algorithm aims to reduce the variability and processing time involved in manual segmentation while maintaining comparable results.

Figure 1 (below) shows a comparison of a lesion imaged with sonoelastography and measured using the semi-automated algorithm (a) and a volume reconstruction of the same lesion from gross pathology photographs (b). Lesion volumes obtained from imaging (1.7 cm^3) are comparable to gross pathology (2.2 cm^3) results. Semi-automatic segmentation outperforms manual segmentation in accuracy, speed, and repeatability. Results suggest that sonoelastography in combination with the algorithm could be used as a complementary technique to conventional ultrasound for thermal ablation monitoring and follow-up imaging.

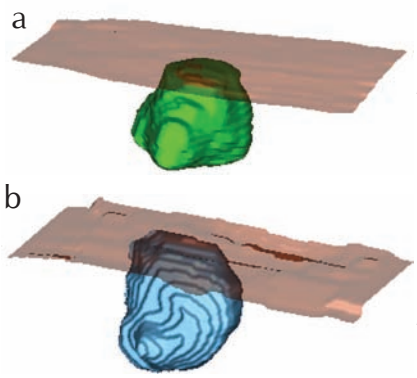


Figure 1. *A thermal ablated lesion in a porcine liver was imaged with sonoelastography and measured with the semi-automated algorithm* ***(a)****, and then reconstructed from the gross pathology photographs* ***(b)****.*

Update from the Biomedical and Materials Multimodality Imaging Laboratory

María Helguera, PhD

The Biomedical and Materials Multimodality Imaging Laboratory at the Rochester Institute of Technology is advancing innovative ways to visualize, analyze and characterize biological tissues and synthetic materials by means of multimodal medical imaging devices. The following provides an overview of recent work from the lab in the areas of ultrasound materials characterization and multimodal breast imaging.

I. Ultrasound materials characterization

The aim of one line of investigation in the Helguera lab is to establish a relationship between the mechanical properties of a powder coating, extracted using ultrasonic analyses, and the extent of its curing. These polymer powder coatings are typically used in paints and toners. This work was necessitated by the fact that most current methods either focus on in-process temperature monitoring or on laboratory analysis of powder samples, and not on post-curing characterization of industrial samples. Working towards the objective, a recent study involved investigating powder coating films by employing transmission mode ultrasound, involving multiple reflections to extract the dimensionless material descriptor, tan (δ), an indicator of the stiffness of the material. It has been demonstrated that trends observed in the mechanical properties of the coatings extracted by processing the ultrasonic signal corresponded to those experimentally extracted using mechanical testing.

Results are shown in Figure 1 for 3 different curing times:

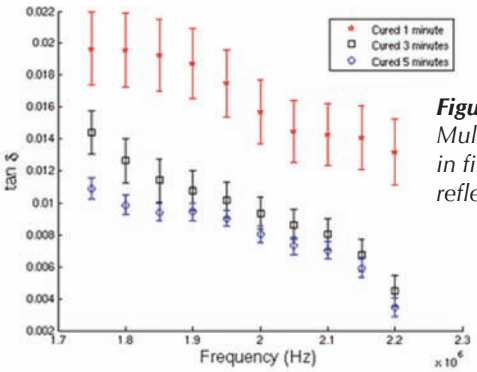


Figure 1. *Multispectral tan(δ) in film (Multiple reflections)*

II. Multimodal breast imaging

The thrust of this project in the Helguera lab focuses on the field of Multimodality Image Fusion and Visualization of breast tissue. This is a rapidly evolving field due to the constant upgrading and improvement of medical imaging and computational systems. This project presents an approach to taking advantage of information currently collected from different imaging modalities that do not share the same piece of equipment, and presenting it in a more cohesive way via image processing techniques.

Registration: Automatic target recognition for registration is accomplished via an algorithm based on a MACH (maximum average correlation height) filter, a class of composite correlation filters that allows for shift and rotational invariance, i.e. if the input image is translated by some amount, the filter output will shift by the same amount. The algorithm detects the locations of fiducial skin markers in both PET and MRI image stacks and uses this output to automatically register these image volumes. This shift is estimated by the

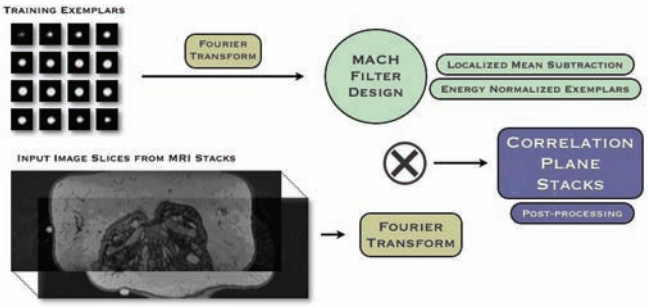


Figure 2. *Block diagram representing the implementation of the MACH correlation filter.*

location of the correlation peak. Correlation filters can be designed to achieve noise tolerance and discrimination among other properties. The process is shown in a schematic way in Figure 2 (previous page).

Visualization: A tool was developed for the visualization of fused volumes that takes into consideration factors such as information content, observer interaction, ease of use, and inherent understanding. From an information theory point of view, it is desirable to maximize the amount of information present in the fused image. Ideally, the registered images would be viewed as a single image that contains all of the information contained in both the MRI image and the PET image. The tool, FusionViewer, downloadable from http://kgbtechnologies.com/, was designed and implemented with a modular object oriented design. The viewer provides both traditional and novel tools to fuse 3D data sets such as CT, MRI, PET, and single photon emission tomography (SPECT) of the same subject, to create maximum intensity projections (MIP) and to adjust dynamic range. Different look-up-tables (LUT) can be selected for display. A snapshot of the tool is shown in Figure 3.

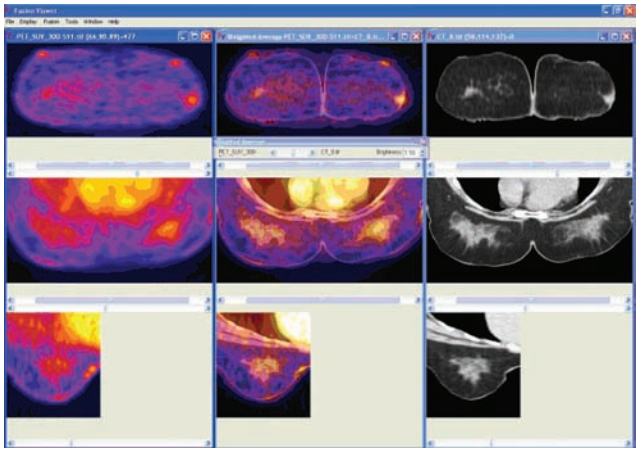


Figure 3. Left: *The three orthogonal images are from the PET data set after the application of the Fire color table.* ***Right:*** *Three orthogonal images from the CT data set.* ***Center:*** *Three orthogonal images in the center from fusing the PET and CT images using the weighted average fusion plug-in. Not only can we see the anatomical structure, but we can also see the metabolic activity for each structure.*

Image Synthesis: Obtaining "ground-truth" data in medical imaging is an almost impossible quest when pathology reports are not available. One way to circumvent this limitation is by creating digital synthetic phantoms with the appropriate physical properties and characteristics that can be imaged using digital simulators. Digital simulators can be used to study system design, acquisition protocols, reconstruction techniques, and evaluate image processing algorithms. Specifically, in this work, simulated images can aid in the evaluation of the registration procedure, and provide data for studies assessing the ability of radiologists to use specific visualization techniques. In addition to providing a precise ground truth, they can be used to save significant time and money compared to finding volunteers, and arranging and paying for scanner time. The simulators selected for this work are SimSET for PET and SIMRI for MRI.

A breast phantom has been designed to support current and future projects on breast imaging. The phantom, when combined with appropriate physical properties, can be used with SIMRI, SimSET, or another simulator. The phantom contains ten different tissues including adipose tissue, areola, blood, bone (rib), ductal tissue, Cooper's ligament, lobule, muscle (pectoral), skin, and stroma connective tissue. Some elements in the phantom are shown in Figure 4.

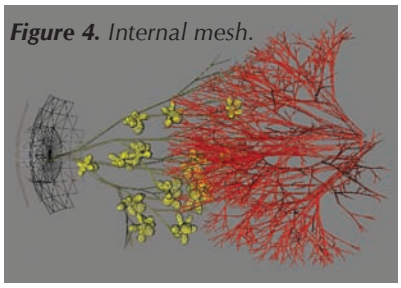


Figure 4. *Internal mesh.*

Skeletal muscle tissue characterization using quantitative sonoelastography

Kenneth Hoyt, PhD, Benjamin Castaneda MS, Kevin J. Parker, PhD

Demonstration of muscle tissue characterization in vivo using elasticity imaging-based techniques has been reported by several groups. The first known example was by RCBU member Stephen Levinson in his seminal 1995 publication. Despite these pioneering efforts, knowledge regarding the viscoelastic properties of human skeletal muscles in vivo is still very limited, which may be attributed to a lack of repeatable tech-

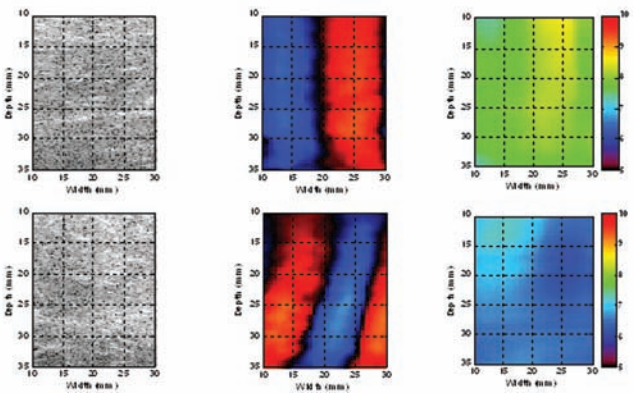


Figure 1. *Experimental sonoelastographic results from* ex vivo *skeletal muscle specimens including: B-scan US (left), crawling wave (middle), and shear velocity (units of m/s) (right) images. Results are depicted for shear wave polarization perpendicular to muscle fibers (200 Hz) and shear wave propagation parallel (top) and perpendicular (bottom) to muscle fibers.*

niques permitting quantitative assessment of muscle function noninvasively. Important applications for in vivo assessment include, but are not limited to, sports training, physical therapy, and progression of degenerative diseases such as muscular dystrophy. Therefore, the motivation for this aspect of Hoyt's research is to develop and evaluate novel quantitative sonoelastographic techniques for the in vivo characterization of skeletal muscle tissue.

During initial feasibility studies as reported by Hoyt et al., frequency-dependent sonoelastographic data were collected in both ex vivo bovine (IEEE Ultrasonics Symposium: 365-368, 2007) and in vivo human skeletal muscle tissues (Proceedings of the Sixth International Conference on Ultrasonic Measurement and Imaging of Tissue Elasticity, 2007). Experimental results were obtained using a GE Logiq 9 ultrasound scanner with demodulated colorflow data saved for processing. Shear velocity sonoelastograms were produced offline from the reconstructed crawling wave images using an autocorrelation-based estimation technique. Statistics were computed from shear velocity sonoelastogram sequences (equating to one spatial wavelength of crawling wave propagation). Further details regarding the experimental setups can be found in the above cited references.

Results on ex vivo skeletal muscle samples demonstrate shear wave anisotropy and existence of fast and slow shear waves corresponding to propagation parallel and perpendicular to muscle fibers, respectively, Figure 1 (previous page). Comparison of relative frequency-dependent changes between shear velocity estimates for both shear wave propagation parallel and perpendicular to muscle fibers suggests increased viscoelastic effects for the former. Subsequently, crawling wave sonoelastographic data were collected from the relaxed quadriceps femoris muscles in two healthy male volunteers to assess clinical utility. Comparison of frequency-dependent shear velocity data from contralateral muscles and between subjects was not statistically different ($p > 0.74$ and $p > 0.91$, respectively), which demonstrates reproducibility albeit based on limited data, Figure 2. Furthermore, a systemic dependence of shear velocity estimates on shear rate confirms that human skeletal muscle tissue is viscoelastic. Current research is focused on evaluating quantitative sonoelastography for characterizing the dynamic viscoelastic properties of skeletal muscle tissue in both health and disease.

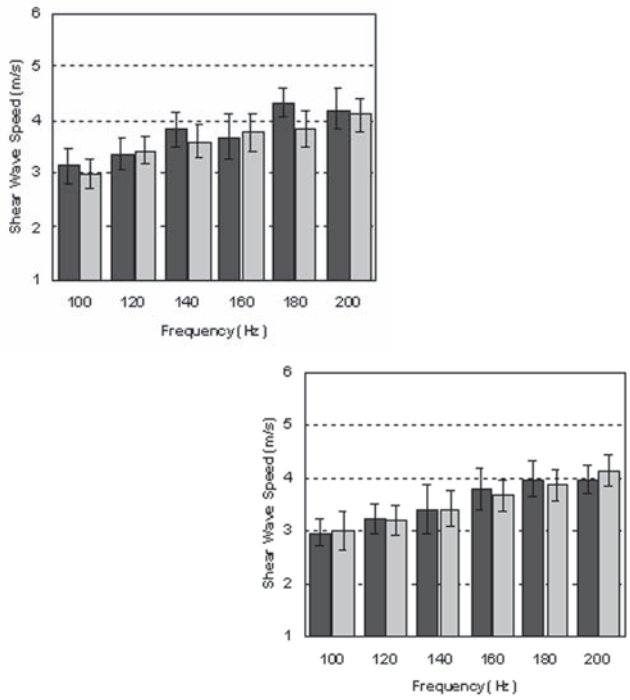


Figure 2. *Summary of in vivo shear velocity estimates from relaxed rectus femoris muscles. Results from two different healthy male subjects, left and right, respectively, are depicted as a function of frequency for the right (black) and left (gray) rectus femoris muscles. Note shear wave propagation was parallel to muscles fibers as verified using B-scan guidance.*

Bioeffects of ultrasound contrast agents

Diane Dalecki, PhD, Carol H. Raeman, AAS, Sally Z. Child, MS

A long-standing area of research in our laboratory is ultrasound contrast agents. Ultrasound contrast agents currently enhance the capabilities of diagnostic imaging and are also providing new avenues for therapeutic applications of ultrasound. Efforts in our laboratory focus on developing an understanding of the physical and biological mechanisms of interaction of acoustic fields with tissues containing microbubble contrast agents.

Ultrasound contrast agents are suspensions of gas-filled microbubbles. Microbubble contrast agents can increase the likelihood of bioeffects of ultrasound associated with acoustic cavitation. Ongoing work from our lab continues to investigate ultrasound-induced bioeffects of microbubble contrast agents in the cardiovascular system. Recent work from our lab has demonstrated that the presence of ultrasound contrast agents lowers the threshold for ultrasound-induced premature cardiac contractions and capillary rupture in various organs and tissues. Results of a series of mechanistic investigations are consistent with the hypothesis that acoustic cavitation is the mechanism for the production of premature cardiac contractions with ultrasound and microbubble contrast agents. Current collaborations with Sheryl Gracewski provide unique capabilities to computationally simulate the response of a microbubble to sound exposure within a confining blood vessel (see related story on page 13). Experimental measurements and observations within our lab will be used to validate the simulation results and also to obtain additional insights into the nonlinear bubble dynamics that can occur within blood vessels.

New Collaborations—New Directions

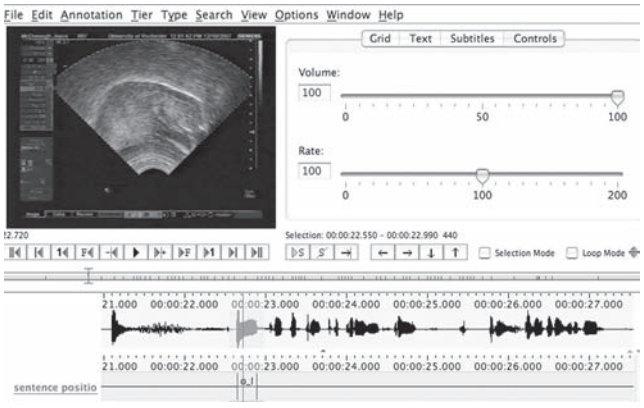
Innovations in biomedical ultrasound require the collaborative expertise of basic scientists, engineers, physicians, and clinicians. The RCBU provides an ideal forum to stimulate such cross-disciplinary research. Below are highlights of new, multidisciplinary research collaborations that have been forged by RCBU members.

Using ultrasound to image speech production for linguistics research

Heike Lehnert-LeHouillier, PhD, Stephen McAleavey, PhD, Mathews Jacob, PhD, Diane Dalecki, PhD and Joyce McDonough, PhD

The Department of Biomedical Engineering (Stephen McAleavey, Mathews Jacob, and Diane Dalecki) and the Department of Linguistics (Heike Lehnert-LeHouillier and Joyce McDonough) have joined forces on a new, multidisciplinary project that aims to investigate the production of speech using ultrasound techniques to image the vocal track. The question of how speakers produce spoken language is a major research area within linguistics and speech sciences in general. However, the articulator used in the production of most speech sounds, the tongue, cannot be easily inspected during speech. Various methodologies are available to study the movements of the tongue during speech, such as X-ray techniques (including X-ray mircobeam), fMRI and electromagnetic articulography (EMA). Unfortunately, these methodologies either have safety concerns for participants (X-ray), are cumbersome and expensive (X-ray mircrobeam and EMA), or don't have a high enough temporal resolution (fMRI) to track the fast moving tongue during speech. Using ultrasound for the investigation of tongue movements during speech has proven to be a valuable tool for speech research; it is non-invasive and can provide a real-time resolution that allows imaging of the rapidly moving tongue surface. Over the past decade, this tool has been developed for speech research at several top speech research centers, but many issues remain before this tool can be widely adapted, problems which this team will be taking up.

Since establishing their collaboration in the fall of 2007, Drs. Lehnert-LeHouillier and McAleavey have developed an integrated system for ultrasound imaging and speech research in the McAleavey laboratory. In initial studies, the team has collected ultrasound images and auditory data for a study that links the tongue shape for a given speech sound to that sound's position-in-utterance (i.e. initial, medial or utterance final position), factors known to have an effect on the acoustics, causing amplitude and pitch range dampening, durational differences and formant structure changes. However, crucially, little or no data is available on the movement of the actual articulators involved, data that is critical to our understanding of the complex relationship between production and perception of speech. Shown below is the analysis of an ultrasound image of the tongue during speech (using currently available ELAN software from the Max Planck Institute for Psycholinguistics in Nijmegan). Under the supervision of Dr. Mathews Jacob, the team plans to develop new image and signal processing techniques to further facilitate their analysis procedures. A new, high-resolution digital video recording system in the McAleavey lab will provide enhanced imaging and processing capabilities. For the upcoming year, the team is excited to apply their joint expertise to several linguistics research topics, and continue their development of instrumentation and analyses procedures spanning the fields of ultrasound imaging and speech production and processing.



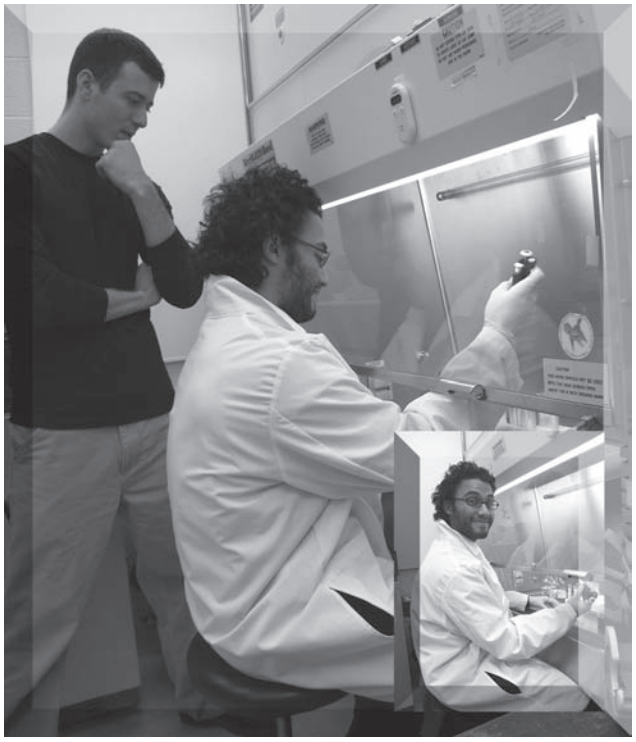
Ultrasound image of the tongue during the production of the sound "o" in "dog" as displayed in ELAN for segmentation.

Ultrasound technologies for tissue engineering

Denise Hocking, PhD, Diane Dalecki, PhD, Stephen McAleavey PhD, Sheryl Gracewski, PhD

Tissue engineering and regenerative medicine are potentially revolutionary approaches for replacing diseased or destroyed organs and tissues. Funded by the NIH, Center members, Denise Hocking and Diane Dalecki, lead a new research program focused on developing ultrasound-based, enabling technologies for the fabrication and monitoring of functional, 3D engineered tissues. Through the project, they will develop the use of ultrasound to regulate the structure and organization of the extracellular matrix in order to stimulate cell processes that are critical for engineering functional tissue constructs. Current studies are testing the ability of ultrasound to produce conformational changes in fibronectin, an extracellular matrix protein that plays key roles in regulating cell growth and migration. Working with co-investigators Stephen McAleavey and Sheryl Gracewski, the team is also developing and applying new ultrasound imaging and tissue characterization techniques to noninvasively monitor the material and biological properties of engineered tissues, and to validate the measurements through mechanical testing and finite element modeling.

*RCBU member **Carol Raeman** (standing) and BME graduate student **Kelley Garvin** (seated and inset) working in the cell culture lab in Goergen Hall.*



*BME graduate students **Dan Roy** (standing) and **Carlos Sevilla** (seated and inset) in Dr. Hocking's laboratory.*

Neural effects of underwater sound

John Olschowka, PhD, Diane Dalecki, PhD

Underwater sound fields are used for numerous commercial and military applications, including imaging, oil exploration, mapping the ocean, and harbor surveillance. Sponsored by the U.S. Navy, Drs. Olschowka and Dalecki have embarked on a new collaborative project that will investigate the interactions of continuous and impulsive underwater sound fields with the brain and spinal cord. The Olschowka lab, in the UR Department of Neurobiology and Anatomy, has long-standing expertise in examining injury to neural tissues, including trauma, using molecular, protein, and immunohistochemical techniques. Using the acoustic sources and technical expertise of the Dalecki lab, the team will investigate neural bioeffects of sound fields at frequencies ranging from 500 Hz–30 kHz. To also study the effects of acoustic impulses, the facilities and expertise available at Hydroacoustic, Inc. will be employed to generate underwater impulsive sound fields using an air gun system. Neural tissues of animals exposed to these continuous and impulsive underwater sound fields will be assessed for vascular damage, axonal injury, and glial activation. Results of this project will help to establish safe exposure guidelines for human divers and marine life exposed to underwater sound fields.

New Directions—New Collaborations

INNOVATION

The RCBU is continually advancing novel concepts in ultrasound technology. Recent news, and some of the patents that originated at the RCBU are summarized below. For more information, contact the University of Rochester Technology Transfer office at (585) 275-3998.

University of Rochester Licenses Ultrasound Technology to General Electric

Tissue harmonic imaging technology, developed by RCBU member Ted Christopher, PhD, was licensed to General Electric Company, the world's largest producer of ultrasound equipment. General Electric now joins Royal Philips Electronics and Acuson Corporation as a licensee of this ultrasound imaging technology.

The imaging modality exploits the nonlinear propagation of ultrasound through tissue. Dr. Christopher discovered that higher harmonic signals, generated by finite amplitude distortion, can be used to create much clearer images of living tissues (see Dr. Christopher's patent information on right). "We are delighted to see Dr. Christopher's work come to fruition by improving diagnostic imaging," said RCBU Director Diane Dalecki. "His work builds on a 40-year legacy at Rochester in nonlinear acoustics, starting with the work of Professor David Blackstock in the 1960's."

University of Rochester a Leader in Technology Commercialization

The University of Rochester is again rated as one of the best educational institutions in the nation for patent licensing revenue, according to the Association for University Technology Managers. 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.

In 2006, the UR received over $38 million in royalty revenue for its licensed patents, ranking it ninth in the nation. For six years in a row, the UR has ranked in the top ten among U.S. universities. The technological advances by members of the Rochester Center for Biomedical Ultrasound continue to contribute to the UR's success.

The University of Rochester Office of Technology Transfer protects the scientific and intellectual advances developed at the UR, and engages in activities to transfer these technologies into the private sector where they can benefit society. For more information, visit the University of Rochester Technology Transfer office at http://www.rochester.edu/ott/.

U.S. Patents

- ***Finite Amplitude Distortion-Based Inhomogeneous Pulse Echo Ultrasonic Imaging***
  U.S. Patent No. 7,104,956 issued to **Ted Christopher** on September 12, 2006
- ***System for Model-Based Compression of Speckle Images***
  U.S. Patent No. 5,734,754 issued to **Kevin J. Parker** on March 31, 1998
- ***Blue Noise Mask***
  U.S. Patent Nos. 5,111,310 (1992); 5,477,305 (1995); 5,708,518 (1998); 5,543, 941 (1996); and 5,726,772 (1998) issued to **Kevin J. Parker** and Theophano Mitsa
- ***Thin-Film Phantoms and Phantom Systems***
  U.S. Patent No. 5,756,875 issued to **Daniel B. Phillips** and **Kevin J. Parke**r on May 26, 1998
- ***System and Method for 4D Reconstruction and Visualization***
  U.S. Patent No. 6,169,817 issued to **Kevin J. Parke**r, Saara SM Totterman, and Jose Tamez-Pena on January 2, 2001
- ***The Acoustic Filter***
  U.S. Patent No. 5,334,136 issued to **Karl Schwarz, Richard Meltzer**, and Charles Church on August 2, 1994
- ***Multiple Function Infant Monitor***
  U.S. Patent No. 5,479, 932 issued to Joseph Higgins, **E. Carr Everbach**, **Kevin J.Parker** on January 2, 1996
- **Apparatus for Bone Surface-Based Registration**
  U.S. Patent No. 6,106,464 issued to WA Bass, RL Galloway, Jr., CR Maurer, Jr, and RJ Maciunas on August 22, 2000
- ***Sonoelasticity Imaging Estimators***
  U.S. Patent No. 5,086,775, issued to **Ron Huang, Robert Lerner, and Kevin Parker** on February 11, 1992
- ***Butterfly Search Technique***
  U.S. Patent No. 5,419, 331 issued to S. Kaisar Alam and **Kevin J. Parke**r on May 30, 1995
- ***Smart Endotracheal Tube***
  U.S. Patent No. 5,785,051 issued to **Jack Mottley** and Randy Lipscher on July 29, 1998.

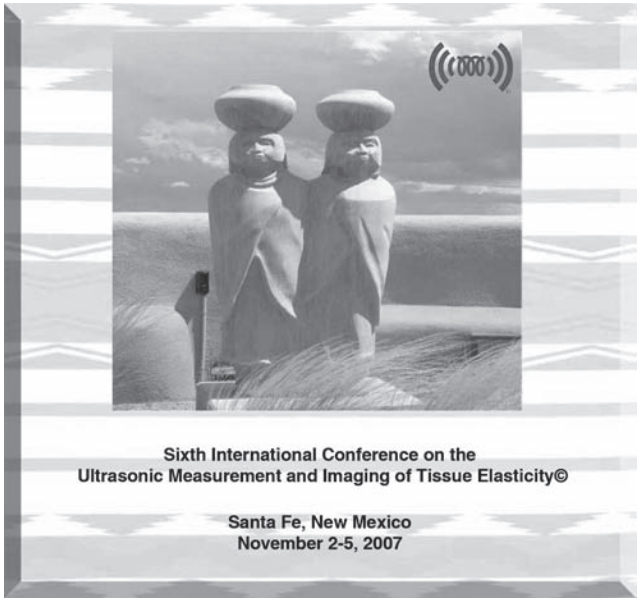
TISSUE ELASTICITY CONFERENCE HIGHLIGHTS

The Sixth International Conference on Ultrasonic Measurement and Imaging of Tissue Elasticity was held November 2-5, 2007 in Santa Fe, New Mexico. The goal of this conference is to provide an international forum for the advancement of knowledge and methods for the measurement and imaging of elastic properties of tissues with ultrasound.

Many RCBU members participated in the conference, including Kevin Parker, Deborah Rubens, Kenneth Hoyt, Benjamin Castaneda, Stephen McAleavey, and Manoj Menon.

The conference has no parallel sessions and provides ample time for discussion. There were 122 abstracts accepted this year. The Conference was divided into 17 sessions, including:

- Signal and Image Processing I, II, & III
- Live Oral Summaries of Posters
- Instrumentation I & II
- Cardiovascular Elasticity I & II
- Methods for Imaging Elastic Tissue Properties I & II
- Mechanical Measurement Techniques for Tissue I & II
- Forward and Inverse Problems I & II
- Clinical and Animal Applications I, II
- Mechanical Properties of Tissues



In addition to research presentations, exhibits, and posters, two tutorials were presented:

- *From Physics to Physic—A Hands-On Approach to Breast Elasticity Imaging: Is it Just Shear Stress and Strain?* by Dr. W.E. Svensson from Charing Cross Hospital in London
- *Optical Elastography—High Resolution at a Cost* by Dr. S.J. Kirkpatrick from Oregon Health and Science University in Beaverton, Oregon.

The conference is jointly sponsored and organized by the RCBU and the Ultrasonics Laboratory in the Department of Diagnostic and Interventional Imaging at the University of Texas Health Science Center at Houston.

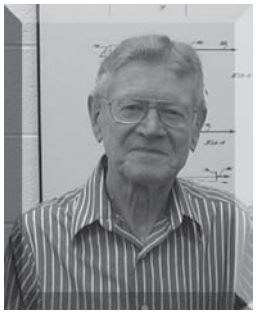
Next year's conference will be held October 27-30, 2008. See the conference web site for the latest information, http://www.uth.tmc.edu/schools/med/rad/elasto/conference/index.htm.

AWARDS AND FUNDING NEWS

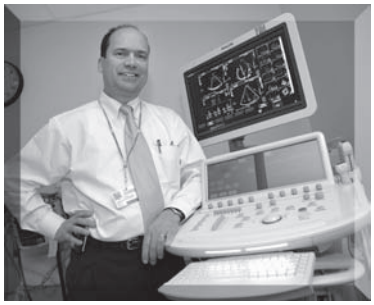
AWARDS

- The Acoustical Society of America's Helmholtz-Rayleigh Interdisciplinary Silver Medal was awarded to **Edwin Carstensen** (Founding RCBU Director) at the spring 2007 ASA Meeting in Salt Lake City. The award recognizes Dr. Carstensen's outstanding contributions to the physics of biomedical ultrasound.

- **David Blackstock** was awarded the Rossing Prize in Acoustics Education from the Acoustical Society of America. The award was presented at the fall 2007 ASA Meeting in New Orleans. Dr. Blackstock presented the following paper in response to the award: D.T. Blackstock, "Songs my students sang to me," J. Acoust. Soc. Am. 122, 3026, 2007.



- **Karl Schwarz, M.D.,** professor of Medicine in the Cardiology Division and Director of the UR Echocardiography Laboratory, and RCBU member, received the UR Board Excellence Award in the Physician category. The Chairman's Excellence Awards are received by employees whose professional and personal standards exemplify quality patient care, mirroring the values of the institution's Strong Commitment initiative: integrity, compassion, accountability, respect and excellence.



- **Benjamin Castaneda** was the winner of the Predictive Model Contest 2007 sponsored by Humana, Inc. Ben was also a finalist in the New Investigator Award Competition at the 2007 AIUM Annual Convention. He also received an honorable mention in the Mondialogo Engineering Award 2007 sponsored by UNESCO and Daimler.

FUNDING NEWS

- **Diane Dalecki** and **Denise Hocking** serve as multi-PIs on a newly awarded grant from the NIH NIBIB titled "Ultrasound Technologies for Tissue Engineering". The overall goal of this project is to develop ultrasound-based enabling technologies for the fabrication and monitoring of functional, 3D artificial tissues (see story page 21).
- **Deborah Rubens** (PI) and **Kevin Parker** (co-I) were awarded a grant from the NIH titled "3D Prostate Cancer Imaging Based on Crawling Wave Excitation". The goal of this project is to develop a novel 3D scanner, based on crawling wave technology, for application to prostate cancer.
- **Sheryl Gracewski** (PI) and **Diane Dalecki** (co-PI) were awarded an NSF grant from the CMMI division titled "Dynamic Response of Constrained Bubbles to Acoustic Excitation." This project will theoretically and experimentally characterize the linear and nonlinear dynamics of acoustically excited bubbles that are constrained within tubes and channels. The results of this work will be directly relevant to the use of ultrasound microbubble contrast agents in diagnostic imaging and new ultrasound-based therapies.
- **John Olschowka** (PI, Dept. of Neurobiology & Anatomy) and **Diane Dalecki** (co-I) received a two-year grant from the U.S. Navy titled "Neural Effects of Underwater Sound" (see story on page 21).
- **Stephen McAleavey** (PI) was awarded a grant from the Stanford Center on Longevity for research on a "Wireless Urine Monitor and Aids for Bladder Training and Incontinence Management." The goal of this project is to develop an assistive device for bladder training. The device, which incorporates a disposable sensor and wireless monitor, records the time of incontinence episodes. Urinary incontinence affects at least 10% of the age 65 or older population, and as many as 60% of those living in nursing homes.
- Center members **Kevin Parker** (PI), **Robert Lerner, Stephen McAleavey,** and **Diane Dalecki** received funding from the Stanford University Center on Longevity for the project titled, "Elastography in the Early Detection and Management of Liver Disease". The goal of this project is to develop a safe, non-invasive, inexpensive tool for the early detection and monitoring of liver disease.

RCBU PEOPLE

IN MEMORIAM
Richard Meltzer, MD

We mourn the loss of Dr. Richard Meltzer, a long-time member of the Rochester Center for Biomedical Research.

"Dr. Meltzer was one of the earliest and most vigorous supporters of the Rochester Center for Biomedical Ultrasound," said Dr. Edwin L. Carstensen, Founding Director of the RCBU.

Dr. Meltzer earned his M.D. degree from Harvard Medical School. He joined the University of Rochester in 1986 as a professor of Medicine (Cardiology) and Radiology, and Director of Echocardiography. During his tenure at the UR (1986-1997), he led an internationally-recognized research program in echocardiography.

An author of over 100 peer-reviewed articles, Dr. Meltzer is often thought of as one of the "godfathers of contrast echocardiography." In addition to leading Cardiology's clinical ultrasound program, his contributions to basic science included the use of microbubbles as contrast agents at a time before commercial products were available. He catalyzed a collaborative research effort in Vascular Medicine and the Department of Electrical Engineering exploring the mechanisms by which ultrasound enhances the enzymatic lysis of blood clots.

"Dr. Meltzer was a visionary individual who foresaw the blockbuster utility of ultrasound for the diagnosis and treatment of cardiac disease," said Dr. Karl Q. Schwarz, Professor of Medicine. "However, I think that his greatest legacy is the many researchers and clinicians whose careers he touched. Dr. Meltzer offered paid research and clinical positions to students from all over the world, and in some cases rescued them from oppressive or life-threatening circumstances. Many of these former students are now themselves mentors to young investigators, and I know that one of the lessons they teach is the generosity of opportunity taught to them by Dr. Meltzer."

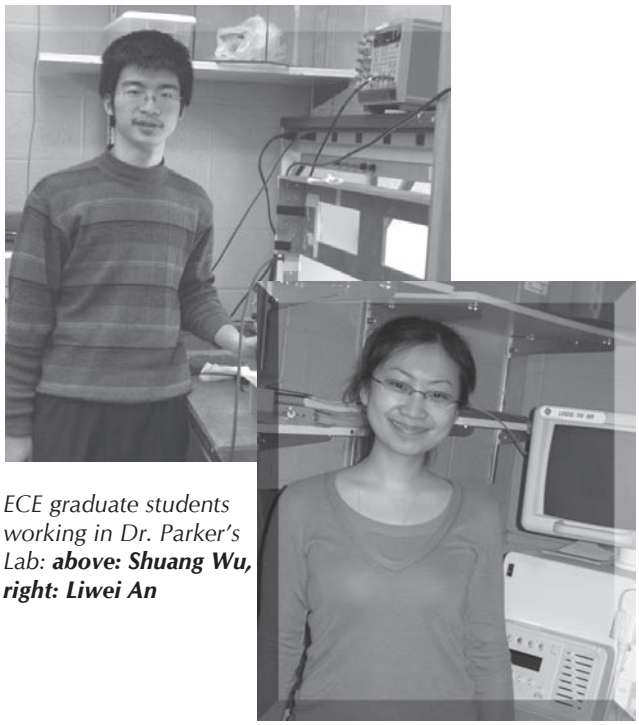
Richard Meltzer, M.D.

NEW MEMBERS

- **Dr. Denise Hocking** joined the RCBU this year. Dr. Hocking is an Associate Professor in the Department of Pharmacology and Physiology and the Department of Biomedical Engineering. Dr. Hocking is an expert in cell and extracellular matrix biology and is working to develop the use of ultrasound in wound healing and tissue engineering.

- **Maria Randazzo** joined the RCBU staff, serving as the Public Relations Assistant. Maria is a UR alumna with majors in English and History, and is also a graduate of the RIT Promotional Writing and Design certificate program.

- **Recent graduate student** members of the RCBU include **Etana Elegbe, Kelley Garvin, Timothy Kneezel, Liwei An, Carlos Sevilla, and Shuang Wu.**



ECE graduate students working in Dr. Parker's Lab: ***above: Shuang Wu, right: Liwei An***

EDUCATION

ENGINEERING FOR THE AMERICAS

Under the leadership and vision of **Kevin Parker** (Dean, UR School of Engineering and Applied Sciences), the University of Rochester and the University of Miami have established a unique international program known as the Engineering for the Americas (EFTA). EFTA seeks to provide engineering students from across the Americas the opportunity to expand their international network and community of professionals throughout the western hemisphere. The program teaches students how to work together while educating them in professional aspects that go beyond the typical curriculum. RCBU member **Ben Castaneda** was a student participant in the 2007 Sessions.

The EFTA program met for two sessions in 2007. The inaugural session took place in January at the University of Miami. The second session was held at the University of Rochester in June. For more information on the program, see the EFTA web site http://www6.miami.edu/efta/.

University of Miami Session

Several topics were addressed at the inaugural session: Innovation & Entrepreneurship, Intellectual Property Management, Technology Transfer, Leadership, and Engineering for the Life Sciences. The students had the opportunity to listen to and interact with high-quality speakers on these topics. Also, they visited the Telefónica Data Center and the Center for Southeastern Tropical Advanced Remote Sensing (C-STARS).

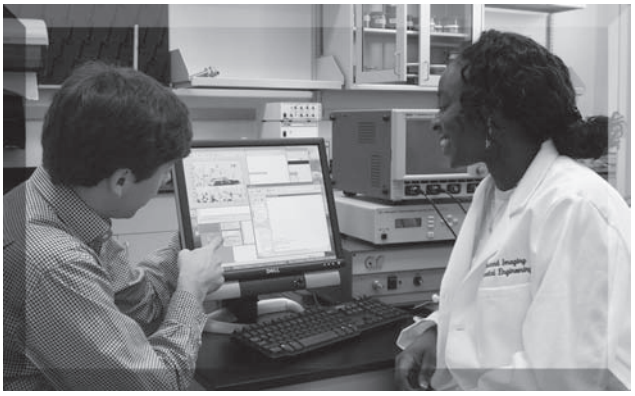
University of Rochester Session

After five months, the participants regrouped for the Rochester session. The topics for this session focused on Sustainable Energy for the Americas and Global Engineering Enterprises. The students had the opportunity to interact with leaders from General Electric, Kodak, and Xerox among other global companies. They also toured the laboratory for Laser Energetics and visited Niagara Falls and its power plant.

EDUCATIONAL ACHIEVEMENTS

- **Maggie (Man) Zhang** received her Ph.D. in Biomedical Engineering in May 2007. Her thesis, titled "The Measurement and Imaging of Viscoelastic Properties of Soft Tissues and Lesions", was supervised by Kevin Parker. Maggie is now working as a Post-doctoral fellow at the University of Michigan.

- **David Blackstock** taught the summer acoustics course, ECE 432–Acoustic Waves at the University of Rochester.
- **Sheryl Gracewski** and **Diane Dalecki** organized and co-chaired a scientific session titled "Modeling of Acoustic Cavitation in Vivo" at the Spring ASA Meeting in Salt Lake City.
- **Kenneth Hoyt** was co-chair of the scientific session on Signal and Image Processing at the 6th International Conference on the Ultrasonic Measurement and Imaging of Tissue Elasticity.



Stephen McAleavey *(above left) and* ***Etana Elegbe*** *(above right and below) review experimental results from the McAleavey lab.*

EDUCATION

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.

Advanced Biomedical Ultrasound (BME 453)

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 correction, velocity estimation, and flow imaging.

Medical Imaging-Theory and 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.

MR Imaging: From Spins to Brains (BME 513)

Introduces the physics of magnetic resonance (MR) imaging and reviews its application to medical imaging. Provides a comprehensive background of the MR imaging technique and its application to medical or research issues. Discusses how the MR technique takes advantage of physiological principles and tissue structure to provide diagnostic images for clinicians and researchers. Introduces functional brain imaging and related issues in data analysis.

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 (ME449)

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)

Examines the theory and application of nonlinear finite element analysis in solid and biosolid mechanics. Topics include generalization of FE concepts, review of solid mechanics, nonlinear incremental analysis, displacement-based FE formulation for large displacements and large strains, nonlinear constitutive relations, incompressibility and contact conditions, rubber-like materials, biomechanical materials, and solution methods.

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.

Physiological Control Systems (BME 428)

Focuses on the application of control theory to physiological systems. Presents modern control theory in the context of physiological systems that use feedback mechanisms. Begins with an overview of linear systems analysis, including Laplace transforms and transfer functions. Discusses the response dynamics of open- and closed-loop systems such as the regulation of cardiac output and level of glucose, stability analysis, and identification of physiological control systems.

Microhydrodynamics (BME 466)

Develops insight into the motion of small particles in a viscous fluid. Such problems are found in biology, biotechnology, and composite materials processing. Specific topics include flow past spheres and arbitrary bodies (thermally driven), motion of bubbles and drops, slendor body theory, and leading-order inertial corrections.

All courses are not offered each semester. See the University of Rochester Undergraduate and Graduate Bulletins for more information.

2007 PUBLICATIONS

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Zhang M, Castaneda B, Wu Z, Nigwekar P, Joseph J, **Rubens DJ, Parker KJ.** Congruence of imaging estimator and mechanical measurements of viscoelastic properties of soft tissues. Ultrasound Med. Biol., 33(10):1617-31; 2007.

2007 PRESENTATIONS

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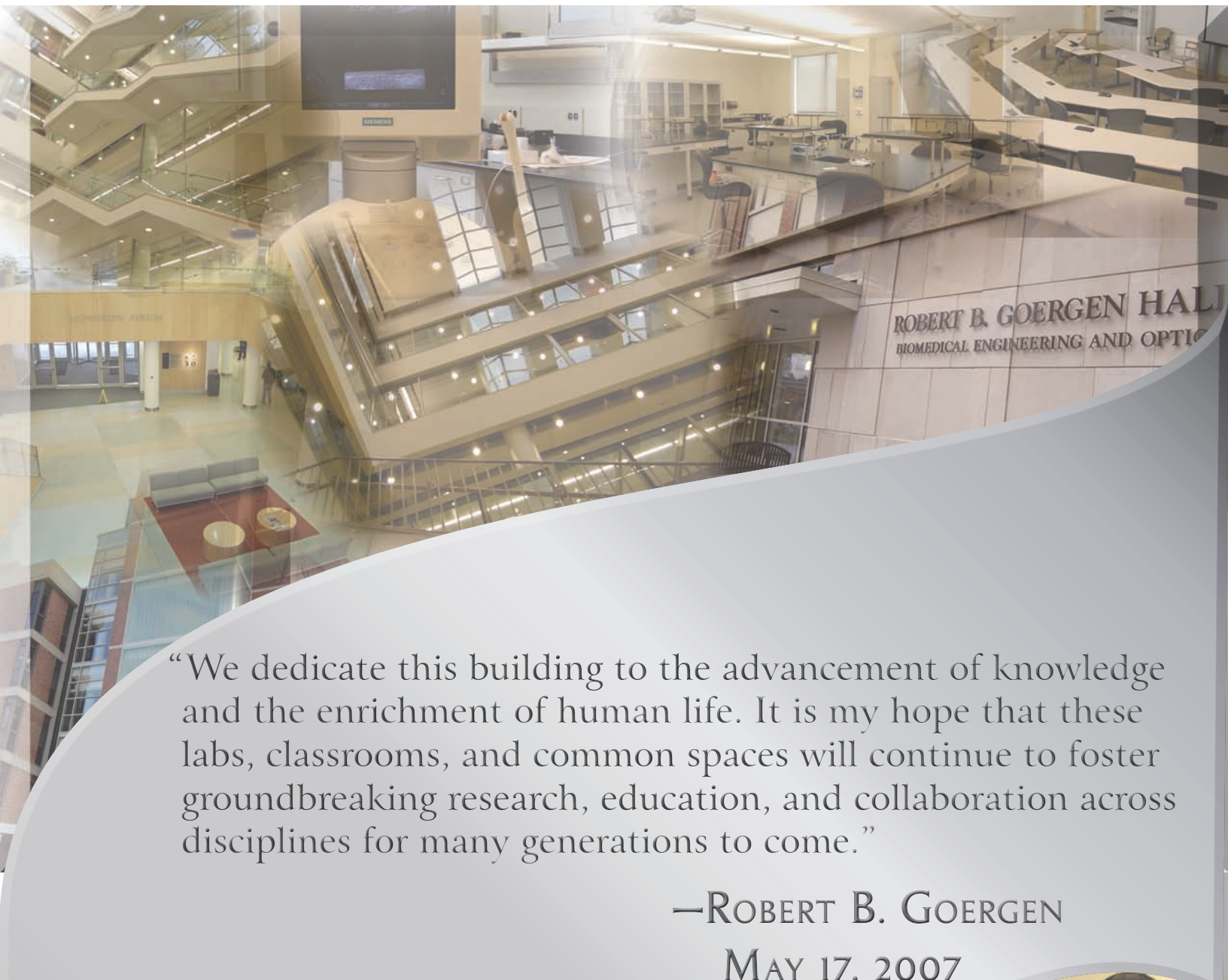

"We dedicate this building to the advancement of knowledge and the enrichment of human life. It is my hope that these labs, classrooms, and common spaces will continue to foster groundbreaking research, education, and collaboration across disciplines for many generations to come."

—Robert B. Goergen

May 17, 2007

From Dedication on Wall Plaque
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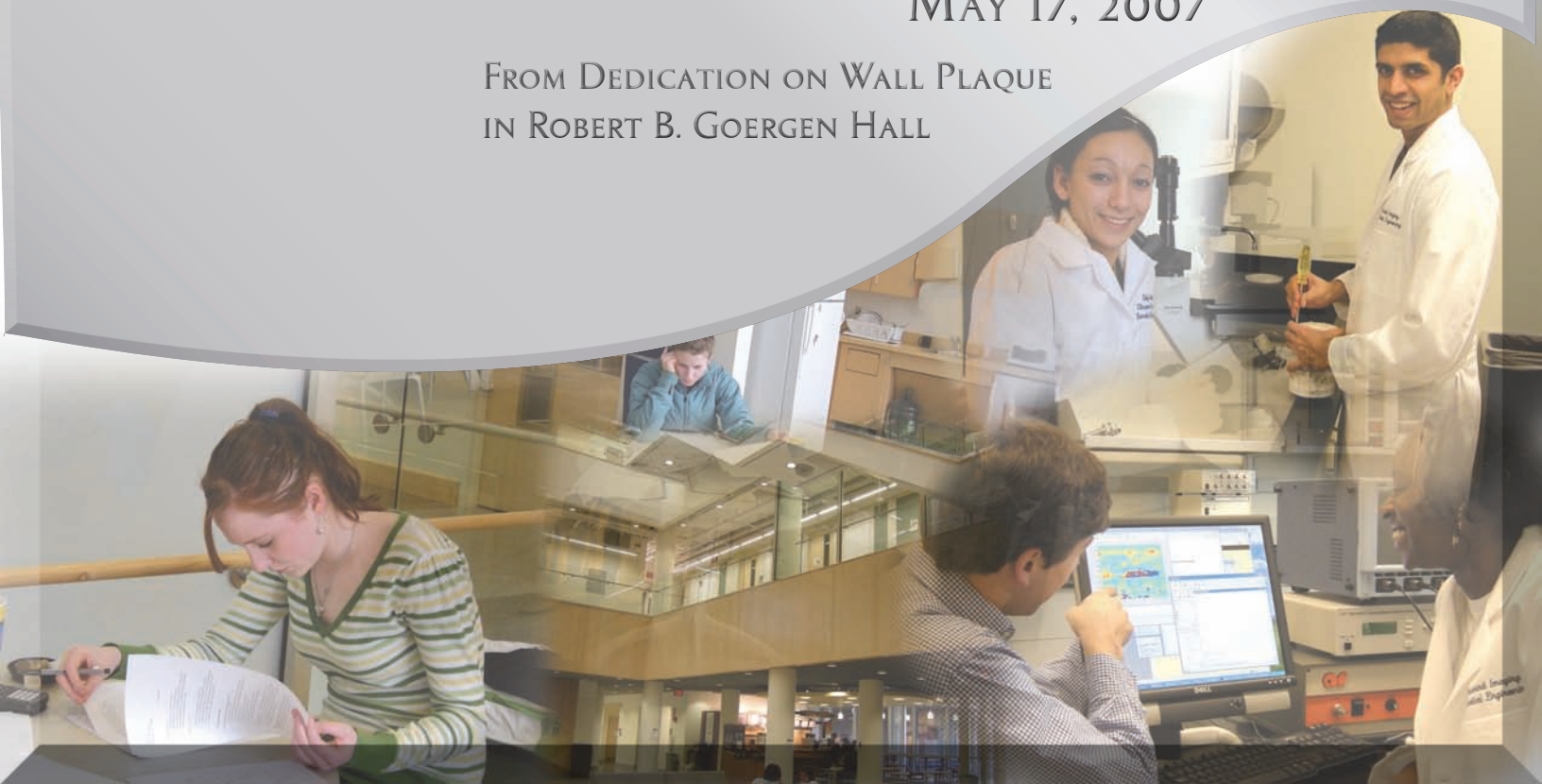

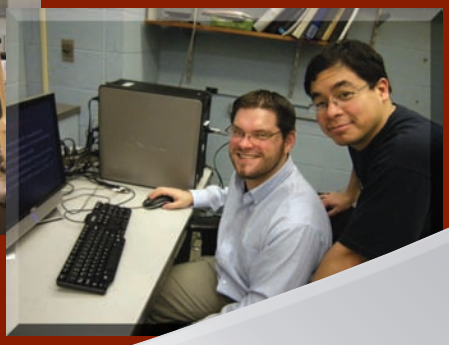

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