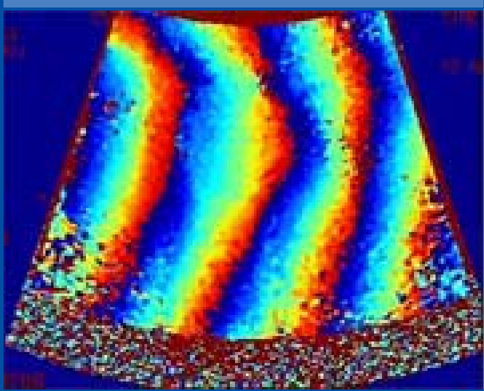
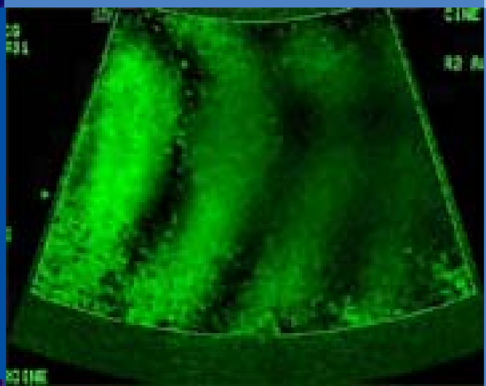
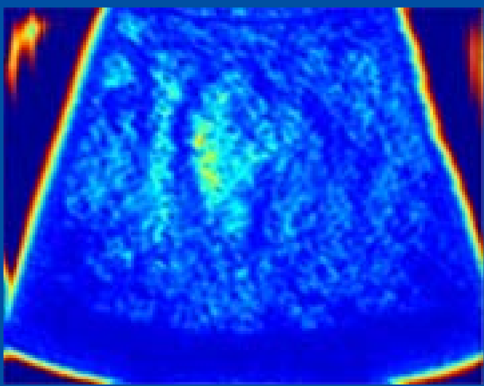
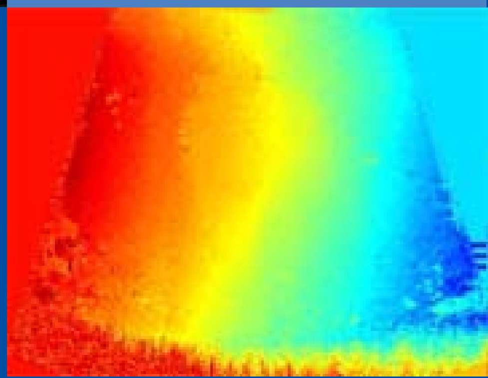
Rochester Center for Biomedical Ultrasound

Annual Report 2005









On the Cover

The images on the cover are from Zhe "Clark" Wu, PhD, showing shear wave patterns in various modes. The discovery of these "crawling waves" by Wu opens an entirely new dimension in real-time quantification of biomaterials. See the research brief on page 21 for more information.

Rochester Center for Biomedical Ultrasound

Director: Kevin J. Parker, PhD, **Associate Director**: Deborah J. Rubens, MD | **Executive Committee**: Diane Dalecki, PhD, Vikram S. Dogra, MD, Morton W. Miller, PhD, Kevin J. Parker, PhD, and Deborah J. Rubens, MD | **Provost**: Charles E. Phelps, PhD | **Vice Provost** and **Dean** of The College Faculty: Joanna Olmsted, PhD | **Dean**, School of Medicine and Dentistry: David S. Guzick, MD, PhD | **Annual Report Editor** and **Designer**: Betsy Christiansen

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About the Center

The Rochester Center for Biomedical Ultrasound (RCBU) is celebrating 20 years at the University of Rochester. The Center was created in 1986 to unite professionals from the medical, engineering, and applied science communities at the University, Rochester General Hospital, and Rochester Institute of Technology. The Center has grown over the years from 30 to more than 100 members, with several visiting scientists from locations around the country.

The Center provides a unique environment where researchers can join together to investigate the use of very high frequency sound waves in medical diagnosis and therapy.

The inside back page of this report shows the diverse departments involved in collaborative ultrasound research.

The Center's objectives include:

Research
Includes interaction with joint laboratories, technical discussion in formal meetings, and communication through a Center newsletter. In addition, interactions with industry, government, and foundations provide an assessment of the needs of the field and encourage mutually beneficial research programs and fellowships.

Education
Includes graduate-level courses in biomedical ultrasound and closely related fields, specialized short courses open to the international community, and post-doctorate collaborations with bioimaging areas within the University.

Innovation
The University of Rochester has a long history of leadership and innovation in biomedical ultrasound. For more than two decades, there has been steady progress in the quality of images of organs within the body which are reconstructed from the echoes of very short pulses of ultrasound.

University of Rochester Medical Center

In the late 1960s, the late Center member Raymond Gramiak led a team that first reported the use of an ultrasound contrast agent. At that time, agitate liquids were injected via a catheter while performing an ultrasound examination of the heart and great vessels. A dramatic increase in echoes was produced from the highly reflective air bubbles contained within the injected solution. Work has progressed through the years in this and other areas. Current projects include: nonlinear acoustics, contrast agents, 3D and 4D sonoelastography, ultrasound and MRI fusion, high-intensity focused ultrasound (HIFU), scattering, bioeffects, therapeutics, advanced imaging systems, and more.

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.

From the Directors

From Associate Director Deborah J. Rubens and Chief Sonographer Nancy Carson

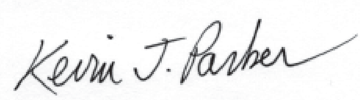
For the first half of 2005, the number of exams performed by the Division of Ultrasound was stable as compared to 2004. However, since July, the number of exams has increased by 7% compared to 2004. We are currently scanning with two ATL 5000s, two Sequoias, one GE Logiq9 that has true 3D capabilities, and two state-of-the-art research Logiq9s, both with 3D and 4D capabilities. The sonographers and radiologists have been evaluating machines from various vendors, including Zonare, Toshiba, GE, Siemens, and Philips in preparation for upgrades to some of the older equipment during 2006.

Early in 2005, we became one of several test sites across the nation to evaluate GE's cine-loop protocols. The improved cine-loop capabilities let the sonographer acquire data in one or two volumetric sweeps, rather than multiple still images, thus improving efficiency by decreasing scan time, while actually capturing more diagnostic information. Cine-loop protocols were compared to traditional scanning protocols for renal, thyroid, and scrotal exams. Thus far, we have submitted data from 143 patients to GE which show that cine-loop protocols are actually 25% more efficient than traditional protocols. Preliminary results for renal ultrasound were presented at the Society of Radiologists in Ultrasound (SRU) in October and final results will be presented at meetings of the American Institute of Ultrasound in Medicine (AIUM) and the American Roentgen Ray Society (ARRS) in 2006. We also performed clinical studies involving venous leg ultrasound waveforms and post-liver transplant Doppler assessment, which will be presented at the World Federation in Ultrasound Medicine and Biology (WFUMB) and AIUM meetings in 2006.

We completed our study with pediatric nephrology, assessing carotid intimal thickness compared to hypertension in a select group of patients. This demonstrated strong evidence that pediatric primary hypertension is associated with increased intimal thickness. The abstract was submitted to the American Society of Hypertension (ASH) 21st Annual Scientific Meeting and Exposition. In 2006, we will continue to work with pediatric hematology in evaluating aspirin prophylaxis in sickle cell disease. For this study, ultrasound will be used to monitor flow velocities in the circle of Willis on serial transcranial Doppler ultrasound exams.

In July, the department welcomed Dr. Vikram Dogra as their director. A profile of Dr. Dogra is on page 7.

From Director Kevin J. Parker



The RCBU was pleased to co-sponsor the Fourth International Conference on Ultrasonic Measurement and Imaging of Tissue Elasticity, held in Austin, Texas. Gathering investigators from around the world, this event was organized jointly with Dr. Jonathan Ophir of the Ultrasonic Laboratory at the University of Texas Medical School at Houston, who also acted as the local host. Details of the conference start on page 27.

Elastography imaging is emerging as a promising and exciting new field with numerous approaches and clinical applications. Plans are underway for the Fifth International Conference, which is being held in Utah in October. More details about the upcoming conference can be found at the RCBU Web site:
www.ece.rochester.edu/users/rcbu/conference

The RCBU has, over the years, been a generating source of fundamental concepts and innovations. Many of today's developments—contrast agents and nonlinear techniques—have a scientific history that includes benchmark experiments at the University of Rochester.

This year's annual report documents continued progress across broad fronts, from the fundamentals of tissue ultrasound interactions to advances in imaging and therapy. We welcome your comments on any of the enclosed reports.

New BME/Optics Building

The Department of Biomedical Engineering (BME) will soon have a new home. The 92,000 square foot facility will also offer expanded space for the Institute of Optics, providing exciting opportunities for collaborative research. RCBU members Diane Dalecki, Amy Lerner, Steve McAleavey, and Rick Waugh will move their research laboratories to the new building. The facility will also house classrooms, lecture halls, and teaching laboratories for the BME program. An enclosed walkway will connect the new building with the Carlson Engineering Library in the Computer Studies Building. The new building is expected to be ready by spring 2007.

New Biomedical Engineering building under construction on the University of Rochester campus

Rendering of what the new Biomedical Engineering building will look like once it is completed

Tribute to Jeanne Cullinan

Jeanne Cullinan, MD lost her courageous fight against cancer on January 7, 2006. Dr. Cullinan was an associate professor of Radiology at the University of Rochester, program director for the Diagnostic Radiology Residency Program, and director of the Women's Imaging Center, with special interest in mammography and ultrasound. She was also a member of the RCBU.

Dr. Cullinan graduated from the Hahnemann University Medical School in Pennsylvania in 1978 and completed her residency at the University of Pennsylvania (1979-82) in high risk obstetrics-gynecology. Following a career in ob-gyn, including perinatology at the University of Rochester, she worked for a year with Dr. Stephanie Wilson at the University of Toronto and did her radiology residency at Mount Sinai Medical Center (1989-92) in Miami Beach. From there she joined Dr. Arthur Fleisher at Vanderbilt University where she pioneered sonohyster-ography. She also had clinical and academic appointments at Allegheny General Hospital in Pittsburgh.

Dr. Cullinan's colleague, Deborah Rubens, said, "at the University of Rochester, Dr. Cullinan served as the director of women's imaging, but also maintained her expertise in cross-sectional imaging, including ultrasound and CT. She was an outstanding teacher and always made time to help out a colleague or a resident. She was an excellent writer as well, and contributed a great deal to ultrasound and radiology literature. Most of all, she was a "can do" person, always willing to take on a new project, help someone out, and fill in when needed. She was beloved by everyone she worked with, for her humor, her kindness, her interest, and her generosity of spirit. We all have been enriched by her time with us and will feel her loss."

Kevin Parker said of Dr. Cullinan, "We found her to be a first-class radiologist and someone of rare character, with a wonderful sense of humor. She was friendly and down to earth. She was a wonderful collaborator on research projects and had enthusiasm and ideas for making ultrasound better for patients and for diagnosis and treatment of disease. We shall never forget her wonderful personality and contributions, and we will miss her greatly."

Profile

Vikram S. Dogra**,** MD joined the University of Rochester Medical Center faculty as Professor of Diagnostic Radiology, Director, Division of Ultrasound, and Associate Chair of Education and Research.

Vikram S. Dogra

Dr. Dogra first got interested in ultrasound while he was practicing in Delhi, India in 1983 – 1984. He read an article about using ultrasound for obstetric exams. At that time, there was no ultrasound available in Delhi. He struggled to find out more, leading him to subscribe to the *Journal of Clinical Ultrasound*. He purchased an ultrasound machine and began experimenting, discovering a passion for ultrasound research. This led him to the United States in 1992. He often visits India for speaking engagements, sharing information and encouraging practitioners there to embrace ultrasound.

One of Dr. Dogra's missions at the University is to encourage new research. In support of that mission, he will be visiting the Chongqing Haifu (HIFU) Technology Co. Ltd. in China in April 2006 to discuss collaboration on evaluating a high-intensity focused ultrasound machine, which is approved in China and Europe for HIFU clinical trials, but not in the United States.

Other responsibilities for Dr. Dogra include assisting and organizing the research efforts in the Imaging Sciences Department for residents, fellows, and other PhDs. Dr. Dogra is deeply involved with education. He has already implemented improvments to the residency program. A survey of the residents led him to reorganize education conferences, resulting in increased attendance by residents and attendings. He also invites prominent visiting professors to lecture once a month. He has collaborated with the RCBU to bring visiting professors to lecture on new and upcoming imaging technology.

In the Division of Ultrasound, he has started a two or four-week visiting fellowship series. For sonographers, he has started an education fund and a monthly lunch session so they can bring any issues to the forefront and recommend improvements if needed.

Dr. Dogra comes from Case Western Reserve University in Cleveland, OH, where he served as Vice-Chairman of Education and Associate Professor of Diagnostic Radiology & Biomedical Engineering. Dr. Dogra was the Radiology Residency Program Director, the Director, Division of Ultrasound, and the Section Head, GU Radiology.

Dr. Dogra has a strong background in ultrasound research; he has published many significant articles related to radiology and is the author of several textbooks and book chapters. He is the co-editor, along with Deborah Rubens, of *Ultrasound Secrets.* In addition, he is frequently invited to speak at national and international conferences and is a reviewer for several major journals. Dr. Dogra has earned many honors and awards in his career, including, most recently in 2005:

- Elected honorary fellow of the Society of Uroradiology (USA)
- Elected Honorary Fellow of European Society of Uroradiology (ESUR)
- Elected Senior Member of AIUM
- Received Distinguished Committee Service Award (Ultrasound) given by the American College of Radiology (ACR)

In December, Dr. Dogra started a two-year term as president of the 3,000-member American Association of Radiologists of Indian Origin.

A new worldwide journal, *Ultrasound Clinics of North America*, selected Dr. Dogra to be the geneto-urinary section editor. Dr. Rubens was his co-editor for the first issue, which debuted at the 2005 RSNA conference. Dr. Dogra said it was a "great honor to do the first issue and wonderful for the department."

Dr. Dogra says he is happy to be part of the RCBU and values his association with Kevin Parker and Deborah Rubens. He says it has been a pleasure collaborating with PhD students Benjamin Castaneda and Maggie Zhang and post-doctoral fellow Ken Hoyt. He says he is also thankful to Rick Waugh and Kevin Parker for supporting his joint appointment to the Department of Biomedical Engineering.

Selected Presentations

DT Blackstock, "Clayton H. Allen's discovery of nonlinear acoustic saturation," 149th Meeting of the Acoustical Society of America, Vancouver, Canada, May 2005

DT Blackstock, "Once Nonlinear, Always Nonlinear," 17th International Symposium on Nonlinear Acoustics, Pennsylvania State University, State College, Pennsylvania, July 18-22, 2005

S Bhatt, RM Paspulati, **VS Dogra**, "Utility of Color Flow Doppler in Adnexal Sonography," 91st Scientific Assembly and Annual Meeting of the Radiological Society of North America (RSNA), Chicago, IL, November 27-December 2, 2005

D Dalecki, M Stratmeyer, "Basic Science: Bioeffects, " AIUM Annual Convention, Orlando, FL, June 2005

VS Dogra was invited by the RSNA to moderate the scientific paper presentation session on Prostate Sonographic Imaging and Ultrasound (Vascular Contrast) at the 91st Scientific Assembly and Annual Meeting, Chicago, IL, November 27-December 2, 2005

K Hoyt, F Forsberg, CRB Merritt, JB Liu, J Ophir, "An In Vivo Comparative Assessment of Adaptive Elastographic Techniques," Fourth International Conference on the Ultrasonic Measurement and Imaging of Tissue Elasticity, October 2005

KJ Parker, LS Taylor, SM Gracewski, DJ Rubens, "From Static to Dynamic Elastography: The Unified Range of Elastic Response," Fourth International Conference on the Ultrasonic Measurement and Imaging of Tissue Elasticity, October 2005

DJ Rubens, "Biopsy Do's and Don'ts" and "Just Images: Abdominal ultrasound and Doppler," AIUM Annual Convention, Orlando, FL, June 2005

S Voci, J Strang, D Rubens, and N Carson, "Venous Doppler Sonography: Visceral and Extremity Applications," workshop at the RSNA 91st Scientific Assembly and Annual Meeting, Chicago, IL, November 27-December 2, 2005

ZC Wu, "Visualization of Shear Wave Propagation in Biomaterials with Sonoelastography," AIUM Annual Convention, Orlando, FL, June 2005

ZC Wu, KJ Parker, "Shear wave interferometry, an application of sonoelastography," 149th Meeting of the Acoustical Society of America, Vancouver, Canada, May 2005

M Zhang, **LS Taylor**, **DJ Rubens, KJ Parker**, "Three Dimensional Sonoelastography and Elasticity Measurement of HIFU Ablation Lesions in Bovine Livers In Vitro," AIUM Annual Convention, Orlando, FL, June 19-22, 2005

M Zhang, ZC Wu, DJ Rubens, KJ Parker, "Mechanical Measurement of Elastic Properties of Bovine Liver and Human Prostate Under Compression," Fourth International Conference on the Ultrasonic Measurement and Imaging of Tissue Elasticity, October 2005

Deborah Rubens, Anne Hall, and Clark Wu with the GE Logiq9 ultrasound system

Selected Publications

G P Bezante, **X Chen**, G Molinari, A Valbusa, L Deferrari, V Sebastiani, N Yokoyama, **S Steinmetz**, A Barsotti, **KQ Schwarz**, "Left ventricular myocardial mass determination by contrast enhanced color Doppler compared with MRI." *Heart* 91(1):38-43, January 2005

GP Bezante, GM Rosa, R Bruni, **X Chen**, G Villa, A Scopinaro, M Balbi, A Barsotti, **KQ Schwarz**, "Improved assessment of left ventricular volumes and ejection fraction by contrast enhanced harmonic color Doppler echocardiography." *The International Journal of Cardiovascular Imaging* 21:609-616, 2005

S Bhatt and **VS Dogra**, "Doppler Imaging of the Uterus and Adnexae." *Ultrasound Clinics*, December 2005

VS Dogra, **S Bhatt**, and **DJ Rubens**, "Sonographic Evaluation of Testicular Torsion." *Ultrasound Clinics*, December 2005

D Dalecki, **C Rota**, **CH Raeman**, **SZ Child**, "Premature cardiac contractions produced by ultrasound and microbubble contrast agents in mice." *Acoust. Res. Let. Online*, 6:221-225, 2005

D Dalecki, "Biological Effects of Microbubble Ultrasound Contrast Agents" in *Medical Radiology-Diagnostic Imaging*: *Contrast Media in Ultrasonography, Basic Principles and Clinical Applications.* Editor, Emilio Quaia, Springer-Verlag. pg. 77-85, 2005

SM Gracewski, H Miao, **D Dalecki**, "Ultrasonic excitation of a bubble near a rigid or deformable sphere: Implications for ultrasonically induced hemolysis." *J. Acoust. Soc. Am.* 117(3): 1440-1447, March 2005

H Miao, **SM Gracewski**, **D Dalecki**, "Numerical simulation of an acoustically-excited bubble near a fixed rigid object." *Acoust. Research Lett. Online*-ARLO 6 (3): 144-150, July 2005

MW Miller, HE Miller, CC Church, "A new perspective on hyperthermia-induced birth defects: the role of activation energy and its relation to obstetric ultrasound." *J. Thermal Biology* 30: 400-409, 2005

V Misic, BA Winey, H Liu, **L Liao**, **P Okunieff**, **KJ Parker**, B Fenton, **Y Yu**, "Tumor detection in vivo with optical spectroscopy." *Proceedings of the 2005 IEEE, Engineering in Medicine and Biology 27th Annual Conference*, September 1-4, 2005

KJ Parker, LS Taylor, SM Gracewski, DJ Rubens, "A Unified View of Imaging the Elastic Properties of Tissue." *J. Acoust. Soc. Am.* 117(5): 2705-2712, May 2005

KJ Parker, M Zhang, DJ Rubens, "Color in Medical Imaging." *Biophotonics International* 12 (1) pp. 44-48, January 2005

S Bhatt, E Kocakoc, **DJ Rubens**, AD Seftel, and **VS Dogra**, "Sonographic Evaluation of Penile Trauma." *J Ultrasound Med* 24: 993-1000, 2005

L Fu, WS Ng, H Liu, W O'Dell, **DJ Rubens**, **J Strang**, MC Schell, R Brasacchio, **L Liao**, **E Messing**, **Y Yu**, "Bouquet brachytherapy: Feasibility and optimization of conically spaced implants." *Brachytherapy* 4(1):59-63, 2005

LS Taylor, **DJ Rubens**, **BC Porter**, **Z Wu**, RB Baggs, **PA di Sant'Agnese**, G Nadasdy, D Pasternack, **EM Messing**, P Nigwekar, **KJ Parker**, "Three-dimensional sonoelastography for in vitro detection of prostate cancer." *Radiology* 237(3): 981 - 985, December 2005

RC Waag, JP Astheimer, "Statistical estimation of ultrasonic propagation path parameters for aberration correction." *IEEE Trans Ultrason Ferroelectr Freq Control* 52(5):851-69, May 2005

BA Winey, V Misic, B Fenton, S Paoni, **L Liao, P Okunieff,** H Liu, **KJ Parker**, **Y Yu**, "In vivo optical spectroscopy of acoustically induced blood stasis." *Proceedings of the 2005 IEEE, Engineering in Medicine and Biology 27th Annual Conference*, September 1-4, 2005

People, Promotions, and Awards

Raymond Baggs received the University Dean's Award for Meritorious Service in PhD Defenses at the University of Rochester 2005 commencement ceremony.

One of the Goergen Awards for Curricular Achievement in Undergraduate Education was awarded to the **Department of Biomedical Engineering** at the University of Rochester College Convocation in September 2005.

David Blackstock taught Electrical and Computer Engineering 432, Acoustic Waves, in summer 2005.

Edwin Carstensen and **David Blackstock** attended the semi-annual meeting of the NIH Pilot Project Group (PPG) on lithotripsy, held in Indianapolis, Indiana in September. They are external reviewers for this project.

Sally Child celebrated 40 years of service to the University of Rochester.

Betsy Christiansen won a Merit Award from the Rochester Chapter of the Society for Technical Communication for the RCBU 2004 Annual Report.

Diane Dalecki was promoted to Associate Professor with Tenure in the Department of Biomedical Engineering with a secondary appointment in the Department of Electrical and Computer Engineering. Diane was elected to the Board of Governors of the American Institute of Ultrasound in Medicine and was also elected to a 3-year term on the AIUM Bioeffects Committee.

Vikram Dogra and **Deborah Rubens** are guest editors for *Ultrasound Clinics*, a new journal published four times a year by Elsevier. The first issue was released at the RSNA annual meeting in November-December 2005.

Vikram Dogra received the Distinguished Committee Service Award (Ultrasound) from the American College of Radiology (ACR).

Sheryl Gracewski is now a Fellow of the Acoustical Society of America.

Maria Helguera and **Navalgund Rao** won a Department of Central Intelligence (DCI) award for their project "Development of a Novel Ultrasound-Based Methodology to Detect the Presence of an Artificial Finger on a Fingerprint Scanner."

Kenneth Hoyt joined the RCBU as a postdoctoral fellow, focusing on sonoelasticity with applications for prostate and breast cancer.

Stephen McAleavey received the Wallace H. Coulter Foundation 2005 Early Career Award for "Characterization and Development of Acoustic Radiation Force Imaging of the Prostate."

Jack Mottley received the Edward Peck Curtis Award for Excellence in Undergraduate Teaching at the University of Rochester 2005 commencement ceremony.

Paul Okunieff received an NIH Centers for Medical Countermeasures Against Radiation grant for "Biophysical Assessment and Risk Management Following Irradiation."

Kevin Parker was named the William F. May Professor of Engineering in June 2005.

Wayne Pilkington received his PhD in Electrical and Computer Engineering and is an Assistant Professor of Electrical Engineering at Cal Poly College of Engineering in San Luis Obispo, CA.

Brian Porter accepted a position in the Sensor Applications and National Security Assessments Division of Areté Associates in Arlington, VA.

Claudio Rota received his PhD in Biomedical Engineering. His thesis, titled "Cardiac Arrhythmias Produced by Ultrasound and Contrast Agents," was supervised by **Diane Dalecki**. Claudio is now working as a Biomedical Engineering Licensing Manager in Patents & Licensing for the University of South Florida in Tampa.

Zhe (Clark) Wu completed his PhD in Electrical and Computer Engineering. **Kevin Parker** served as the adviser for his thesis, "Shear Wave Interferometry and Holography, an Application of Sonoelastography." Clark is now working for General Electric Medical Systems in Milwaukee, WI.

Yan Yu received the R33 phase of a combined R21/R33 grant from the NIH/NCI in August. The main goal is to evaluate the sono-contrast spectroscopy method clinically for breast cancer characterization. Other investigators include **Lydia Liao**, Bruce Fenton, Vladimir Misic, Brian Winey, and **Kevin Parker**.

Center Seminars

At the June RCBU meeting, **Catherine Theodoropoulos**, PhD, presented the VisualSonics' Vevo 770™ High-Resolution Imaging System. The high-resolution micro-imaging technology provides real-time, high-resolution imaging and blood flow analysis for small animal preclinical research. It is a non-invasive solution that facilitates longitudinal studies, from embryonic analysis through adulthood and blood flow analysis for small animal research. The product offers image resolution of anatomical and physiological structures down to 30 microns.

Anne Hall, PhD, a senior scientist with General Electric Healthcare, delivered a lecture in August 2005 to RCBU members and Department of Imaging Sciences residents on "Future Trends in Ultrasound" and worked with PhD students in Biomedical Engineering and Electrical and Computer Engineering.

Dr. Hall provided a broad overview of the ultrasound technology that she finds most interesting. She first discussed the history of ultrasound, describing the accelerating advances in image quality and productivity, along with promising new applications. Dr. Hall then described several current growth themes—compact ultrasound, contrast agents, the proliferation of 4D imaging, and general advances in ultrasound technology, which are clinical areas interesting to GE.

Benjamin Castaneda, Ken Hoyt, Anne Hall, and Clark Wu during Dr. Hall's visit to the University of Rochester Medical Center

Catherine Theodoropoulos of VisualSonics

Brian Winey and Vladimir Misic

Brian Winey, MS and **Vladimir Misic**, PhD, presented results of their research, "Cancer Diagnosis: Acoustically Induced Blood Stasis and Optical Spectroscopy," to RCBU members and Department of Imaging Sciences residents in November 2005.

2005 Research

Ultrasound-induced thermal mechanisms

Morton W. Miller, MD

Morton Miller 's research for 2005 emphasized ultrasound-induced thermal mechanisms. His published paper, "A new perspective on hyperthermia-induced birth defects: the role of activation energy and its relation to obstetric ultrasound" (Miller, Miller, Church) dealt with the rate of birth defects induced by hyperthermic conditions during gestation. These defects occur with low rates under apparently normal physiologic conditions, but with substantially higher rates with appropriate timing of a hyperthermic event during gestation. The concept of "free energy of activation" is invoked to explain not only the background rate but also the effect of a short-term, acute (additive) thermal dosing. Thus, the paper is both retrospective and prospective in approach. It briefly addresses the historical data in this area and then, following a novel mathematical procedure whereby the activation energy for a specific type of hyperthermia-induced birth defect is determined, prospectively applies this information to predict what the outcome would be in a clinical situation such as obstetric diagnostic ultrasound, where it is known that the clinical procedure can involve a temperature increment for a specific duration. A major outcome of this review is that there appear to be no thresholds for hyperthermic events, that any temperature elevation for any duration during pregnancy has some potential for inducing a deleterious effect. The paper includes an analysis that for the first time allows a calculation of risk for such defined thermal insults, with broader implications for any natural or other clinical situation in which the temperature of the embryo or fetus is raised above the normal physiologic level. For example, our analyses indicate that at 1 or 2 °C above normal physiological temperature for, say, 21 minutes, it would be virtually impossible for an obstetrician to discern any change in the yield of birth defects within his or her practice; it is also not likely that epidemiological investigations would detect such small increases. It is possible that clinical experience might lead to the detection of a threefold increase in anomalous neonates (which is projected to occur with a temperature increment of
3 °C), but only if many or most of such anomalous fetuses were not electively aborted. Elected abortions in this situation would lower the rate of neonates with birth defects. At 4 °C, because the Arrenhius relation is exponential with temperature increase, the yields become epidemic.

Statistical estimation of ultrasonic propagation path parameters for aberration correction

Robert Waag, PhD and Jeffery Astheimer, PhD

Parameters in a linear filter model for ultrasonic propagation are found using statistical estimation. The model uses an inhomogeneous-medium Green's function that is decomposed into a homogeneous-transmission term and a path-dependent aberration term. Power and cross-power spectra of random-medium scattering are estimated over the frequency band of the transmit-receive system by using closely situated scattering volumes. The frequency-domain magnitude of the aberration is obtained from a normalization of the power spectrum. The corresponding phase is reconstructed from cross-power spectra of subaperture signals at adjacent receive positions by a recursion. The subapertures constrain the receive sensitivity pattern to eliminate measurement system phase contributions. The recursion uses a Laplacian-based algorithm to obtain phase from phase differences. Pulse-echo waveforms were acquired from a point reflector and a tissue-like scattering phantom through a tissue-mimicking aberration path from neighboring volumes having essentially the same aberration path. Propagation path aberration parameters calculated from the measurements of random scattering through the aberration phantom agree with corresponding parameters calculated for the same aberrator and array position by using echoes from the point reflector. The results indicate that the approach describes, in addition to time shifts, waveform amplitude and shape changes produced by propagation through distributed aberration under realistic conditions.

HIFU focusing efficiency and a twin annular array source for prostate treatment

Ted Christopher, PhD

A measure of focusing efficiency is introduced for high-intensity, focused ultrasound (HIFU). The measure consists of the fraction of the total acoustic power emitted that linearly propagates through a circle located at the focus. The medium is absorption-free water, and power is computed using pressure and the normal component of velocity. Three MHz phased-array designs involving different element layouts and curvatures are placed in square apertures 2.2 cm in length (Fig. 2). The acoustic fields of these devices then are propagated to on-axis foci. The resulting focal efficiencies then are calculated using a two wavelength (0.1 cm) radius circle. Among these array designs, an annular array with 27 wavelength-wide rings is then extended to be the basis of a twin phased-array device for prostate hyperthermia treatment. The two annular arrays (Fig. 1) are attached to door-like hinges to allow for joint two-dimensional focusing. The focusing efficiency of this device is then compared to rectangular element-array devices with the same 5.4 by 2.2 cm source extent. With the addition of absorption and finite-amplitude distortion, the heating rate and temperature rise produced by the twin annular device in prostate tissue is considered. As a final look at the potential of annular array-based designs, three larger 2 MHz devices are briefly considered for abdominal treatment.

Ted Christopher received the PhD degree in electrical engineering from the University of Rochester in 1993. From 1987 to 1999 he held a number of ultrasound research and computer programming teaching positions at the University of Rochester. He currently writes software and consults.

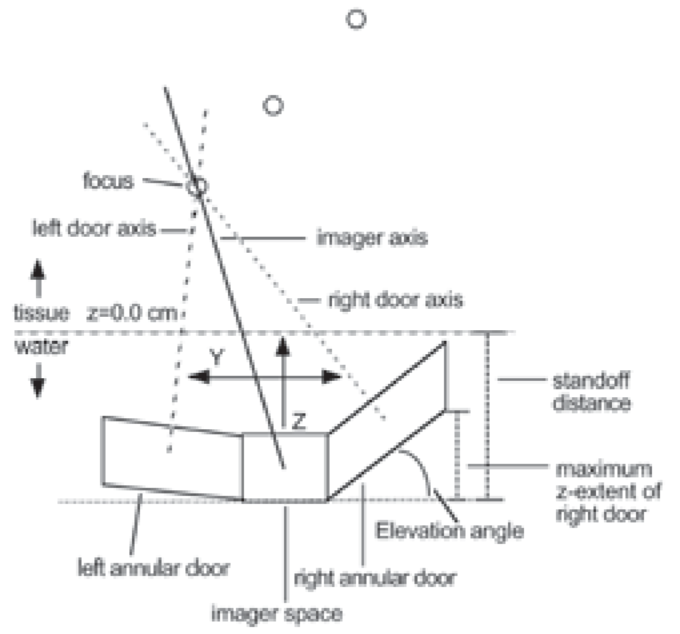


Fig. 1: Geometry of twin annular array or two-door prostate treatment device.

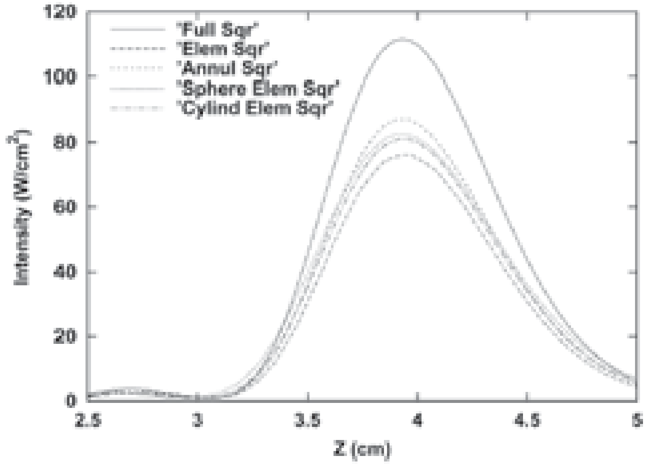


Fig. 2: The axial intensity profiles for several of the 2.2 cm square source designs.

Cardiac arrhythmias produced by ultrasound and contrast agents

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

In May 2005, Claudio Rota completed his PhD in Biomedical Engineering. His thesis, titled "Cardiac Arrhythmias Produced by Ultrasound and Contrast Agents," was supervised by Diane Dalecki. Following is the abstract from his thesis.

"Ultrasound is used widely in medicine for both diagnostic and therapeutic applications. Ultrasound contrast agents are suspensions of gas-filled microbubbles used to enhance diagnostic imaging. Microbubble contrast agents can increase the likelihood of bioeffects of ultrasound associated with acoustic cavitation. Under certain exposure conditions, the interaction of ultrasound with cardiac tissues can produce cardiac arrhythmias. The general objective of this thesis was to develop a greater understanding of ultrasound-induced premature cardiac beats. The hypothesis guiding this work was that acoustic cavitation is the physical mechanism for the production of arrhythmias with ultrasound. This hypothesis was tested through a series of experiments with mice in vivo and theoretical investigations.

Results of this research supported the acoustic cavitation hypothesis. The acoustic pressure threshold for premature beats was significantly lower with microbubble contrast agents present in the blood than without. With microbubbles, the threshold for premature beats was below the current output limits of diagnostic devices. The threshold was not significantly dependent upon contrast agent type and was not influenced by contrast agent dose over three orders of magnitude. Furthermore, the dependence of the threshold on acoustic frequency was consistent with the frequency dependence of acoustic cavitation. Experimentally determined thresholds for premature beats in vivo were in excellent agreement with theoretically estimated thresholds for inertial cavitation. A passive cavitation detector (PCD) was used to measure the acoustic emissions produced by cavitating microbubbles in vivo. A direct correlation between the amplitude of the PCD and the percentage of ultrasound pulses producing a premature beat was consistent with cavitation as a mechanism for this bioeffect. Although this thesis focused on the mechanistic understanding of ultrasound-induced arrhythmias, more persistent effects on the murine heart were also discovered. In the presence of microbubbles, ultrasound could produce morphological changes in the ECG and vascular damage in the myocardium. Taken together, these results indicate that ultrasound-induced arrhythmias were produced by intravascular microbubble activity. The findings of this thesis provide a greater understanding of acoustic cavitation in vivo, useful for the advancement of ultrasound contrast agents in imaging and therapy."

Thresholds for lung hemorrhage from underwater sound

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

Investigations are underway in our laboratory to study the effects of underwater sound on biological tissues. These projects are supported by the US Navy and have relevance to the safety of divers and marine mammals exposed to sonar fields. These investigations aim to develop a greater understanding of the response of biological tissues to underwater sound necessary for the development of guidelines for the safe use of sonar.

Through several different avenues of investigation, we have shown that murine lung and intestine can respond to low-frequency acoustic fields as resonant structures.

The air-filled lung is particularly sensitive to underwater sound exposure. Over the years, the Dalecki lab has been working to quantify the thresholds for lung hemorrhage over a broad range of acoustic frequencies (~100 Hz to 1 MHz) and identify the physical mechanisms for sound-induced lung hemorrhage. Medical ultrasound at diagnostic frequencies (i.e., > 1 MHz) is known to produce lung hemorrhage in numerous mammalian laboratory animals. In comparison, when the wavelength of the sound field is much greater than the radius of the lung, the whole lung is exposed to a homogeneous sound field. Through several different avenues of investigation, we have shown that murine lung and intestine can respond to low-frequency acoustic fields as resonant structures. The resonance frequency of an adult murine lung is ~325 Hz. At the resonance frequency, the response of the lung to sound exposure is maximized and the threshold for lung hemorrhage is lowest.

Recent experiments in our lab have determined the thresholds for sound-induced lung hemorrhage for frequencies above the resonance frequency of the lung. To accomplish this, we employed various acoustic source systems to generate acoustic fields at frequencies ranging from ~2 – 1000 kHz. Within our laboratory, two specialized exposure systems are available for the generation of very low frequency (100 – 3000 Hz) underwater sound fields. Horn transducers were employed for experiments at 10 kHz and 27 kHz, and single element ultrasound transducers were used for frequencies of 50 – 1000 kHz. Lung hemorrhage was observed in response to sound exposure at all frequencies. The extent of damage increased with increasing pressure amplitude. Thresholds for sound-induced lung hemorrhage decreased with decreasing frequency. 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 all the experimental lung threshold data over the 2.5 – 1000 kHz range.

Ongoing projects focus on determining the acoustic mechanism for lung damage in response to exposure to underwater sound. Experiments continue to measure the mechanical response of the lung to sound exposure as a function of various acoustic exposure parameters. New computational efforts aim to model the response of lung to sound exposure to lend insight into mechanical mechanisms for sound-induced lung hemorrhage.

Vascular effects of carbon ultrafine particle inhalation in diabetics

Alpa Shah, MD, Judith Stewart, MS, Anthony Pietropaoli, MD, Mark Utell, MD, Mark Frampton, MD, Sherry Steinmetz, RDMS, Karl Schwarz, MD, Xucai Chen, PhD

Diabetics have vascular endothelial dysfunction, which may increase their risk of adverse cardiovascular effects from airborne particles. We hypothesized that inhalation of carbon ultrafine particles (UFP) would further impair pulmonary and systemic endothelial function in people with type 2 diabetes mellitus.

Methods: Diabetics were exposed to filtered air or 50 $\mu g/m^3$ UFP (count median diameter 30 nm, geometric standard deviation 1.8) by mouthpiece for 2 hours, in a randomized, double-blinded crossover study. Exposures were separated by at least two weeks. The following markers of endothelial function were measured before and at intervals after exposure: pulmonary diffusing capacity for carbon monoxide (DLCO), flow mediated brachial artery dilatation (FMD) by ultrasound, and blood leukocyte expression of adhesion molecules.

Results and Conclusions: Subject enrollment is ongoing for this study. Preliminary results suggest that inhalation of carbon UFP may alter pulmonary and systemic endothelial function in people with type 2 diabetes.

This study is funded by a grant from the NIH.

Estrogen and the pathophysiology and outcomes of sepsis

Anthony P. Pietropaoli, MD, received a five-year Research Career Development Award from the NIH for this study. His collaborators include RCBU members Xucai Chen, Karl Q. Schwarz, and Sherry Steinmetz.

The goal of this proposal is to establish if estrogen levels are independently associated with endothelial function and oxidative stress during sepsis, and if such hormonally influenced responses are associated with clinical outcomes. The following hypotheses will be tested:

Patients with sepsis have impaired endothelial function, increased oxidative stress, and deranged nitric oxide (NO) metabolism and gonadal hormone levels, relative to healthy control subjects.

During sepsis, preserved endothelial function and reduced oxidative stress are associated with less severe illness and more favorable clinical outcomes. During sepsis, endogenous estrogen levels are associated with preserved endothelial function and reduced oxidative stress.

Patients with higher estrogen levels will therefore have less severe illness and improved clinical outcomes. This may account for the epidemiological observation of reduced sepsis incidence and improved sepsis outcome in females vs. males.

At the conclusion of this project, we will know whether gonadal steroid levels correlate with endothelial function, NO metabolism, and oxidative stress. We will also learn if these measurements are independently associated with clinical outcome. This knowledge will promote development of novel therapeutic interventions specifically targeting hormonally-based pathophysiologic processes, resulting in improved outcomes in this deadly syndrome. In particular, if higher estrogen concentrations are associated with preserved endothelial function, reduced oxidative stress, and better clinical outcome, clinical trials of short-term estrogen therapy will be considered.

Three-dimensional sonoelastography and elasticity measurement of HIFU ablation lesions in bovine livers in vitro

Man Zhang, MS, Lawrence S. Taylor, PhD, Deborah J. Rubens, MD, Kevin J. Parker, PhD

High intensity focused ultrasound (HIFU) is a promising therapeutic method which creates coagulation necrosis for non-invasively killing malignant tumors within a well-defined volume in the tissue. In this study, sonoelasto-graphy was investigated for the visualization of HIFU-induced lesions in bovine livers in vitro. Furthermore, mechanical testing and viscoelastic modeling were used to clarify the relationship of the tissue characteristic and the sonoelastography image formation. Tissue samples
(~ 4 x 4 x 4 cm^3) were cut from fresh bovine liver and then degassed overnight. Lesions were created in the tissue samples by a single-element HIFU transducer. A volumetric series of 2D sonoelastography images were acquired from the liver-embedded agar phantom. Each lesion displayed as a dark area surrounded by a bright green background in the image. IRIS explorer was used to reconstruct 3D lesion images. After imaging, lesions were examined by gross pathology to verify their size, shape, and volume. Uniaxial unconfined compression was carried out by an MTS system to test the tissue viscoelasticity. The Kelvin-Voigt fractional derivative (KVFD) model was applied as the viscoelastic model.

The gross pathology results showed that HIFU lesions were relatively uniform, palpably harder, and brighter than the normal tissue. The mean volumes of three 1 x 2 compound lesions, three 2 x 2 lesions and three 3 x 3 lesions measured by fluid displacement were 1.8 cm^3, 2.4 cm^3, and 6.0 cm^3, respectively. The smallest lesion in the test, a single HIFU lesion with 1.3 cm^3 in volume, was also successfully detected by 3D sonoelastography. The mean sonoelastography volume of the 10 lesions was 83% of the volume measured by fluid displacement. Curve fitting results indicated that the stiffness ratio of HIFU lesion and normal bovine liver was 8.4:1. A good correlation (R2 = 0.9749) was found between the lesion dimensions determined by 3D sonoelastography and gross pathology. The KVFD model may successfully illuminate tissue viscoelastic effects on sonoelastography imaging. This study demonstrates that sonoelastography is a potential real-time method to accurately monitor the HIFU therapy of cancerous lesions.

Mechanical measurement of elastic properties of bovine liver and human prostate under compression

Man Zhang, MS, Zhe Wu, PhD, Deborah J. Rubens, MD, Kevin J. Parker, PhD

The goal of this study was twofold: first, to establish a reliable and accurate technique for measuring the elastic properties of soft tissues; and second, to compare mechanical measurement results with those obtained from the sonoelastography shear wave interference method.


Man Zhang

Background
Over the past two decades, ultrasound elasticity imaging has been continuously developed for imaging soft tissue elasticity. However, fundamental knowledge of mechanical properties of soft tissue is lacking. In this study, we proposed the tissue stress-relaxation experiment and the Kelvin-Voigt fractional derivative (KVFD) model to clarify the frequency-dependent elastic properties of bovine liver (normal and HIFU ablated) and human prostate (normal and cancer).

Cylindrical samples (10 mm diameter, 8 mm thickness) were acquired from normal and HIFU-ablated liver tissues. During the experiment, a 3% compressional strain was applied to measure the stress-relaxation data over 1000 seconds. After that, the stress-relaxation curve of each sample was fitted to the KVFD model, in which α and η are the two important parameters. Finally, the complex elastic modulus at any frequency was obtained by the Fourier transform of the time domain response. The same procedure was also applied to the human prostate samples. Sonoelastography was used to visualize shear wave interference patterns. Shear wave velocity, and thus shear stiffness can be estimated from those patterns. A piece of fresh bovine liver was placed in between a pair of shear wave sources and the shear wave interference was recorded and analyzed to estimate the liver's shear stiffness.

The α ratio and the η ratio (Table 1) between the HIFU lesion and the normal liver are about 2:1 and 9:1, respectively. The η ratio reflects the stiffness contrast between the two tissues. Fig. 1 shows the frequency-dependent elastic properties of three types of liver tissues. The complex elastic modulus slightly increases with frequency. The shear wave interference method estimated that the Young's modulus of a bovine liver sample was 2.7 kPa at 50 Hz while it was 2.9 kPa from the mechanical testing. Shear wave interference experiments at more frequencies are scheduled. We have also tested over 30 samples from 11 different human prostates. For normal prostate samples, we have found that an average value for the elastic constant is 17.5 ± 2.1 kPa at 100 Hz.

Samples	η (kPa sec$^{\alpha}$)	α	R^2
Normal *(n=8)*	7.127	0.108	0.956
4 min HIFU *(n=8)*	66.760	0.208	0.985
2 min HIFU *(n=3)*	27.049	0.190	0.987

Table 1

Cancerous prostate samples were tested as well. In particular, three samples were acquired from one gland, each containing 90%, 70% and 0% cancerous tissue, respectively. The stiffness contrasts of these samples had a ratio of 2.7 to 2 to 1.

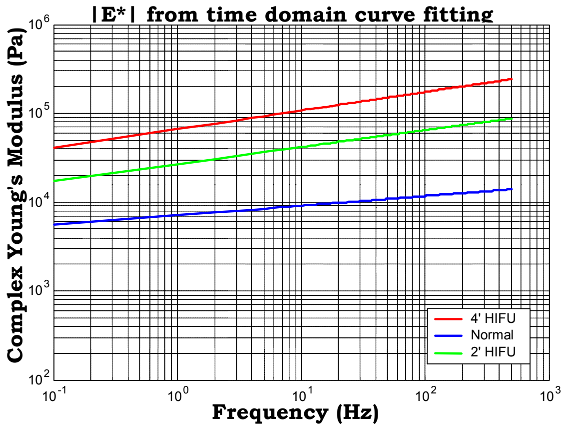


Fig. 1. Frequency-dependent elastic moduli of bovine liver.

The stress-relaxation test produces repeatable results which fit well to the KVFD model. The sonoelastography shear wave interference method provides preliminary estimation of shear stiffness of the bovine liver, which agrees with the mechanical measurement results. (See Fig. 2.) Elastic properties of normal and cancerous human prostates are systematically tested and the preliminary results are provided.

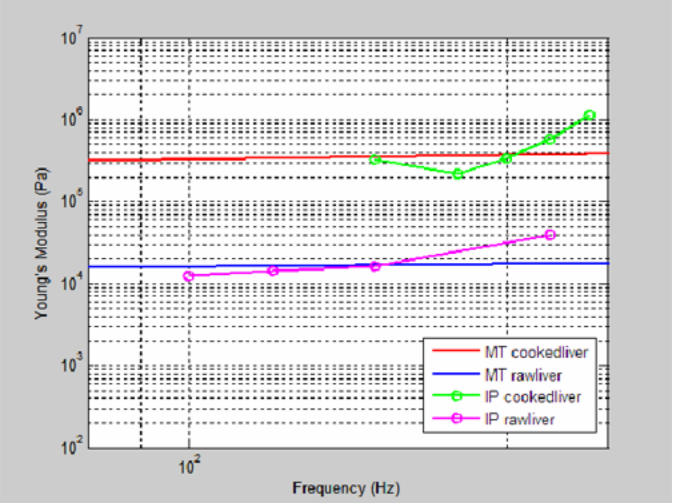


Fig. 2. Comparison of two methods: mechanical testing and shear wave interference (bovine liver).

Post-curing characterization of isotropic layered media using pulse-echo ultrasound and plate-guided waves

R.S. Pai Panandiker, PhD, Navalgund Rao, PhD,
Maria Helguera, PhD

The objective of this research was to study and develop the protocol required to isolate Lamb wave modes and employ pulse-echo ultrasound in powder-coated plates to characterize the curing of the coating layer. Powder coatings are dry polymer-based surface coatings that are sprayed onto the object surface using an electrostatic spray gun and then cured by heating the object in a convection oven. The plates used had coatings that were cured for different time durations. In the pulse-echo mode, we employed a high-frequency transducer. Discriminating parameters obtained included amplitude at nominal frequency, peak frequency, full width at half maximum (FWHM), and peak to side-lobe ratio of the received signal. One puzzling phenomenon that was observed was the time shift in the echo pulse. Although the distance between the plate and the transducer was kept fixed and the thickness of the plates was exactly the same, there was a shift in the location of the pulse. The magnitude of the pulse shift was approximately equivalent to the thickness of the plate itself and could be used as a characterizing parameter of the cure state. Lamb waves are a variation of longitudinal waves that are observed in plates due to the wave-guide effect of the acoustic boundaries created by the two surfaces. There are an infinite number of symmetric and asymmetric Lamb wave modes and all of them exhibit the phenomenon of dispersion. A set of 2 MHz transducers was used in pitch-catch mode to detect the waves. The drive signal used for the transmitting transducer varied from broadband and narrow-band chirps to monochromatic signals. Initially, the experiments were designed to generate only the two fundamental Lamb wave mode viz. A0 (asymmetric) and S0 (symmetric). We observed that the signal attenuates in correlation with the waveguide material acoustic properties, i.e., the different wave modes attenuate depending on the extent of curing of the coating layer. Other discrimination characteristics obtained were peak amplitude of signal and multi-spectral attenuation and phase difference signatures. The study is currently being extended to the separation of the Lamb wave modes at higher frequencies wherein a large number of the higher order modes are also present in the received signal. One of the tools being used is the Fractional Fourier Transform (FrFT). The FrFT is similar to the Fourier Transform, but with chirps as the basis signals. The understanding is that the chirp drive signals will be altered due to the dispersive nature of the different modes and provide a unique signature that will be observed in a FrFT sinogram. Current experiments do indicate observable differences in the sinograms of the different modes (Fig. 1 and Fig. 2).

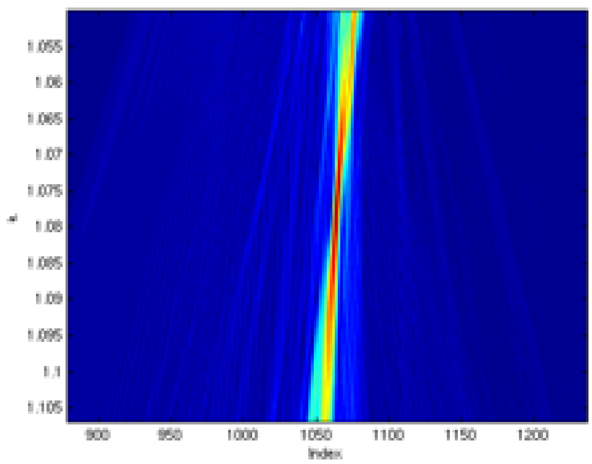


Fig. 1: FrFT sinogram of higher order symmetric mode. Peak in sinogram at FrFT parameter a = 1.08.

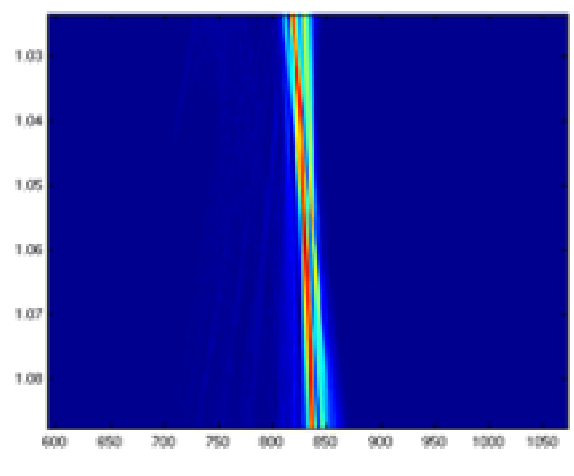


Fig. 2: FrFT sinogram of higher order asymmetric mode. Peak in sinogram at FrFT parameter a = 1.06.

Medical imaging segmentation and registration

Benjamin Castaneda, MS

We continue to advance our research on segmentation and registration of medical images, including ultrasound B-mode, sonoelasticity, CT, and histology images. We have developed a semi-automatic segmentation algorithm for prostate detection in B-mode ultrasound images using Support Vector Machines, a pattern recognition technique (see Fig. 1). We have also implemented a segmentation algorithm for tumor detection in sonoelasticity images using Level Set Methods (see Fig. 2). Currently these algorithms are under evaluation. We have also installed the hardware and software for a 3D ultrasound system that uses electromagnetic sensors. This system is capable of generating an ultrasound volume from a series of 2D free-hand B-mode images.

We continue to work on algorithms for ultrasound image compounding and for registration of B-mode and histology images.

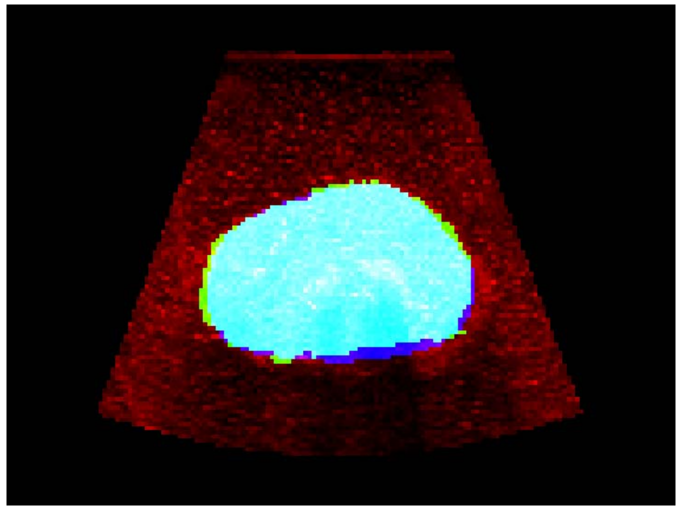


*Fig. 1. Red: B-mode image, blue: manual segmentation, green: algorithm segmentation.
Results: Specificity 98.73%, sensitivity 94.80%, difference in area -1.66%*

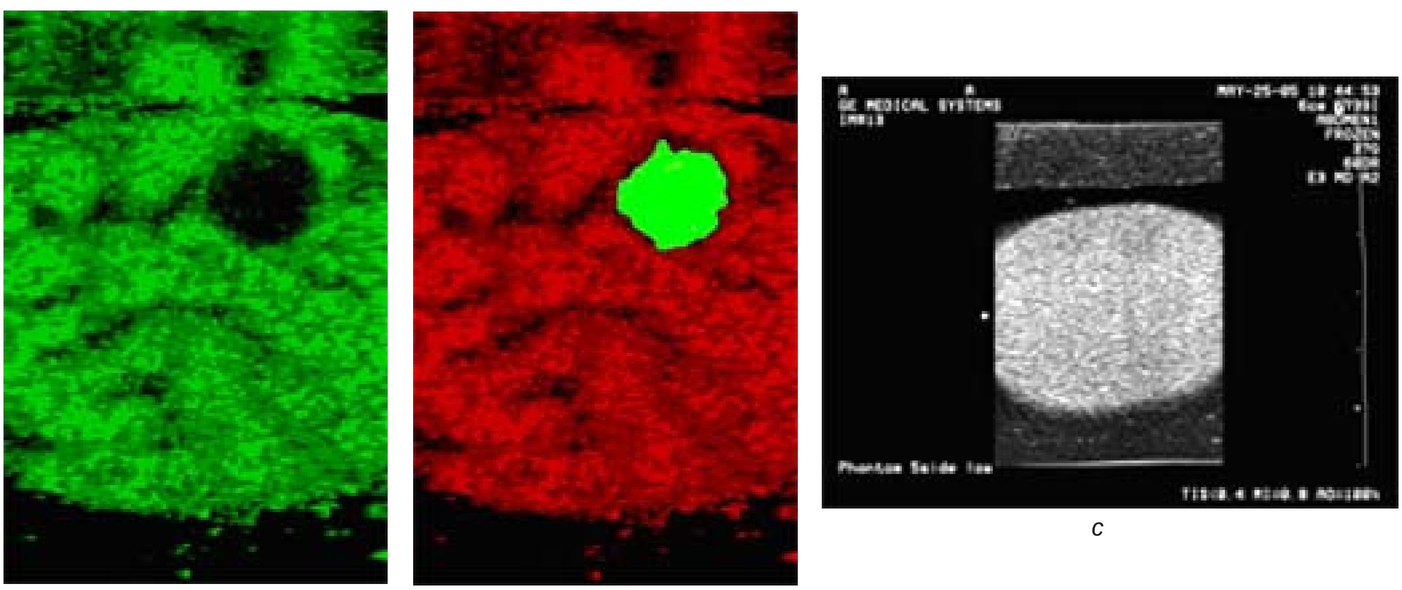


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Fig. 2. (a) Sonoelastography image of a prostate phantom. (b) Segmented image. Green: segmented tumor. Red: original image. (c) B-mode image of the prostate phantom

Visualization of cancers in prostate using sonoelastography and propagating shear wave interference patterns

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

Early and accurate detection of prostate cancer is an urgent priority because it is the most prevalent type of cancer and the second most frequent cause of cancer deaths in men. In the United States, the number of new cases of prostatic cancer in 2005 is expected to be 232,090 and deaths are estimated to be 30,350 (Jemal et al. 2005). The motivation for early prostate cancer detection is not only to reduce the mortality from this disease, but also to prevent side effects from local symptoms such as bleeding, urinary tract obstruction, and development of painful metastases.

To date, the lack of reliable imaging techniques to indicate the presence and extent of prostate cancer impedes clinical adoption. However, in a recent discovery by researchers at the University of Rochester, it was found that slowly propagating shear waves (with determined velocity) can be generated using a pair of mechanical sources vibrating at slightly offset frequencies. More importantly, these shear wave (interference) patterns can be visualized in real-time using an ultrasound-based tissue elasticity imaging technique known as sonoelastography (Fig. 1). These "crawling wave" images faithfully demonstrate the shear wave propagation patterns and allow for estimation of the spatial elastic properties. In particular, the shear wave modulus μ of tissue is approximated as $(v \cdot \lambda)^2 \rho$ where v denotes the frequency of excitation, λ is the shear wave wavelength and ρ is tissue density. Given a priori knowledge regarding shear wave frequency and tissue density (nearly equal to water for most biological tissues), local wavelength estimation of shear wave propagation patterns may allow quantification and imaging of the local shear modulus throughout the scan plane. Knowledge regarding the tissue shear modulus distribution may prove to be clinically significant since it has been shown experimentally that cancers of the prostate may exhibit a modulus contrast in excess of 10 dB when compared to normal prostatic tissue.

Initial studies by our research group have demonstrated that low frequency propagating shear waves (i.e., crawling waves) can be induced in ex vivo prostate specimens. The resultant shear wave vibrational patterns can then be analyzed to detect regions of prostatic disease (Fig. 2). The arrows indicate the distinct shear wave pattern deformation (i.e., increase in shear wave pattern wavelength) in the prostate specimen indicative of a stiff lesion (i.e., region of elevated shear modulus). Pathological evaluation of the prostate specimen confirmed that this tissue region contained a focal cancer. These findings demonstrate the feasibility of employing crawling waves for tissue elasticity assessment and cancer detection in prostate. By developing algorithms to analyze the shear wave vibration patterns and reconstruct the underlying tissue shear modulus distributions, an objective approach to cancer detection using imaging science may be finally realized. Future work will focus on optimizing this technology for in vivo applications and the subsequent translation to a clinical setting.

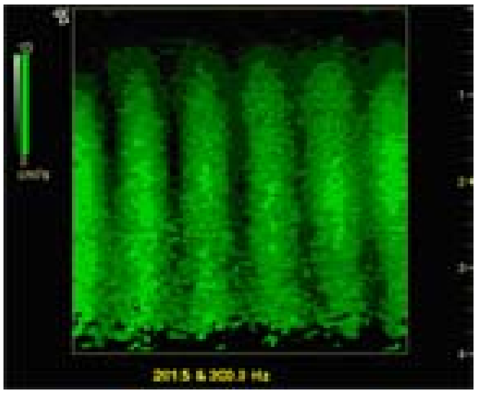

Fig. 1. Sonoelastographic image of shear wave interference patterns induced in a homogeneous tissue-mimicking phantom.

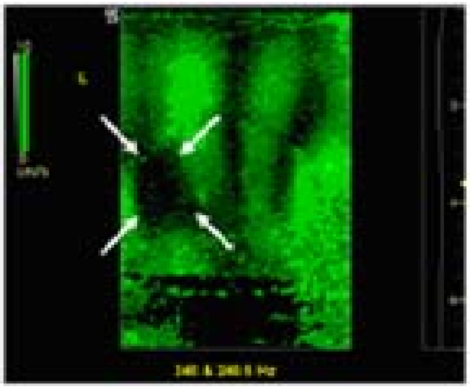

Fig. 2. Sonoelastographic image of ex vivo prostate specimen embedded in agar gel. Inspection of interference pattern distortion indicates a stiff mass (arrows).

Visualization of shear wave propagation in biomaterials with sonoelastography

Zhe Wu, PhD and Kevin J. Parker, PhD

Objective: To visualize the exact shear wave propagation in soft tissues using a commercially available ultrasound scanner with a sonoelastography modification.

Method: We propose a novel approach to visualize the shear wave propagation in soft materials in real time with the ultrasound technique called sonoelastography.

In this approach, one shear wave source propagates shear waves into the medium at the frequency ω. An ultrasound (US) probe is held above the surface of the medium. The ultrasound probe is vibrated by a vibrator at the frequency $\omega - \Delta\omega$, where $\Delta\omega$ is much smaller than ω. The ultrasound probe is carefully positioned so that there is always an ultrasound gel filled gap between the probe and the surface of the medium to ensure the vibration of the US probe does not propagate into the phantom.

The total field estimated by the ultrasound scanner is the shear wave propagation relative to the probe vibration, which we call the modulated field. The modulated field is proven to be a representation of the propagating shear wave field, only at a different frequency and thus different velocity. By carefully selecting ω and $\Delta\omega$, the shear wave propagation can be virtually slowed down so that it can be visualized by sonoelastography.

This proposed technique is validated in both a homogeneous phantom experiment and an inhomogeneous phantom experiment.

Results: The propagation of the shear wave wavefronts are clearly visible in both the homogeneous phantom and the inhomogeneous phantom. In the inhomogeneous phantom, the wavefronts are distorted by the stiff inclusion. (See Fig. 1.) The distortion of the wavefronts indicates the shear wave speed difference in the background and in the stiff inclusion. Therefore, the location and the size of the inclusion can be estimated.

Conclusion: This method provides many of the advantages of magnetic resonate elastography (MRE), but with the additional advantages of real time visualization of the vibration fields.

Shear wave interferometry, an application of sonoelastography

Zhe Wu, PhD and Kevin J. Parker, PhD

Sonoelastography is an ultrasound imaging technique where low-amplitude, low-frequency (LF) vibration is detected and displayed via real-time Doppler techniques. When multiple coherent shear wave sources exist, shear wave interference patterns appear. Two shear wave sources at the same frequency create hyperbolic shaped interference patterns in homogeneous, isotropic elastic media. Shear wave speed can be estimated from the fringe separation and the source frequency. If the two sources are driven at slightly different sinusoidal frequencies, the interference patterns no longer remain stationary. It is proven that the apparent velocity of the fringes is approximately proportional to the local shear wave velocity. With this approach, local shear wave speed in elastic media can be estimated. In addition, with a single shear wave source at frequency f and the ultrasound probe externally vibrated at frequency $f-\Delta f$, a novel type of moving interference between the shear waves and the frame of reference motion is created. The moving interference fringes represent the shape of shear wave wavefronts while traveling at a much slower speed. This approach provides a real-time visualization of shear wave propagation and local wave speed estimation from which local stiffness is inferred.

This work is supported by the NIH.

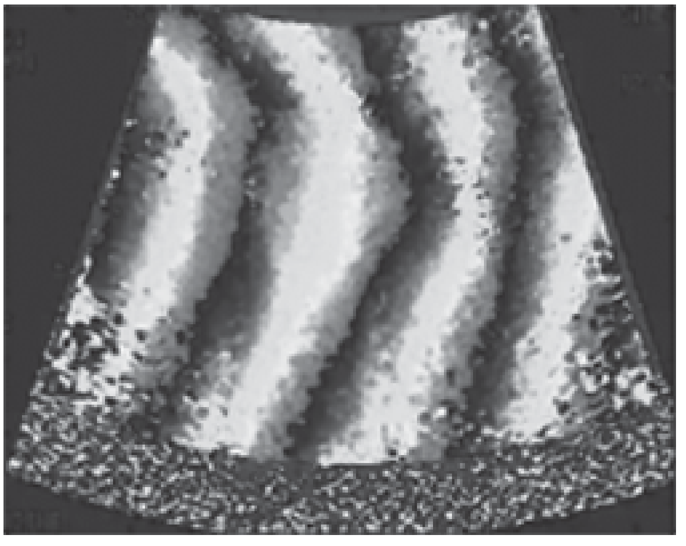

Fig. 1: Inhomogenous phantom experiment.

The relation between lung damage induced by acoustic excitation and the subharmonic response

Jonathan Young, MS, Sheryl Gracewski, PhD, Stephen McAleavey, PhD, Diane Dalecki, PhD

Over the years, the Dalecki Lab has studied the effects of ultrasound and low frequency underwater sound on gas-containing mammalian tissues. We have determined the thresholds for lung hemorrhage produced by acoustic fields for frequencies between 10^2 and 10^6 Hz and demonstrated that the lowest threshold occurs at the resonance frequency of the lung. Recently, our group hypothesized that the mechanism for lung hemorrhage at resonance depends on non-linear vibration of the lung with frequency of order one-half of resonance frequency.

To approximate the behavior of small mammalian lung at resonance, we developed a spherically symmetric balloon model. The theory of bubble dynamics given by the Rayleigh-Plesset equation was generalized to include the effect of an elastic membrane surrounding a spherically symmetric bubble to model the balloon. Numerical simulations of the modal contributions of the non-spherically symmetric surface disturbances were used to determine the stability of specific modes to predict the onset of the subharmonic response of the balloon models. The results gave an average applied pressure amplitude threshold of 0.87 kPa for the onset of non-spherical modes of oscillation.

To test the accuracy of the simulations, four balloons were made by filling a 0.09 mm thick latex-rubber membrane with air to an equilibrium radius of 10 mm. The resonance frequencies of the balloons were determined by measuring the total acoustic field as a function of frequency in an inertial calibration exposure chamber. We determined displacement measurements at a point on the balloon surface by calculating the cross-correlation of successive echoes emitted from a 5 MHz pulse/echo transducer and reflected by the balloon. Displacement amplitude data were collected as the applied acoustic pressure amplitude was increased from 0.3 kPa to 1.0 kPa, and the acoustic frequency was that of the resonance of the balloon.

A pressure threshold for the onset of large amplitude subharmonic modes was found to be 0.5 ± 0.05 kPa in the balloon models, as seen in Fig. 1. This result is comparable to our model predictions, which gave the

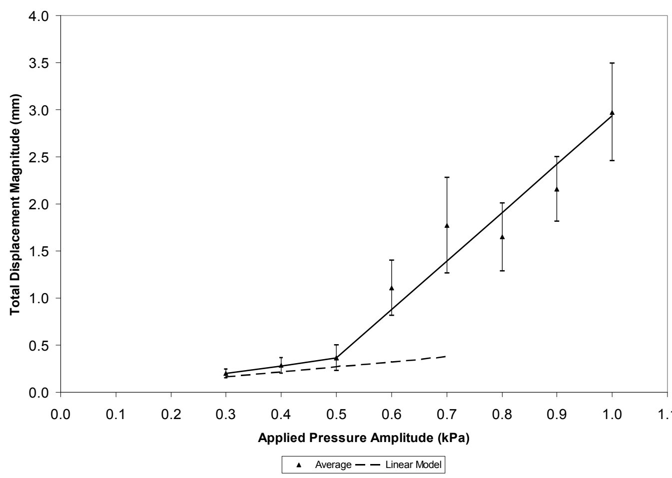

Fig. 1: Balloon wall displacement amplitude of the subharmonic ($f_{1/2}$) and fundamental (f_0) as a function of applied pressure amplitude. The dashed line is the balloon model given by an equation for spherically symmetric displacements.

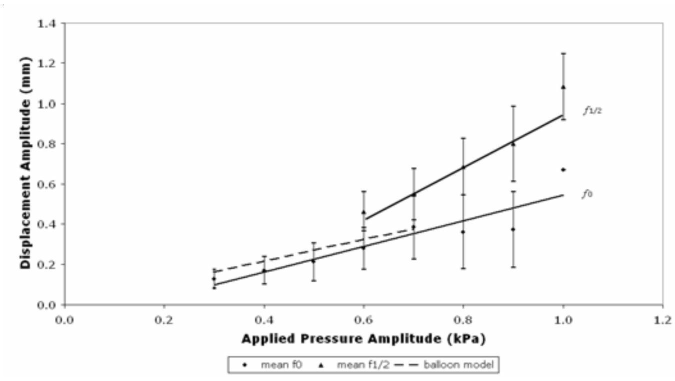

Fig. 2: Average total displacement amplitude measurements for the balloons when forced at the resonance frequency of the balloon (with standard error). The dashed line again represents the spherically symmetric model, which is valid while $pA \leq 0.5$ kPa. Above the threshold, the total displacement amplitude is dominated by the subharmonic.

threshold to be 0.87 kPa. At this pressure threshold, the vibration of the balloon surface becomes non-linear, oscillating with both the fundamental (resonance) and subharmonic (half resonance) frequencies. Higher order harmonics of these frequencies were also present but with significantly smaller amplitude in comparison to the subharmonic and fundamental. The onset of the subharmonic occurs at a sharp threshold, also predicted in the numerical simulations. Interestingly, this phenomenon is similar to the sharp threshold for sound-induced lung hemorrhage at resonance.

We measured the total displacement from the time-domain of the displacement data as half the peak-to-peak value of the minimum and maximum in the signal. The mean total displacement (with standard error) is shown in Fig. 2 as a function of applied pressure amplitude. Recalling Fig. 1, we can see that when the subharmonic is present ($p_A > 0.5$ kPa), the slope of total displacement amplitude increases by roughly a factor of five. In analyzing the frequency-domain of the displacements, we see that the large amplitude total displacements are due to the subharmonic frequency and a low-frequency oscillation. The subharmonic is due to the non-linearity in the oscillations of the balloon, while the low-frequency mode is likely due to a translational mode.

Ongoing efforts aim to extend our results from the balloon model to more realistic models in vitro and to mammalian lung in vivo. A second in vitro model of murine lung that we are currently testing consists of an air cavity of equilibrium radius 1 cm enclosed by 3% agar. To further understand the role of non-spherical oscillations of the lung in sound-induced lung hemorrhage, we will refine our experimental techniques for measuring lung displacement and further adapt and expand our numerical models to simulate the non-linear, non-spherical response of lung.

Radiation Oncology Therapy

Paul Okunieff, MD

The major research interests of the radiation therapy group include:

- Radiation bioterror and normal tissue response to irradiation
- Extracranial radiosurgery
- Radiation neurooncology

Currently, they are working on an NIH Centers for Medical Countermeasures Against Radiation grant for biophysical assessment and risk management following irradiation.

The group also participates in the Radiation Therapy Oncology Group (RTOG) Translational Research Program, a national cooperative research organization. They are currently studying radiation therapy, either alone or in conjunction with surgery and/or chemotherapeutic drugs.

Characterization and development of acoustic radiation force imaging of the prostate

Stephen McAleavey, PhD

The overall goal of the Wallace H. Coulter Foundation 2005 Early Career Award is to develop acoustic radiation force imaging (ARFI) as a tool for prostate cancer imaging. Having shown promise in in vitro experiments on tissue mimicking phantoms, we proposed research to fill in the gaps in our understanding of tissue heating effects, pushing pulse physics, and image quality to make ARFI clinically relevant and of commercial interest. To accomplish our goal we proposed the following specific aims:

1. Assemble a system for near-real-time ARFI imaging.
2. Develop pulse sequences appropriate for ARFI imaging of the prostate.
3. Compare ARFI images of excised human prostates with histology.
4. Perform in-vivo ARFI imaging of a human prostate and compare with histology.

We are pleased to report progress towards achieving these aims.

Aim 1: Assemble a near-real-time ARFI system.
We now have a functioning ARFI research system. Since the start of this project, we have assembled a scanner, support computer, and MATLAB software to allow ARFI pulse sequences to be loaded into the scanner and sequenced. An attached laptop computer processes the RF echo data generated by the scanner. Movies of tissue displacement through time are generated ~15 seconds after data acquisition. While not yet near real-time, the system at present is fast enough to guide phantom and excised tissue studies, so that data are not collected "blind."

Not yet complete is the development of a parallel-processing implementation of the tracking code, which is anticipated to allow generation of ARFI images within a second of pulse sequencing. We have not yet purchased computers dedicated solely to real-time ARFI data processing. However, our laboratory does have a dual-processor machine on which we can develop this code. While we anticipate completing this software and adding computers over the next year, our ability to acquire data (barring equipment failure) is secured.

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Aim 2: Develop pulse sequences for ARFI imaging of the prostate.
Pulse sequences for VF10-5 and EC9-4 probes have been generated and tested. Both probes have successfully produced ARFI images. We have encountered an unexpected limitation on pushing-pulse power; however, this may be a software error. We are working with Siemens to resolve it. This problem has not prevented us from obtaining useful data, but has temporarily limited our ability to make ARFI images at depths greater than 2 - 3 cm.

We have made progress in understanding the relationship between pushing pulse duration and induced displacement. This relationship was not specifically identified for study in the original proposal, but is related to our aim of developing appropriate pulse sequences for prostate imaging. The question to be studied is: for a given amount of ultrasound energy deposited in the tissue (i.e., a given integrated ultrasound push-pulse intensity), is there an optimal temporal distribution such that the tissue displacement is maximized?

Using the FEMLAB Finite Element (FE) program, we have created models to study this question. A uniform elastic, lightly damped cylindrical solid was used to model tissue, with a density of 1000 kg/m^3, Poisson's Ratio of 0.49, and Young's Modulus of 2 kPa (note this is significantly softer than prostate tissue, but convenient for modeling). The acoustic radiation force was modeled as a body force within a 1 mm radius, 4 mm tall cylinder on the body axis, with pulse durations of 20 µs to 20 ms. The amplitude of each pulse was adjusted to maintain a constant intensity-time product. Thus, each pulse would deposit an equal amout of heat into the tissue.

The results of the simulation indicate that the effect of pushing pulses shorter than a threshold are indistinguishable, and result in maximum displacement. The threshold is approximately equal to the width of the pushing region divided by the shear wave velocity. Pushes longer than the threshold result in reduced peak displacement for a given amount of tissue heating.

This finding is important in that it provides guidance as to the maximum pulse duration that can be used without causing excessive tissue heating. The mechanical bioeffects threshold (i.e., cavitation threshold) limits maximum pulse pressure. These two pieces of information indicate that the large displacements are most efficiently generated with a pushing pulse just below the cavitation threshold and just shorter than the above mentioned duration threshold. The thermal studies described in the proposal will investigate the suitability of such pulses from a heating standpoint. This finding is also important to eventual commercialization, as it suggests the scanner transmit circuitry must be capable of producing intense pulses for maximum efficiency.

Aim 3: Compare ARFI images of excised human prostates with histological results.
We have scanned excised human prostates, but we have not yet made any comparisons to histology. These scans have enabled us to get a feel for how prostate cancer appears under ARFI imaging and make early evaluations of pulse sequences. Based on the results of these early scans, we plan to obtain a transducer better matched to prostate imaging requirements than the VF10-5 used at present. See Fig. 1.

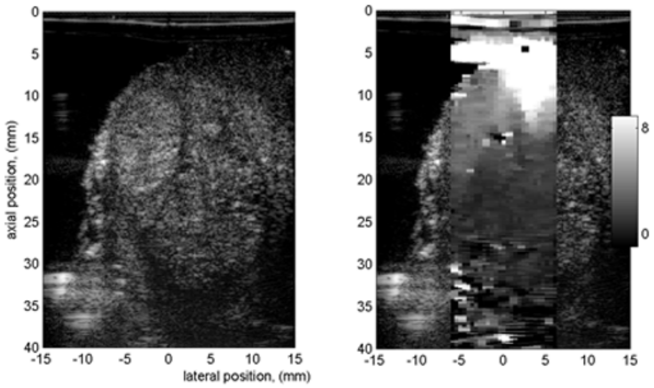


Fig 1. B-mode (left) and ARFI image (right) of excised human prostate. Note the correspondence between the hyperechoic oval lesion in the B-mode and the darkened region in the ARFI image, indicating the greater stiffness of the lesion. Grayscale indicates displacement in µm.

Aim 4: Perform in-vivo ARFI imaging of human prostate.
We have not yet performed an in vivo scan of the prostate.

Obstetrics and Gynecology Ultrasound Unit

Eva K. Pressman, MD

The unit is involved in clinical practice and multiple research endeavors. We continue to expand the availability of first trimester screening for aneuploidy, with nine physicians and sonographers certified to obtain nuchal translucency measurement. Research areas include postnatal follow up of prenatally diagnosed fetal renal anomalies, evaluation of fetal growth in obese patients, and prediction of abnormal pregnancy by first trimester blood flow evaluation.

The unit performed more than 17,200 obstetric and gynecologic procedures in 2005. In addition to diagnostic sonograms, the unit performed 550 amniocenteses, 84 chorionic villus samplings, 204 sonohysterograms, and 10 fetal blood samplings and transfusions.

See recently completed research projects on this page.

One size does not fit all: when are long bones too short?

John Christopher Glantz, MD, MPH

Objective: Shortened humerus lengths (HLs) are associated with increased trisomy risk, but there are various definitions of shortening and each affects sensitivity and specificity. A definition that works in one population may not be appropriate for another. The objective of this study is to compare different definitions when applied to a single heterogenous population.

Study Design: A 2004 ultrasound database included 2870 patients having sonography between 13-24 weeks in which HLs were measured routinely; 298 were for genetic amniocentesis. Twelve cases of trisomy 21 were identified. Trisomy 21 sensitivity, false positives (FP), and positive predictive values (PPV) of Benacerraf's formula: HL<(.9)*(-7.9+.85*BPD) were compared to various regression formulas derived from the local population using biparietal diameter (BPD) versus best gestational age (GA), and <90% expected versus <5th percentile.

Results: Benacerraf's formula had 55% sensitivity but 11% FP and PPV only 1.8% in the study population. Using a similar population-derived BPD formula, these parameters were 46%, 8%, and 2.1% respectively. Using a <5th percentile GA formula, they were 58%, 6% and 3.8%. Best GA performed slightly better than BPD (regression F=2230 and 1500, respectively). Formula slopes, when limited to women undergoing amniocentesis, were lower than slopes derived from non-amniocentesis women, and HL was a better predictor of trisomy after 17 weeks gestation than before this age.

Conclusion: Published formulas for what constitutes a short humerus are population-dependent, particularly when derived from groups at high genetic risk. These formulas may yield high FP rates when applied to low-risk populations, subjecting many women to unnecessary anxiety and procedures. In our population, formulas for HL <5th percentile using best GA as the independent variable performed best.

Ultrasound findings and the decision to terminate down syndrome pregnancies

Sandy Perry, MD, Angela Woodall, MD,
Eva K. Pressman, MD

Objective: To evaluate the association of abnormal ultrasound findings with the decision to terminate trisomy 21 pregnancies.

Methods: Pregnancies diagnosed with trisomy 21 prior to 24 weeks gestation were identified using a database of abnormal karyotypes from 1997-2005. We reviewed the medical records and ultrasound databases for each affected pregnancy. Logistic regression, chi-square test, and Fishers exact test were used for statistical analysis.

Results: Fifty-nine pregnancies were eligible for study. The overall termination rate was 72.9%. We found no difference in gravidity, parity, race, marital status, and gestational age at diagnosis between those who terminated and those who continued their pregnancies. The mean age in those who terminated was higher (36.1 vs. 32.3), but this was not statistically significant (P=0.059). Major and minor ultrasound abnormalities were associated with significantly lower termination rates, 50% and 64%, respectively, as compared to those with normal or limited ultrasound examinations, 92% (p=0.026 and p=0.022, respectively).

Conclusion: Patients with abnormal ultrasound results were more likely to continue a trisomy 21 pregnancy than patients with normal ultrasound examinations. This may be due to difference in plans for termination among patients who undergo amniocentesis for age or maternal serum screening versus those who are counseled only after an ultrasound abnormality is found. Unfortunately, this information was not available from our database.

Education

Biomedical Ultrasound (BME 451). This course 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 of utrasound, ultrasonography, dosimetry, hyperthermia, and lithotripsy.

Advanced Biomedical Ultrasound (BME 453). This course 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. A strong emphasis is placed on readings of original sources and student assignments and projects based on realistic acoustic simulations.

Microhydrodynamics (BME 466). This course develops insight into the motion of small particles in a viscous fluid. Such problems are encountered 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 intertial corrections.

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.

Nonlinear Finite Element Analysis (BME 487). This course 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). This course introduces students to major diagnostic methods in biomedical optics. Currently, 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.

Fundamentals of Acoustical Waves (ECE 432). Introduction to 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.

Medical Imaging - Theory and Implementation (ECE 452). This course 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.

Elasticity (ME449). This course presents an analysis of stress and strain, equilibrium, compatibility, elastic stress-strain relations, and material symmetries. Additional topics examined include torsion and bending of bars, plane stress and plane strain, and stress functions. Applications to half-plane and half-space problems, wedges, notches, and 3D problems via potentials are also discussed.

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

Tissue Elasticity Conference

Session TUT: Tutorial: Inverse Methods for Shear Stiffness Imaging

Chair: JB Weaver, USA Co-Chair: MM Doyley, USA

Imaging Shear Stiffness Tissue Properties Using Inverse Methods When Measurements Are Time Dependent. JR McLaughlin, Rensselaer Polytechnic Institute, Troy, NY.

Inferring Biomechanical Properties from Quasistatic Deformations: An Introduction to Associated Inverse Problems. PE Barbone, Boston University, Boston, MA 02215.

Session POS: Poster Session – Live Oral Presentations

Chair: J Bamber, UK Co-Chair: TA Krouskop, USA

3D Simulation Models for Ultrasound Elastography. AV Patil[1,2], TA Krouskop[3], J Ophir[1,2], S Srinivasan[2,4]. [1]University of Houston, Houston, TX, USA; [2]University of Texas Medical School, Houston, TX, USA; [3]Baylor College of Medicine, Houston, TX, USA; [4]Siemens Acuson Ultrasound, Mountain View, CA, USA.

Preliminary Results of Elasticity Imaging to Aortic Plaque. T Osaka[1], T Matsumura[1], T Mitake1, S Nakatani[2], T Shiina[3]. [1]Hitachi Medical Corporation, Chiba, Japan; [2]National Cardiovascular Center, Osaka, Japan; [3]University of Tsukuba, Ibaraki, Japan.

Two-Step Cross-Correlation Method to Improve Image Quality in Elastography. H Chen et al., University of Wisconsin-Madison, Madison, WI.

Regularization Issues in Young's Modulus Reconstruction. J Jiang, T J Hall, University of Wisconsin-Madison, Madison, WI.

Significant Clinical Results in the Diagnosis of Breast Lesion by Means of Real-Time Elastography. A Thomas[1], S Kümmel[1], H Frey[3], G Kristiansen[1], T Fischer[1]. [1]Charité – CCM, University Berlin, Berlin, Germany; [2]Hitachi Medical Systems, Wiesbaden, Germany.

Sonoelastography of the Testicles: Preliminary Results in the Diagnosis of Different Pathological Processes. L Pallwein, et al., Medical University, Innsbruck, Austria.

Simulation Study of Reconstruction of Shear Modulus, Density, Poisson's Ratio Distributions – 2[nd] Report. C Sumi, Sophia University, Tokyo, Japan.

Thermal Properties Reconstruction Based on Temperature Measurement – 2nd Report. C Sumi, Sophia University, Tokyo, Japan.

Real-Time Elastography for Prostate Cancer Detection: Preliminary Experience. E Pallwein et al., Medical University, Innsbruck, Austria.

An Application of the Lagrangian Speckle Model Estimator to Non-Invasively Characterize the Carotid Artery: Simulation Investigations. E Mercure et al., University of Montréal Hospital, Montréal, Quebec.

Non-Rigid Soft Tissue Tracking With Three-Dimensional Ultrasound. P Jordan[1,3], T Zickler[1], S Socrate[2], RD Howe1,[3]. [1]Harvard University, Cambridge, MA; [2]Massachusetts Institute of Technology, Cambridge, MA; [3]Harvard-MIT Division of Health Sciences and Technology, Cambridge, MA.

Detection of Non-Deformable Objects in the Body Using Ultrasound Elasticity Imaging. U Bae, Y Kim, University of Washington, Seattle, WA.

Absolute Elasticity Estimation with a New Ultrasonic-Mechanical Device. T Sato1, et al., Tokyo Metropolitan University, Tokyo, Japan.

The Feasibility of Using Elastographic Techniques for Assessing Meat Quality Attributes. R Righetti[1], J Ophir[1], RK Miller[2], TA Krouskop[1,3]. [1]The University of Texas Health Science Center at Houston, Houston, TX; [2]Texas A&M University, College Station, TX; [3]Baylor College of Medicine, Houston, TX.

Novel Strain Elastographic Techniques. R Righetti[1], A Thitai Kumar[1,2], S Srinivasan[1,3], J Ophir[1,2], TA Krouskop[1,4], [1]The University of Texas Health Science Center at Houston, Houston, TX; [2]University of Houston, Houston, TX; [3]Siemens Acuson Ultrasound, Mountain View, CA; [4]Baylor College of Medicine, Houston, TX.

Viscoelastic Characterization of Thermal Lesions in Liver. MZ Kiss, T Varghese, University of Wisconsin-Madison, Madison, WI.

Noise Reduction in Elastographic Strain Estimated From Displacement. L Xu, JC Bamber, Institute of Cancer Research and Royal Marsden NHS Trust, Sutton, Surrey, England.

Virtual Endoscopic Elastography – An Initial Experience In Vivo. PF Zhang[1], X Yi[2], HJ Su[3], M Zhang[1], WQ Chen[1], Y Zhang[1], [1]Shandong University Qilu Hospital, Jinan, Shandong Province, China; [2]Chinese Ministry of Education Key Laboratory of Cardiovascular Remodeling and Function Research, Jinan, Shandong Province, China; [3]Shandong University, Jinan, Shandong Province, China.

Plaque Volume Compression Ratio – A New Index in Evaluating Plaque Elasticity Properties. PF Zhang[1], GH Yao[1], M Zhang[1], H Jiang[2], Y Zhang[1], [1]Shandong University Qilu Hospital, Jinan, Shandong Province, China; [2]Chinese Ministry of Education Key Laboratory of Cardiovascular Remodeling and Function Research, Jinan, Shandong Province, China.

Phantom Experiments and Computer Simulation for Breast Cancer Elastography by Water Bag Pressing. Y Hayakawa[1], K Ishida[1], K Tsuji[1], M Kaitoo[1], M Nakamura[2], [1]Toin University of Yokohama, Yokohama, Kanagawa-ken, Japan; [2]Yokohama General Hospital, Yokohama, Kanagawa-ken, Japan.

Preliminary Clinical Study of Semi-Quantitative Freehand Elastography for the Assessment of Radiation Induced Breast Fibrosis. NL Bush[1], JC Bamber[1], PE Barbone[3], JR Yarnold[2]. [1,2]Institute of Cancer Research and Royal Marsden NHS Trust, Sutton, Surrey, England; [3]Boston University, Boston, MA.

Progress in Quantitative Biomechanical Imaging. NH Gokhale et al., Boston University, Boston, MA.

Tissue Motion and Elasticity Imaging Evaluated By Ultrasound in a Tissue-Mimicking Phantom. AAO Carneiro[1], H Chen[2], T Varghese[2], TJ Hall[2], JA Zagzebski[2]. [1]Universidade de São Paulo, Ribeirão Preto, São Paulo, Brazil; [2]University of Wisconsin-Madison, Madison, WI.

Comparison Between Axial Elastograms of a Connected and Disconnected Inclusion in Homogeneous Background: A Simulation Study. A Thitai Kumar[1,2], J Ophir[1,2], TA Krouskop[1,3]. [1]The University of Texas Medical School, Houston, TX; [2]University of Houston, Houston, TX; [3]Baylor College of Medicine, Houston, TX.

Theoretical and Simulation Study of Wave Generation and Its Effect on Lesion Detection in Sonoelastography. JM Park[1], SJ Kwon[1], MK Jeong[1], MH Bae[2]. [1]Daejin University, Pocheon, Kyeonggi, Korea; [2]Hallym University, Chuncheon, Kangwon, Korea.

Ultrasound Characterization of Mechanical Properties of Silicone Tube Walls. E Haeggstrom, et al., Helsinki University, Helsinki, Finland.

Elasticity and Pathology Imaging Correlation of Breast Tumours. WE Svensson[1], A Usupbaeva[1], S Shousha[1], S McLaggan[1], A Al-Kufaishi[1], PTR Thiruchelvam[1], JSK Lewis[1], HD Sinnett[1], J Malin[2], C Lowery[2].

[1]Charing Cross Hospital, London, England; [2]Siemens Medical Solutions Ultrasound Group, Issaquah, WA.

Effects of Viscoelasticity in Shear Wave Speed Reconstruction. J Klein, JR McLaughlin, Rensselaer Polytechnic Institute, Troy, NY.

Viscoelastic Characterization of Soft Materials Through Creep Test Experiments. JJ Ammann[1,2], R Rivera[1], J Ophir[3]. [1]Universidad de Santiago de Chile, Santiago, Chile; [2]CIMAT, Santiago, Chile; [3]The University of Texas Health Science Center at Houston, Houston, TX.

Session MIP-1: Methods for Imaging Elastic Tissue Properties – I

Chair: A Sarvazyan, USA Co-Chair: R Rohling, Canada

From Static to Dynamic Elastography: The Unified Range of Elastic Response. KJ Parker et al., University of Rochester, Rochester, NY.

Ultrasonic Tracking of Acoustic Radiation Force-Induced Displacement in Homogeneous Media. ML Palmeri[1], SA McAleavey[2], GE Trahey[1], KR Nightingale[1]. [1]Duke University, Durham, NC; [2]University of Rochester, Rochester, NY.

The Impact of Physiological Motion On Abdominal Acoustic Radiation Force Impulse Imaging. BJ Fahey et al., Duke University, Durham, NC.

Radiofrequency Ablation Electrode Displacement Elastography – A Phantom Study. S Bharat et al., Univ. of Wisconsin , Madison, WI.

In-Vitro Demonstration of Real Time Monitoring of Regional Tissue Elasticity During Focused Ultrasound Therapy Using Harmonic Motion Imaging. C Maleke et al., Columbia University, New York, NY.

Normal and Shear Strain Estimation and Angular Compounding Using Beam Steering on Linear Array Transducers. M Rao et al., University of Wisconsin-Madison, Madison, WI.

Design of a Hand-Held Probe for Imaging Tissue Elasticity. H Rivaz, R Rohling, University of British Columbia, Vancouver, BC, Canada.

Session FIP-1: Forward and Inverse Problems – I

Chair: T Varghese, USA Co-Chair: T Mitake, Japan

Shear Modulus Reconstruction Using Direct Finite Element Inversion Algorithm in Transient Elastography. E Park, AM Maniatty, Rensselaer Polytechnic Institute, Troy, NY.

Finite Element Analysis and Young's Modulus Reconstruction for Elasticity Imaging with Deformation by a Radiofrequency Ablation Electrode. J Jiang et al., University of Wisconsin-Madison, Madison, WI.

At the conference dinner, Dr. Youseph Yazdi, Corporate Director of Science and Technology for Johnson & Johnson spoke about "Lessons from the World of Medical Device Commercialization. "

Three Dimensional Ultrasound Image Registration And Shear Elastic Modulus Reconstruction. MS Richards et al., Boston University, Boston, MA.

Zero Memory Gauss-Newton Method for the Detection of Small Inclusions. J Fehrenbach[1], M Masmoudi1, R Souchon[2], P Trompette[2]. [1]Laboratoire MIP, Toulouse, France; 2INSERM UMR 556, Lyon, France.

The Influence of Causality On the Reconstruction of Shear Modulus for Dynamic Elastography. B Robert et al., Laboratoire Ondes et Acoustique, ESPCI, Paris, France.

Session CVE: Cardiovascular Elasticity

Chair: SY Emelianov, USA Co-Chair: HM Langevin, USA Rio Grande I

Motion Compensation for Intravascular Ultrasound Palpography for In Vivo Vulnerable Plaque Detection. KYE Leung[1], RA Baldewsing[1], F Mastik[1], MG Danilouchkine[1], JA Schaar[1], A Gisolf[2] , AFW van der Steen[1,3]. [1]Erasmus MC, Rotterdam, the Netherlands; [2]Delft University of Technology, the Netherlands; [3]Interuniversity Cardiology Institute of the Netherlands, Utrecht, the Netherlands.

A Compounding Method for Reconstructing the Heterogeneous Young's Modulus Distribution of Atherosclerotic Plaques from Their Radial Strain. RA Baldewsing[1], F Mastik[1], JA Schaar[1], AFW van der Steen[1,2]. [1]Erasmus MC, Rotterdam, the Netherlands; [2]Interuniversity Cardiology Institute of the Netherlands, Utrecht, the Netherlands.

Electromechanical Mapping of the Normal and Ischemic Myocardium. M Pernot et al., Columbia University, New York, NY.

An Integrated Ultrasound-Based Intravascular Imaging of Atherosclerosis. S Sethuraman[1], SR Aglyamov[1], JH Amirian[2], RW Smalling[2], SY Emelianov[1]. [1]The University of Texas at Austin, Austin, TX; University of Texas Health Science Center Houston, Houston, TX.

Angle Independent Strain Estimation in Myocardial Elastography. SD Fung-Kee-Fung, EE Konofagou. Columbia University, New York, NY.

Non-Invasive Vascular Elastography for Carotid Artery Plaque Characterization: In Vivo Feasibility Study. RL Maurice et al., University of Montréal Hospital, Montréal, Québec.

A 3D Simulation Model for Performance Assessment of 2D Myocardial Elastography. WN Lee et al., Columbia University, New York, NY, USA.

Session MMA: 3D, Multi-Modality & Alternative Applications

Chair: KJ Parker, USA Co-Chair: JC Bamber, UK

Frame Filtering for Improved Freehand 3D Ultrasound Elastography. JE Lindop et al., University of Cambridge, Cambridge, England.

An Inverse Deformation Method for the Visualization of Real-Time 3D Lung Dynamics. AP Santhanam, JP Rolland, University of Central Florida, Orlando FL.

Comparison of Three Non-Axial Strain Estimation Techniques for 3D Strain Estimation in Elastic Materials and Tissues. RGP Lopata et al., Radboud University Medical Center, Nijmegen, Netherlands.

Steady-State Harmonic Elastography: Visualizing the Viscoelastic Properties Within Soft Tissues. MM Doyley[1,2], Q Feng[2], JB Weaver[1,2], FE Kennedy[2], KD Paulsen[2]. [1]Dartmouth Medical School, Hanover, NH; [2]Dartmouth College, Hanover, NH.

Session SIP-1: Signal and Image Processing – I

Chair: TJ Hall, USA Co-Chair: T Shiina, Japan

Angular Strain Method for Strain Estimation in Ultrasound Elasticity Imaging. U Bae, Y Kim. University of Washington, Seattle, WA.

Multidimensional Autocorrelation and Doppler Methods Versus Cross-Spectrum Phase Gradient Method. C Sumi. Sophia University, Tokyo, Japan.

High Resolution Time of Flight Measurements with the Pulsed Phase Locked Loop. T Lynch[1], JS Heyman[1], D Blaker[2]. [1]Luna Innovations Inc., Hampton, VA; [2]Luna Innovations Inc., Blacksburg, VA.

Effects of Physiological Tissue Motion Statistics on Predicted Elastographic Image Quality In Vivo. R Chandrasekhar[1,2], J Ophir[1,2], T Krouskop[3], K Ophir[4]. [1]The University of Texas Medical School, Houston, TX, USA; [2]University of Houston, Houston, TX, USA; [3]Baylor College of Medicine, Houston, TX, USA.; [4]Austin, TX, USA.

Elasticity Imaging Using Ultrafast vs. Conventional Ultrasound Imaging. S Park[1], SR Aglyamov[1], J Shah[1], WG Scott[2], SY Emelianov[1]. [1]University of Texas at Austin, Austin, TX; [2]Winprobe Corporation, North Palm Beach, FL.

Equipment Exhibitors

- Hitachi Medical Corporation, Kashiwa, Japan
- Siemens Medical Solutions Ultrasound Group, Issaquah, Washington, USA
- Ultrasonix Medical Corporation, Burnaby, British Columbia, Canada.

Session CAA-1: Clinical and Animal Applications – I

Chair: JM Rubin, USA Co-Chair: BS Garra, USA

Arterial Elastic Modulus Reconstruction From In-Vivo Strain Imaging and PWV. WF Weitzel et al., University of Michigan, Ann Arbor, MI.

Computer Aided Diagnosis of Breast Cancer Based on Elasticity Images. T Shiina[1], M Yamakawa[1], A Itoh[2], E Tohno2, E Ueno[2], T Matsumura[3], T Mitake[3]. [1,2]University of Tsukuba, Tsukuba, Japan; [3]Hitachi Medical Corporation, Kashiwa, Japan.

Diagnosis of Liver Fibrosis in Children Using Fibroscan®. L Sandrin[1], V Miette[1], C Fournier[1], T Lamireau[2], V de Lédinghen[3]. [1]Echosens, Paris, FRANCE; [2]Hôpital Pellegrin, Bordeaux, France; 2Hôpital Haut Lévêque, Pessac, France.

Clinical Evaluation of Thyroid Tumor With Real-Time Tissue Elastography. K Tanaka[1], N Fukunari[2], H Akasu[1], W Kitagawa[1], K Shimizu[2], K Ito[2], T Mitake[3]. [1]Nippon Medical School, Tokyo, Japan; [2]Ito Hospital, Tokyo, Japan; 3Hitachi Medical Corporation, Tokyo, Japan.

Elasticity Imaging of 67 Cancers and 167 Benign Breast Lesions Shows It Could Halve Biopsy Rates of Benign Lesions. WE Svensson[1], D Amiras[1], S Shousha[1], A Rattansingh[1], D Chopra[1], HD Sinnett[1], TJ Hall[2], Y Zhu[3], J Malin[4], C Lowery[4]. [1]Charing Cross Hospital, London, England; [2]University of Wisconsin-Madison, Madison, WI; [3]University of Kansas Medical Center, Kansas City, KS; [4]Siemens Medical Solutions Ultrasound Group, Issaquah, WA.

Session BTM: Biomechanical Tissue Modeling

Chair: WF Weitzel, USA Co-Chair: E Mazza, Switzerland

The Role of Anisotropic Elasticity and Viscosity in Skeletal Muscle Imaging. SF Levinson[1], S Catheline[2], M Fink[2], RL Ehman[3]. [1]Wayne State University, Detroit, MI; [2]Laboratoire Onde et Acoustique, ESPCI, Paris, France; [3]Mayo Clinic Department of Radiology, Rochester, MN.

Micromechanical Analysis of Dentin Elastic Anisotropy. A Misra et al., University of Missouri-Kansas-City, Kansas City, MO.

Calibrating Scanning Acoustic Microscopy for Micromechanical Property Quantification. O Marangos et al., University of Missouri-Kansas City, Kansas City, MO.

Session MMT: Mechanical Measurement Techniques for Tissues

Chair: GE Trahey, USA Co-Chair: L Sandrin, France

Average "Grain-Size" Estimation in Liquid or Solid Channels. D Hazony[1],Y Hazony[2], JL Katz[1,3]. [1]Case Western Reserve University, Cleveland, OH; [2]Boston University, Boston, MA; [3]University of Missouri-Kansas City, Kansas City, MO.

Study of the Effect of Boundary Conditions and Inclusion's Position on the Contrast Transfer Efficiency in Elastography**.** D Sosa Cabrera[1,2], J Ophir[1,3], T Krouskop[4], A Thitai Kumar[1,3], J Ruiz-Alzola[2]. [1]The University of Texas Medical School, Houston, TX; [2]University of Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Canary Islands; [3]University of Houston, Houston, TX; [4]Baylor College of Medicine, Houston, TX.

In Vivo Mechanical Behavior of Human Liver. E Mazza[1], A Nava[1], D Hahnloser[2], W Jochum[2], M Bajka[2]. [1]Swiss Federal Institute of Technology, Zurich, Switzerland; [2]University Hospital, Zurich, Switzerland.

Mechanical Characterization of Soft Tissue: Comparison of Different Experimental Techniques on Synthetic Materials. D Valtorta[1], M Hollenstein[1], A Nava1, V Luboz[2], MH Lu[3], A Choi[3], E Mazza[1], YP Zheng[3], SM Cotin[2]. [1]Swiss Federal Institute of Technology, Zürich, Switzerland; [2]Massachusetts General Hospital, Boston, MA; [3]The Hong Kong Polytechnic University, Hong Kong, China.

Shear Modulus Reconstruction Using Ultrasonically Measured Strain Ratio. C Sumi, Sophia University, Tokyo, Japan.

Noninvasive Intramuscular Pressure Measurements Through Harmonic Analysis of Arterial Pulsations. T Lynch[1], T Ueno[2], AD Cutuk[2], JM Wiemann[2], BR Macias[2], AR Hargens[2]. [1]Luna Innovations Inc., Hampton, VA; [2]University of California San Diego, San Diego, CA.

Session MIP-2: Methods for Imaging Elastic Tissue Properties – II

Chair: R Sinkus, France Co-Chair: JL Katz, USA

The Spatio-Temporal Variation of the Strain Field Inside Compressed Poroelastic Materials. GP Berry et al., Institute of Cancer Research, Sutton, Surrey, England.

A New Compression Method for Generating Poroelastograms in Inherently Noisy Applications. R Righetti[1], J Ophir[1], BS Garra[2], TA Krouskop[1,3]. [1]The University of Texas Health Science Center at Houston, Houston, TX; [2]The University of Vermont College of Medicine, Burlington, VT; [3]Baylor College of Medicine, Houston, TX.

Maximum Strain Accumulation for In Vivo Tissue. AM Sommer et al., University of Wisconsin – Madison, Madison, WI.

Doppler Myography—Detecting and Imaging Intrinsic Muscle Sounds. SF Levinson[1], H Kanai[2], H Hasegawa[2],[1]Wayne State University, Detroit, MI; [2]Tohoku University, Sendai, Japan.

Transient Ultrasound Elastography Using Impulsive Ultrasound Radiation Force. D Melodelima[1], JC Bamber[1], F Duck[2], S Shipley[2]. [1]Royal Marsden NHS Trust and Institute of Cancer Research, Sutton, Surrey, England; [2]Royal United Hospital NHS Trust, Bath, England.

An In Vivo Comparative Assessment of Adaptive Elastographic Techniques. K Hoyt[1,2], F Forsberg[2], CRB Merritt[2], JB Liu[2], J Ophir[3]. [1]Drexel University, Philadelphia, PA; [2]Thomas Jefferson University, Philadelphia, PA; [3]University of Texas Medical School, Houston, TX.

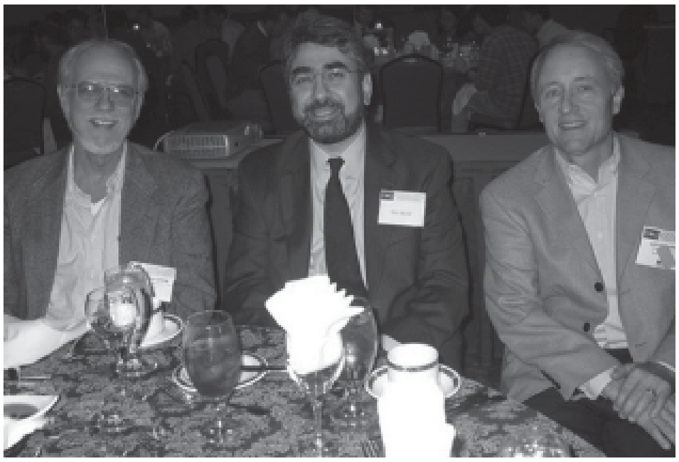
Displacement of a Solid Sphere in a Viscoelastic Medium in Response to an Acoustic Radiation Force: Theoretical Analysis and Experimental Verification. SR Aglyamov et al., The University of Texas at Austin, Austin, TX.

Electrographic Imaging of Uterine Tissue. MA Hobson et al., University of Wisconsin-Madison, Madison, WI.

Session PTO: Phantoms and Test Objects

Chair: AFW van der Steen, The Netherlands Co-Chair: TA Krouskop, USA Rio Grande I

PVA Prostate Phantom for Ultrasound and MR Elastography. W Khaled et al., Institute of High Frequency Engineering, Ruhr-University, Bochum, Germany.



Jonathan Ophir, Youseph Yazdi, and Kevin Parker

A Novel 3D Haptic Sensor System Based on Ultrasound Elastography. W Khaled[1], S Reichling[1], OT Bruhns[1], A Lorenz[2], A Pesavento[2], H Ermert[1]. [1]Ruhr-University, Bochum, Germany; [2]LP-IT Innovative Technologies GmbH, Bochum, Germany.

Tissue Mimicking Materials and Phantoms for Elasticity Imaging. J Beck et al., The University of Texas at Austin, Austin, TX.

Session INS: Instrumentation

Chair: GJ Streekstra, The Netherlands Co-Chair: AM Maniatty, USA

Development of an In Vivo Tissue Indentation System Using an Electromagnetic Spatial Locating Sensor. YP Zheng, et al., Hong Kong Polytechnic University, Hong Kong, China.

Development of a Software Platform for Ultrasound Measurement of Motion and Elasticity (UMME). YP Zheng et al., Hong Kong Polytechnic University, Hong Kong, China.

Measuring Stiffness of Breast Tissue Ex-Vivo. A Iqbal, et al., Ninewells Hospital and Medical School, University of Dundee, Dundee, Scotland.

Session SIP-2: Signal and Image Processing – II

Chair: F Forsberg, USA Co-Chair: EE Konofagou, USA

2D Strain Estimation Based On a Newton Constrained Minimization Strategy: Application to Experimental Data. E Brusseau et al., CREATIS UMR CNRS 5515 INSERM U630, Lyon, France.

Strain Estimation With Pulse Shaping. R Souchon, et al., INSERM UMR 556, Lyon, France.

Signal-to-Noise Ratio Upper-Bound in Shear Strain Elastograms. A Thitai Kumar[1,2], J Ophir[1,2] and TA Krouskop[1,3]. [1]The University of Texas Medical School, Houston, TX; [2]University of Houston, Houston, TX; [3]Baylor College of Medicine, Houston, TX.

Regularization for Strain Measurement And Shear Modulus Reconstruction. C Sumi, Sophia University, Tokyo, Japan.

Session FIP-2: Forward and Inverse Problems – II

Chair: JR McLaughlin, USA Co-Chair: R Souchon, France

2D And 3D Elasticity and Viscosity Imaging Using New Reconstruction Strategies in Dynamic Elastography. J Bercoff et al., Laboratoire Ondes et Acoustique, ESPCI, Paris, France.

An Analytical Model for 3D Longitudinal Wave Propagation in a Viscoelastic Cylinder: Applications to MR Elastography. GJ Streekstra, et al., Academic Medical Center, Amsterdam, Netherlands.

A Bayesian Image Reconstruction Approach for Model-Based Elastography. MM Doyley[1,3], S Srinivasan[2], E Dimidenko[1], N Soni[3], J Ophir[2]. [1]Dartmouth Medical School, Hanover, NH; [2]University of Texas Medical School, Houston, TX; [3]Dartmouth College, Hanover, NH.

Imaging Anisotropic Elasticity Using Supersonic Radiation Force Excitation. JR Yoon[1], D Renzi[2], JR McLaughlin[2], [1]Clemson University, Clemson, SC; [2]Rensselaer Polytechnic Institute, Troy, NY.

Fast Inversion Techniques for 3D Elasticity Imaging. BB Guzina et al., University of Minnesota, Minneapolis, MN.

Session CAA-2: Clinical and Animal Applications – II

Chair: WE Svensson, UK Co-Chair: RL Maurice, Canada Rio Grande I

Ultrasound Elasticity Imaging for Aging Deep Venous Thrombosis in Humans. JM Rubin[1], H Xie[1], K Kim[1], WF Weitzel[1], SY Emelianov[2], S Aglyammov[2], TW Wakefield[1], M O'Donnell[1]. [1]University of Michigan, Ann Arbor, MI; [2]University of Texas at Austin, Austin, TX.

A Novel Performance Descriptor for Ultrasonic Strain Imaging: A Preliminary Study. J Jiang et al., University of Wisconsin-Madison, Madison, WI.

A Comparison of Real-Time and Post-Processed Elastography with Surgical Findings for Intra-Operative Detection of Brain Tumours. A Chakraborty[1], JC Bamber[2], NL Dorward[1]. [1]Royal Free Hospital, London, England; [2]Institute of Cancer Research and Royal Marsden NHS Trust, Sutton, Surrey, England.

Soft Tissue Biomechanical Behavior During Robotic Acupuncture in Low Back Pain Using Ultrasound Elasticity Imaging. HM Langevin[1], EE Konofagou[2], J Wu[1], JR Fox[1] and JC Iatridis[1]. [1]University of Vermont, Burlington, VT; [2]Columbia University, New York, NY.

Real-time Sonoelastography of 156 Breast Lesions in a Prospective Clinical Setting. S Weber[1], S Wojcinski1, K Ertan[1], K Remberger[2], U Stein[2], R Ohlinger[3], A Thomas[4], W Schmidt[1]. [1,2]University of Saarland, Homburg, Saar, Germany; [3]Ernst-Moritz-Arndt University, Greifswald, Germany; [4]Charité – CCM, University Berlin, Berlin, Germany.

Ultrasound Elastography of Skin Under Surface Extensive Loading. L Coutts et al., Institute of Cancer Research, Sutton, Surrey, England.

Session MPT: Mechanical Properties of Tissues

Chair: SF Levinson, USA Co-Chair: C Sumi, Japan Rio Grande I

Differentiating Mechanical Properties of Corneal Phantoms Using an Ultrasound Method. J Liu et al., The Ohio State University, Columbus, OH.

Acoustoelasticty to Biological Tissues: Measurement of Reflection Coefficient Change in Tendons Under Different Tensile Strains. H Kobayashi et al., University of Wisconsin-Madison, Madison, WI.

Acoustoelasticity in Biological Tissues: Ultrasound Wave Velocity Change in Compressed Tissues. H Kobayashi[1], A Oza[1], MS Cooper[2], R Vanderby[1]. [1]University of Wisconsin-Madison, Madison, WI; [2]Portage Veterinary Clinic, Portage, WI.

Noncontact Ultrasound Indentation System for Assessing Bone-Tendon Junction Tissues: Preliminary Results. MH Lu[1], YP Zheng[1], HB Lu[2], QH Huang[1], L Qin[2]. [1]The Hong Kong Polytechnic University, Hong Kong, China; [2]Chinese University of Hong Kong, Hong Kong, China.

Mechanical Measurement of Elastic Properties of Bovine Liver and Human Prostate Under Compression. M Zhang et al., University of Rochester, Rochester, NY.

Viscoelastic and Ultrasonic Properties of the Uterus. MZ Kiss et al., University of Wisconsin-Madison, Madison, WI.

Evaluation of Anisotropy in the Normal Plantar Soft Tissues: Shear Modulus for Shearing Deformation and Compressive Deformation. JB Weaver[1], TB Miller[2], MM Doyley[1], PR Perrinez[2], H Wang[2], YY Cheung[1], JS Wrobel[3,4], FE Kennedy[2], KD Paulsen[2]. [1]Dartmouth-Hitchcock Medical Center, Lebanon, NH; [2]Dartmouth College, Hanover, NH; [3]VA Medical Center, WRJ, VT; [4]Dartmouth Medical School, Hanover, NH.

Session MIP-3: Methods for Imaging Elastic Tissue Properties – III

Chair: YP Zheng, China Co-Chair: J Liu, USA Rio Grande I

Direct Inversion Method for Shear Wave Speed Reconstruction in Elastography. K Lin, JR McLaughlin, Rensselaer Polytechnic Institute, Troy, NY.

Issues in Real-Time Acoustic Radiation Force Impulse Imaging. GE Trahey et al., Duke University, Durham, NC.

In Vitro Measurement and Imaging of the Strain At the Bovine ACL-Bone Insertion. EE Konofagou et al., Columbia University, New York, NY.

FFT Analysis of the Periodic Structures in Haversian Bone Based On Scanning Acoustic Microscopy (SAM). JL Katz et al., University of Missouri-Kansas City, Kansas City, MO.

Shear Stiffness Identification Using Moving Interference Patterns in Sonoelastography. JR McLaughlin, D Renzi, Rensselaer Polytechnic Institute, Troy, NY.

Assessment of Mechanical Properties of PVA-C with Four Different Elastographic Methods. JL Gennisson[1], J Fromageau[1], C Schmitt[1], RL Maurice[1], R Mongrain[2], G Cloutier[1]. [1]University of Montréal Hospital, Montréal, Québec; [2]McGill University, Montréal, Québec.

Patents

The RCBU is continually working on novel concepts in ultrasound research. A collection of patents and software programs that originated at the Center are summarized on the next few pages. For more information, technology transfer arrangements, or licensing agreements for a specific patent, call the University of Rochester Technology Transfer office at (585) 275-3998, or as indicated below.

Finite Amplitude Distortion-Based Inhomogeneous Pulse Echo Ultrasonic Imaging

This method and system for imaging a sample includes the steps of generating an ultrasonic signal, directing the signal into a sample, and determining which signal is distorted and contains a first order and higher order component signals at first and higher frequencies respectively. The received distorted signal is processed, and an image is formed, and then displayed, from one of the higher order component signals of the received distorted signal. U.S. Patent No. 6,206,833 was issued to Ted Christopher on March 27, 2001. A second patent, U.S. Patent No. 7,004,905, was issued on February 28, 2006. For further information contact Eugene Cochran, Research Corporation Technologies, at (520) 748-4461.

System for Model-Based Compression of Speckle Images

Ultrasound images contain speckle. These high-spatial patterns are ill-suited for compression using conventional techniques, particularly by JPEG, which is designed for photographic images with regions of smooth or negligible intensity variations. Conventional compression techniques fail to provide high quality reproductions with high compression ratios. This combination is desirable for telemedicine and other applications where the available bandwidth or storage constraints create a need for high quality and high compression of ultrasound images. U.S. Patent No. 5,734,754 issued March 31, 1998, describes a system for compression of speckle images.

Blue Noise Mask

Medical images are sometimes printed on devices that have limited output states. For example, laser printers can render black or white but not shades of gray. Halftone methods render gray as patterns of black and white dots. The Blue Noise Mask is a halftone screen method for digital or photographic rendering of images. The Blue Noise Mask produces the fastest possible rendering of medical images with an artifact-free halftone pattern. The fax transmission of medical images can also be made faster and with higher quality by utilizing the Blue Noise Mask and new tonefac algorithm. The Blue Noise Mask invention has received numerous patents, including: U.S. Patent Nos. 5,111,310 (1992), 5,477,305 (1995), 5,543, 941 (1996), 5,708,518 (1998), and 5,726,772 (1998). This patented technology has been accepted by over 15 U.S. companies and organizations including Seiko, Epson, Hewlett-Packard, Tektronix, and Research Corporation Technologies. For further information contact Eugene Cochran, Research Corporation Technologies, at (520) 748-4461.

Thin-Film Phantoms and Phantom Systems

Phantoms for testing and measuring the performance of ultrasonic imaging systems have regions of precisely controlled scattering or echogenicity that contain subresolvable scatterers. The phantoms can reveal the combined influences of all the stages in the imaging chain in terms of modulations, transfer function, and resolution limits as well as other artifacts and defects in the system, such as aliasing and frequency response, which cannot be evaluated with conventional ultrasound phantoms. Halftone masks may be used to produce regions of precisely controlled subresolvable scatterers to be used for gray-scale evaluation of the imaging system by producing speckle images of different echogenicity. The thin-film sheets are thinner than the thickness of the ultrasonic beam and enable propagation of the beam in the plane of the sheets to the patterns, which may be located at different depths. The sheets may be made of piezoelectric material having electrodes across which varying electrical signals are applied to displace the sheets, thereby simulating movement of objects for Doppler measurements. U.S. Patent No. 5,756,875 was granted on May 26, 1998, to co-inventors Daniel B. Phillips and Kevin J. Parker.

An Inexpensive Wide-Bandwidth Hydrophone for Lithotripsy Research

Probing the acoustic field of extracorporeal lithotripters places several demands upon conventional hydrophones. "Needle" hydrophones, while better able than "membrane" hydrophones to withstand the cavitation-related damage inherent in lithotripter measurements, nevertheless lack their superior high-frequency response. Even the most popular membrane hydrophones do not have sufficient sensitivity at high frequencies to resolve the rapid rise times (1-20 ns) of waveforms that may occur at a lithotripter focus. To overcome these limitations, we have developed a membrane-type hydrophone that costs hundreds (not thousands) of dollars and has disposable active elements that can be replaced easily when damaged. These elements, of 6 mm PVDF copolymer film, incorporate an electrode pattern that assures identical sensitivity from one element to the next, obviating the need for recalibration after replacement of the element. On-board conditioning electronics increase the effective bandwidth of the hydrophone to over 125 MHz and provide clipping of the undesirable electromagnetically induced transients of spark-discharge lithotripters. For more information, contact Carr Everbach at (215) 328-8079.

System and Method for 4D Reconstruction and Visualization

From raw image data obtained through magnetic resonance imaging or the like, an object is reconstructed and visualized in four dimensions (both space and time). First, the first image in the sequence is divided into regions through statistical estimation of the mean value and variance of the image data and joining of picture elements (voxels) that are sufficiently similar. Then, the regions are extrapolated to the remainder of the images by using known motion characteristics of components of the image (e.g., spring constants of muscles and tendons) to estimate the rigid and deformational motion of each region from image to image. The object and its regions can be rendered and interacted within a four-dimensional virtual reality environment. US Patent No. 6,169,817 was issued January 2, 2001 to co-inventors Kevin J. Parker, Saara S. M. Totterman, and Jose Tamez-Pena.

The Acoustic Filter

The acoustic filter is a system for reducing post-cardiopulmonary bypass encephalopathy due to microembolization of the brain of a patient with gaseous microbubbles (less than 40 microns in diameter). This invention is recommended for use during open heart surgery with a cardiopulmonary bypass machine bypassing a stream of blood from the patient through an ultrasonic traveling wave that propagates across the stream without reflection and sweeps the blood clean of the microbubbles without inducing blood cell trauma. The blood passes through a chamber between an input port and a filtrate exit port. The microbubbles are carried by the traveling wave to a waste exit port in the chamber downstream of the input port. To prevent establishment of resonance conditions, reflections, and traveling waves, the chamber may be submerged in a liquid bath and a body of acoustically absorbed material positioned at an end of the chamber opposite to the end into which the ultrasonic beam is projected. U.S. Patent No. 5,334,136 was issued to co-inventors Karl Schwarz, Richard Meltzer, and Charles Church.

Multiple Function Infant Monitor

Piezoelectric polymer sheets made of polyvinylidene fluoride (PVDF), placed on the floor of a crib, can output voltage that provides information about the heart and breathing rates of an infant in the crib. Using external detection and conditioning with the PVDF sheet, we have constructed a low-cost PVDF infant health monitor. The monitor can alert parents, with the aid of a remote alarm, to a declining heart and/or respiration rate indicative of the onset of sudden infant death syndrome. US Patent No. 5,479, 932 has been issued for this invention. For more information, contact Carr Everbach at (215) 328-8079.

Apparatus for Bone Surface-Based Registration

A novel technique has been developed that could be used for neurosurgical and other applications. The device is entitled "Apparatus for Bone Surface-Based Registration of Physical Space with Tomographic Images for Guiding a Probe Relative to Anatomical Sites on the Image." The co-inventors of this technique are from Vanderbilt University and the University of Rochester: W. A. Bass, R. L. Galloway, Jr., C. R. Maurer, Jr., and R. J. Maciunas. US Patent No. 6,106,464 was issued on August 22, 2000.

Sonoelasticity Imaging Estimators

Sonoelasticity imaging is a novel method for assessing the stiffness, or elastic constants, of tissues. This combination of externally applied vibration and new Doppler imaging techniques was pioneered at the University of Rochester by Robert M. Lerner and Kevin J. Parker in 1986, following earlier work by Dr. Lerner on stiffness and compressibility of phantom materials and basic Doppler studies by Dr. Jarle Holen and colleagues. Since sonoelasticity imaging reveals patterns of vibrations within tissues, stiff tumors that may not be accessible to palpation can be imaged regardless of subtle changes in echogenicity. US Patent No. 5,086,775, concerning time and frequency domain estimators for sonoelasticity imaging, has been issued to co-inventors Ron Huang, Robert Lerner, and Kevin Parker.

Linear and Nonlinear Acoustic Field Propagation Software

We have developed a computational model for the nonlinear propagation of acoustic beams. The physical effects of diffraction, absorption, dispersion, nonlinearity, and planar reflection and refraction are accounted for in an accurate and efficient manner. Descriptions of the novel algorithms accounting for these physical effects have been presented in a series of publications. The model has been compared successfully with theoretical and experimental results. The model has also been used to make predictions about the in vivo performance of biomedical ultrasonic imaging devices and lithotripters. Finally, the model is currently being extended to consider non-axially symmetric source propagation in phase-aberrate media. Contact the RCBU office at 585-275-9542 for more information.

Butterfly Search Technique

We have developed a novel, robust, and accurate blood velocity estimation technique that is implemented by elementary digital signal processing without any transforms, correlation searches, SAD searches, matched filters, or other intensive operations. In this technique, echoes from repeated firings of a transducer are resampled along a set of predetermined trajectories of constant velocity. These are called butterfly lines because of the intersection and crossing of the set of different trajectories at some reference range. The slope of the trajectory on which the sampled signals satisfy a predetermined criterion appropriate for the type of signal in question provides an estimate of the velocity of the target. The search for this trajectory is called Butterfly Search and is carried out efficiently in a parallel-processing scheme. The estimation can be based on the radio frequency (RF) echo, its envelope, or its quadrature components. The Butterfly Search on quadrature components has shown outstanding noise immunity, even with relatively few successive scan lines, and was found to outperform all the common time domain and Doppler techniques in simulations with strong noise. The Butterfly Search can overcome many disadvantages faced by present-day techniques, such as the stringent trade-off criterion between imaging resolution and velocity resolution implicit in Doppler techniques, and the need for computations. US Patent No. 5,419, 331 has been issued to co-inventors Kaisar Alam and Kevin Parker.

Smart Endotracheal Tube

This invention relates to airway management devices for use in medical emergencies and more particularly to an endotracheal tube apparatus that generates a signal to ensure proper placement of the tube in a patient's trachea. A flexible tube extends from the patient's oral or nasal cavity to a distal end within the trachea. An ultrasound transducer is connected to the tube near its distal end, in contact with the forward inner wall at the midpoint of the patient's trachea. A second ultrasound transducer contacts the forward outer skin surface of the patient's neck. Either the first or the second transducer can transmit an ultrasound signal provided by ultrasound transducer excitation, to which it is electrically connected. The other transducer serves as a receiver, connected to an ultrasound detector external to the patient.

Also, a process for monitoring the position of an endotracheal tube inserted in a patient uses a flexible tube extending from the patient's oral or nasal cavity to a distal end and the first ultrasound transducer connected to the tube near its distal end. The first transducer contacts the forward inner wall of the trachea at its midpoint, and a second ultrasound transducer contacts the forward outer skin surface of the patient's neck at a position at least partially overlying the position of the first transmitter. US Patent No. 5,785,051 was issued July 29, 1998, to co-inventors Jack Mottley and Randy Lipscher for this invention.

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