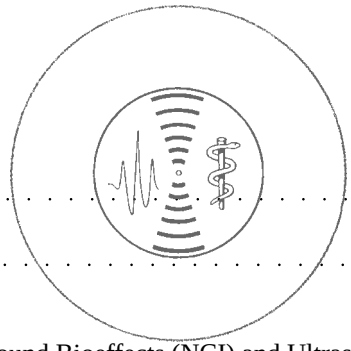
Rochester Center for Biomedical Ultrasound
2001 Annual Report



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From the Directors

From Director Kevin J. Parker:

This summary of advances from the calendar year 2001 covers a wide range of technologies and clinical developments across the multidisciplinary field of medical ultrasound. People unfamiliar with the field sometimes assume that research in medical ultrasound is solely focused on diagnostic imaging. Indeed, this year's report demonstrates much progress toward improved diagnostic imaging (through the fat as an aberrating medium, mapping 3D blood flow, echocardiography for coronary artery disease, and others).

However, there are also many important developments in therapeutic applications (e.g., ultrasound enhancement of fibrinolysis) and in understanding the important health and safety issues of high frequency ultrasound (e.g., response to tissues and contrast agents containing gas).

The Rochester Center for Biomedical Ultrasound (RCBU) has, over the years, been a steady generating source of fundamental concepts and innovations. Many of today's most exciting developments — contrast agents and nonlinear techniques — have a scientific history that includes benchmark experiments at the University of Rochester. This year's RCBU annual report documents continued progress across broad fronts, from the fundamentals of tissue-ultrasound interactions, to therapeutic actions, to advanced diagnostic techniques.

We welcome your comments on any of the enclosed reports.

Save the Date!

Sonoelastography Conference
October 20-22, 2002
Vintage Inns
Niagara-on-the-Lake, Ontario, Canada

Sponsored jointly by Jonathan Ophir, Ph.D., Ultrasonics Laboratory, University of Texas — Houston Health Sciences Center and the Rochester Center for Biomedical Ultrasound

From Associate Director Deborah J. Rubens:

Ultrasound use is growing on all fronts at the University of Rochester Medical Center (URMC). The RCBU comprises several clinical areas.

Reports from the four largest ultrasound divisions are provided below. Dr. Karl Schwarz from Cardiology, Dr. Eva Pressman from Obstetrics and Gynecology, Dr. Susan Voci from Radiology, and Dr. Edward Messing from Urology contributed to these reports.

Cardiology — *Approximately 11,000 patients were seen in the Echocardiography Laboratory in 2001. There has been an increase in the use of ultrasound guided pericardiocentesis by the Echocardiography Laboratory for procedures that were previously done in the Cardiac Catheterization Laboratory. Studies continued with contrast enhanced ultrasound imaging- specifically, stress echocardiography for left ventricle chamber enhancement. Ten to fifteen percent of patients referred to the Echo Laboratory had contrast stress echocardiography because of non-diagnostic or limited diagnostic non-contrasted resting harmonic two-dimensional (2D) images. The contrast enhanced stress test was 95 percent successful in patients who could not be diagnosed properly without contrast. In addition, a database was developed using Pronto software to improve scheduling and billing, as well as to streamline documentation in a wireless environment. At present, there are over 125,000 patient records in the database. This database will be used in Cardiology, Vascular Surgery, and some outside clinics.*

Obstetrics and Gynecology — *The OB/GYN Ultrasound Unit continued expansion of its telemedicine services in 2001. Now covering Strong Memorial Hospital, Highland Hospital, Rochester General Hospital, as well as two additional offsite locations, more than 17,000 obstetric and gynecologic procedures were performed. In addition to diagnostic sonograms, 800 amniocenteses, 115 chorionic villus samplings, 260 sonohysterograms and 10 fetal blood transfusions were performed.*

Radiology — *The Ultrasound Unit experienced many new changes in 2001. Approximately 14,000 ultrasound procedures were conducted in Radiology, doubling the amount performed just ten years ago. Susan Voci assumed the role of Ultrasound Division Head. Nancy Carson was promoted to Chief Sonographer and David Schmanke to Lead Sonographer. Clinical faculty participated in a hands-on refresher course for vascular ultrasound at the RSNA. Ultrasound's PACS has put us a step closer to a*

fully digital electroic environment. A new brachytherapy system, along with new probes and a stepper device, was added; and delivery and start up is expected by the end of January 2002.

Urology — *Prostate brachytherapy remained a major focus of urology and ultrasound. Not only were 40 brachytherapy procedures performed in the operating room (and thus at least 40 preimplant ultrasound performed for sizing purposes), but the PIPER genetic algorithm was approved by the FDA, and a randomized prospective trial comparing intraoperative and preimplant planning and seed placement guidance, completed. In general, intraoperative planning can be performed without prolonging the implant procedure, and achieving at least as good implant quality with the use of few seeds and saving the patient from needing a cumbersome preimplant detected sizing study. This results in considerable saving of money and time for the patient. Additionally, 301 prostatic ultrasounds and biopsies were performed by the urology department in 2001, the overwhelming majority in the office with no sedation or full anesthesia.*

During 2002, further technological developments will be seen, and we will continue to be in the forefront of these advances. We look forward to future collaborations with RCBU members as we work toward offering the best in patient care.

About the Center

The Rochester Center for Biomedical Ultrasound (RCBU) at the University of Rochester was created in 1986 to unite professionals from the medical, engineering, and applied-science communities. The Center started with about 30 members and now has over 110 members, with several visiting scientists from locations around the world.

The Center provides a unique environment where professionals can join together to investigate the use of very high frequency sound waves in medical diagnosis along with other ultrasound-related endeavors.

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

The Center's objectives include:

Research interaction — including 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.

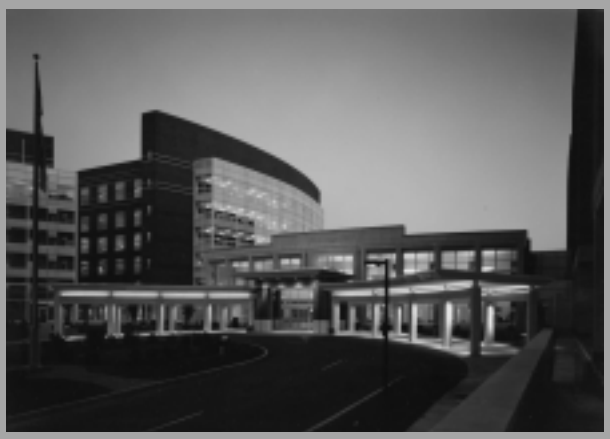
Education — including graduate-level courses in biomedical ultrasound and closely related fields, specialized short courses open to the international community, and post-doctorate collaborations with bioimaging areas within the University.

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.

In the late 1960s, Center Member Raymond Gramiak led a team that became the first to report use of an ultrasound contrast agent. At that time, agitated liquids were injected *via* a catheter while performing an ultrasound 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 sonoelastography, ultrasound and MRI fusion, scattering, bioeffects, therapeutics, advanced imaging systems, and other areas.

The Rush Rhees library, above, centers the academic 'quad' on the River Campus of the University of Rochester.



The main lobby of Strong Memorial Hospital and the Ambulatory Care facility at the University of Rochester Medical Center.

Research

Biophysical Bases of Pulsed Ultrasound Bioeffects (NCI) and Ultrasound-Induced Hyperthermic Teratogenicity (NICHHD)

by Morton W. Miller

Research was conducted on two broad topics related to ultrasound-induced bioeffects, one related to non-thermal and the other to thermal mechanisms of action. Both areas have some relevance to the present on-screen safety indices of diagnostic ultrasound devices (DUS), the Mechanical Index (MI) and the Thermal Index (TI), respectively. These indices were mandated in 1991 by the FDA for all DUS devices that emit the higher allowable acoustic output levels, in recognition of the two major mechanisms by which ultrasound is known to affect cells and tissues.

The project's overall working hypothesis is that non-thermal, ultrasound-induced cellular effects are due primarily to cavitational activity. The second mechanism deals with the potential for ultrasound-induced temperatures to induce birth defects in a rat model system. This latter project's hypothesis is that ultrasound of diagnostically relevant frequencies, intensities and dwell times, is capable of heating the rat embryo by several degrees Celsius; and that this heating, if appropriately timed and of sufficient duration, can induce birth defects.

Non-Thermal Effects. Three projects were completed. The first, undertaken in collaboration with E. C. Everbach (Department of Engineering, Swarthmore College) dealt with a test of the hypothesis that a "second generation" ultrasound contrast agent (Optison™), offering extended echogenicity over that of its "first generation" predecessor (Albunex®) would have the greater potential for sonolysis of human erythrocytes *in vitro*. Whole human blood was anticoagulated and exposed *in vitro* to ultrasound in the presence of one of each or neither of the two ultrasound contrast agents. The ultrasound exposures were for 30 s and involved frequency (1.0, 2.2, and 3.4 MHz) and amplitude (~2.8 to 0.38 MPa) regimens; pulse duration (200 μs) and interpulse interval (20 ms) were held constant. The data supported, with an overall ratio of ~2.5 for relative extent of background-corrected, ultrasound-induced hemolysis of the Optison™/ Albunex® regimens. Passive cavitation detection analyses corroborated the results obtained with hemolysis.

The second dealt with a further test of the hypothesis that cell size is an important biological factor in ultrasound-induced hemolysis, the larger the cell (all other aspects comparable) the greater the sensitivity. The tested hypotheses were: 1) fetal erythrocytes would be more sensitive to sonolysis than adult erythrocytes because of the former's larger size, and 2) erythrocyte sonolytic sensitivity would scale with mean corpuscular volume (MCV). Fetal and adult erythrocytes were exposed for 60 s to 200 μs bursts of 1-MHz ultrasound (peak pressures: ~4.8 MPa positive, ~2.7 MPa negative; duty factor 0.01), either with or without 3.6 volume percent Albunex® (ALX) present. The two hypotheses were supported. Without ALX, mean background-corrected, ultrasound-induced hemolysis was significantly greater than zero for fetal and adult cells, but fetal cell lysis was not significantly greater than adult cell lysis. With ALX, ultrasound-induced hemolytic yields increased ~80-fold and were significantly higher for fetal than for adult cells. There was also a statistically-significant correlation between MCV and ultrasound-induced, background-corrected hemolysis.

The third project, also undertaken in collaboration with Everbach, was a further test of the "cell size hypothesis" (supra) and involved a testing of whole human blood *in vitro* derived from apparently healthy donors or HIV patients on retroviral therapy, the latter group of patients was subdivided into one of two categories: 1) patients with large red blood cells (macrocytic) and 2) patients with normal red blood cells (normocytic). The anticoagulated blood from HIV patients with macrocytic erythrocytes had significantly greater ultrasound-induced hemolysis than blood from apparently healthy normocytic individuals. As a control on whether disease state (i.e., HIV infection per se) might be a contributing factor in ultrasound-induced hemolysis *in vitro*, the blood from HIV patients with apparently normal MCVs was also tested against an additional population of apparently healthy normocytic individuals; there were no statistically-significant differences for ultrasound-induced hemolysis. There were also no statistically-significant differences in viscosities or hematocrits of the whole blood or plasma *in vitro* from HIV-macrocytic or apparently healthy donors, but for all blood types a pooled correlation existed between hematocrit and whole blood viscosity.

Thermal Effects. A two-year research project (Grant RO# HD37669-02, Ultrasound-Induced Hyperhermia Teratogenesis") was completed. The project involved *in vivo* and *in vitro* bioeffect assessments in relation to a novel thermal dose concept. Hyperthermic effects were hypothesized to scale in relation to temperature elevation above the normal physiological temperature for that organism or cells. All data supported the hypothesis, and also indicated that under certain situations an *in vitro* assessment would provide information relevant to a long-term expensive *in vivo* assessment.

Research

A *k*-Space Method for Large-Scale Models of Wave Propagation in Tissue

by T. Douglas Mast, Laurent P. Souriau, D.-L. Donald Liu, Makoto Tabei, Adrian I. Nachman, and Robert C. Waag

Large-scale simulation of ultrasonic pulse propagation in inhomogeneous tissue is important for the study of ultrasound-tissue interaction as well as for development of new imaging methods. Typical scales of interest span hundreds of wavelengths; most current 2D methods, are unable to compute propagation on this scale with the efficiency needed for imaging studies. Furthermore, for most available methods of simulating ultrasonic propagation, large-scale, 3D computations of ultrasonic scattering are infeasible. Some of these difficulties have been overcome by previous pseudospectral and *k*-space methods, which allow substantial portions of the necessary computations to be executed using fast Fourier transforms. This paper presents a simplified derivation of the *k*-space method for a medium of variable sound speed and density; the derivation clearly shows the relationship of this *k*-space method to both past *k*-space methods and pseudospectral methods. In the present method, the spatial differential equations are solved by a simple Fourier transform method, and temporal iteration procedure is shown to be exact for homogeneous media, unconditionally stable for "slow" ($c(x) \leq c_0$) media, and highly accurate for general weakly scattering media. The applicability of the *k*-space method to large-scale soft tissue modeling is shown by simulating 2D propagation of an incident plane wave through several tissue-mimicking cylinders as well as a model chest wall cross section. A 3D implementation of the *k*-space method is also employed for the example problem of propagation through a tissue-mimicking sphere. Numerical results indicate that the *k*-space method is accurate for large-scale soft tissue computations with much greater efficiency than that of an analogous leapfrog pseudospectral method or a 2-4 finite difference time-domain method. However, numerical results also indicate that the *k*-space method is less accurate than the finite-difference method for a high contrast scatterer with bone-like properties, although qualitative results can still be obtained by the *k*-space method with high efficiency. Further information about this research can be found in *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, Vol. 48, No. 2, March 2001.

Time-Shift Estimation and Focusing Through Distributed Aberration Using Multirow Arrays

by James C. Lacefield and Robert C. Waag

The effects of element height on time-shift estimation and transmit focus compensation are demonstrated experimentally. Multirow ultrasonic transducer arrays were emulated by combining adjacent elements of a 3.0-MHz, 0.6-mm pitch, two-dimensional array to define larger virtual elements. Pulse-echo data were acquired through tissue-mimicking distributed aberrators, and time-shift maps estimated from those data were used for transmit focus compensation. Compensated beams formed by arrays with fine row pitches were similar, but focus restoration was significantly less effective for "1.75-D" arrays with a coarse row pitch. For example, when focus compensation was derived from strongly aberrated random scattering data [70-ns nominal rms arrival time fluctuation with 7 mm full-width at half-maximum (FWHM) correlation length], the mean -20 dB lateral beamwidths were 5.2 mm for f/2.0 arrays with 0.6- and 1.8-mm row pitches and 9.5 mm for an f/2.0 array with 5.4 mm pitch. Time-shift maps estimated from random scattering data acquired with 5.4-mm pitch arrays included large discontinuities caused by low correlation of signals received on vertically and diagonally adjacent emulated elements. The results indicate that multirow arrays designed for use with aberration correction should have element dimensions much less than 75 % of the correlation length of the aberration and perhaps as small as 25 to 30 % of the correlation length. Further information about this research can be found in *IEEE Transactionson Ultrasonics, Ferroelectrics, and Frequency Control*, Vol. 48, No. 6, November 2001.

Research

A *k*-Space Method for Coupled First-Order Acoustic Propagation Equations

by Makoto Tabei, T. Douglas Mast, and Robert C. Waag

A *k*-space method for large-scale simulation of ultrasonic pulse propagation has been explored. The present method, which solves the coupled first-order differential equations for wave propagation in inhomogeneous media, is derived in a simple form analogous to previous finite-difference methods with staggered spatial and temporal grids. Like *k*-space methods based on second-order wave equations, the present method is exact for homogeneous media, unconditionally stable for "slow" [$c(\mathbf{r}) < c_0$] media, and highly accurate for general weakly scattering media. In addition, unlike previous *k*-space methods, the form of the method allows straightforward inclusion of relaxation absorption and perfectly matched layer (PML) nonreflecting boundary conditions. Numerical examples illustrate the capabilities of the present *k*-space method. For weakly inhomogeneous media, accurate results are obtained using coarser temporal and spatial steps than possible with comparable finite-difference and pseudospectral methods. The low dispersion of the *k*-space method allows accurate representation of frequency-dependent attenuation and phase velocity associated with relaxation absorption. A technique for reduction of Gibbs phenomenon artifacts, in which compressibility and exponentially scaled density functions are smoothed by half-band filtering, is introduced. When employed together with this smoothing technique, the *k*-space method provides high accuracy for media including discontinuities, high-contrast inhomogeneities, and scattering structures smaller than the spatial grid resolution. Further information about this research can be found in *J. Acoust. Soc. Am.* 111(1), Pt. 1, January 2002.

Ultrasound Enhancement of Fibrinolysis at Frequencies of 27 TO 100 kHz

Valentina Suchkova, Edwin L. Carstensen, and Charles W. Francis

Ultrasound accelerates enzymatic fibrinolysis *in vitro* and in animal models and may be a useful adjunctive therapy for clinical thrombolysis. Successful clinical application will depend on the selection of appropriate ultrasound parameters to optimize fibrinolytic enhancement while limiting adverse effects including heating. Most studies have been done at megakertz frequencies, but tissue penetration is better and heating less at lower frequencies. We have, therefore, now investigated the effects of continuous wave and pulsed ultrasound on fibrinolysis at mid-kilohertz frequencies. Fibrinolysis with t-PA was measured by solubilization of radiolabeled fibrin exposed to a calibrated ultrasound field in a temperature-controlled waterbath. There was significant enhancement of fibrinolysis at frequencies of 100, 40 and 27 kHz, with the greatest effect observed at 27 kHz. The largest effect was observed with continuous wave ultrasound, but significant acceleration was also observed with peak intensities of 1 W/cm^2 duty cycles of 10% and 1%. At a 10% duty cycle there was approximately 60% of the fibrinolytic enhancement observed with continuous wave exposure, indicating a clear advantage of pulsing to optimize fibrinolytic effect while limiting exposure. We conclude that ultrasound in the range of 27-100 kHz is effective in accelerating fibrinolysis at intensities and pulsing conditions that minimize the probability of heating and cavitation in clinical applications.

This work was supported in part by a Grant-in-Aid from the American Heart Association and by Walnut Technologies, Inc.

Research

Diffraction Limited 3D Cell Volume Derivation for Scattering Data Analysis

by N.A.H.K. Rao, Maria Helguera, and
Monica Barbu-McInnis

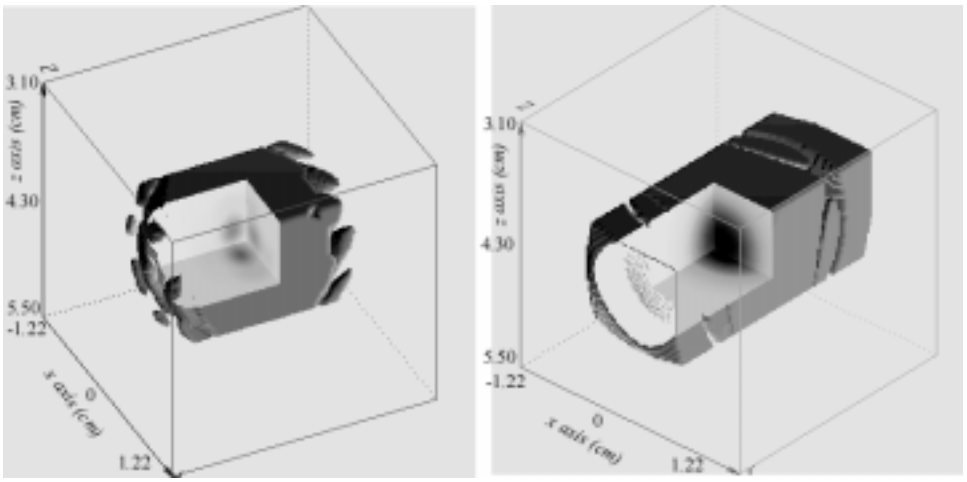
Ultrasound speckle carries information about the interrogated scattering microstructure. The complex signal is represented as a superposition of echo signals due to all scatterers within a resolution cell volume, V_e. A crossbeam geometry with separate transmit and receive transducers is well suited for such studies.

The crossbeam volume, V_e is defined in terms of the overlapping diffraction beam patterns. Given the focused piston transducer's radius and focal distance, a Lommel diffraction formulation, H, suitable for monochromatic excitation is used to calculate V_e as a function of frequency and angle. This formulation amounts to a Fresnel approximation to the diffraction problem and is not limited to the focal zone or the far field. Such diffraction corrections as V_e are needed to remove system effects when characterizing scattering structures using normalized intensity moments.

Theoretically, V_e is numerically integrated within the region of the product of the transmit-receive transfer functions. Experimentally, V_e was calculated from the field pattern of a medium-focused transducer excited by a monochromatic signal detected by a 0.5mm diameter PVDF membrane hydrophone. Additional results were derived from field pattern measurements of the same transducer excited in pulse-echo mode by a signal backscattered from a 0.5mm glass sphere embedded in a gelatin phantom. Theoretical and experimental evaluations of V_e for the crossbeam geometry, and their application to tissue microstructure characterization were analyzed.

The theoretical product of the two transfer functions H_T and H_R, is given in the physical meaning in this work: consider a fictitious scattering point, P, located in the vicinity of the crossbeam geometry of the transmit-receive transducers. If the transmitter were to be driven by a unit amplitude sinusoidal signal with frequency ω_o, the received signal amplitude will result in the magnitude of $H_T(x_o,y_o,z_o,\omega_o)H_R(x_o,y_o,z_o,\omega_o)$, where $(x_o,y_o,z_o,\omega_o)$are the coordinates of point P. On the other hand, scanning a point P, by moving the transmit-receive assembly to various coordinate points (x,y,z) in 3D space will result in a signal amplitude $P(x,y,z,\omega_o)$. Therefore, $P(x,y,z,\omega_o)$ becomes the Point Spread Function (PSF) of the scanning system at frequency ω_o. $P(x,y,z,\omega_o)$ is directly related to the effective cell volume, V_e, as an approximate Fourier transform pair of the Lommel diffraction formulation defined above.

The figure below illustrates the 3D PSF in the "true focus" region as well as in the geometrical focus region. Note that in the "true focus" region the PSF resembles a cube with rounded corners, a pseudo-cube, while in the geometrical focus region the PSF has additional information at two ends of the pseudo-cube. This additional information is due to the contribution of the side lobes of both velocity-potential functions. In the "true focus" region the functions for the transmit-receive transducers are much tighter, therefore, the overlapping region in the cross beam geometry is merely a result of the main lobe. Such differences will affect the effective cell volume. In the "true focus" region the effective cell volume at 2.5MHz was found to be 192.65mm^3, while in the geometrical focus region equals 1120.80mm^3, a significant increase due to the much wider velocity potential main lobe and contribution of the side lobes.



3D PSF in the "true focus" region as well as the geometrical focus region

The Effect of Echo Contrast Agent on Doppler Velocity Measurements.

by Naoyuki Yokoyama, Karl Q. Schwarz, Xucai Chen, Sherry D. Steinmetz, Harald Becher, Christina Schimpky, and Reinhard Schlief

Background. Echo contrast improves the strength of scattered ultrasound signals and is used to enhance spectral Doppler waveforms. However, the effect of this signal enhancement on Doppler velocity measurements made from the spectral display has not been investigated fully. The purpose of this investigation was to determine the effect of echo contrast agent on pulsed wave Doppler velocity measurements.

Methods. A total of 15 intravenous bolus injections of SH U 508A (16 ml at a concentration of 200 mg/ml) were made in 15 patients. The transmitral flow velocity was measured at the E and A wave peaks before the start and at the peak of the contrast effect. The transmitral flow velocity was determined from the Doppler video spectral display and from power spectral analysis of the audio Doppler signal. The Doppler signal intensity was also measured from the audio Doppler signal before the start and at the peak of the contrast effect.

Results. The intensity of the audio power peak frequency increased 17.4 ± 3.5 dB ($p < 0.0001$) following echo contrast. Despite this large increase in audio power peak intensity, the velocity corresponding to the audio power peak frequency did not change significantly (52.8 ± 12.2 vs. 52.1 ± 11.6 cm/sec, difference -0.8 ± 3.3 cm/sec, %Δ = -1.0 ± 6.3 %, p = NS). The spectral peak velocity as determined by the video spectral display or audio spectral analysis showed significant change with echo contrast (%Δ = 24.3 ± 11.7 % and 23.0 ± 10.0 %, respectively, $p < 0.0001$). No significant differences were found between the video and audio spectral peak velocities pre- and post-contrast injection.

Conclusion. Intravenously administered echo contrast agents, such as SH U 508A, are effective tools to increase Doppler intensity. The audio power peak velocity (the modal velocity) corresponds to the true mean velocity and is independent of Doppler signal strength. The visually measured Doppler velocity and audio spectral peak velocity correspond well with one another and represent the typical "peak velocity" measured clinically with spectral Doppler. Both the visually measured Doppler velocity and audio spectral peak velocity are dependent on signal strength and thus are significantly affected by echo contrast. The apparent increase in "visually measured" velocity was due to a shift in the spectral cut-off velocity, not a change in the actual velocity. Measurement of the audio power peak velocity (the modal velocity) would correct the apparent contrast caused measurement error.

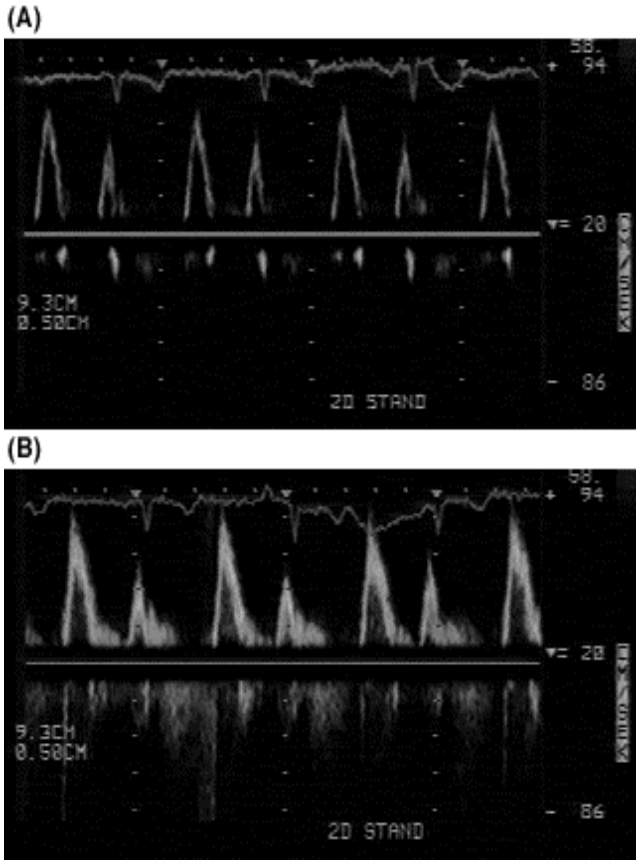


Figure 1. Video spectral display of transmitral flow velocity recorded with pulsed wave Doppler pre- and post-contrast injection of SH U 508A. In the example shown, the pre-contrast E-wave velocity was 69.7 cm/sec (**A**) and was 84.0 cm/sec with contrast (**B**).

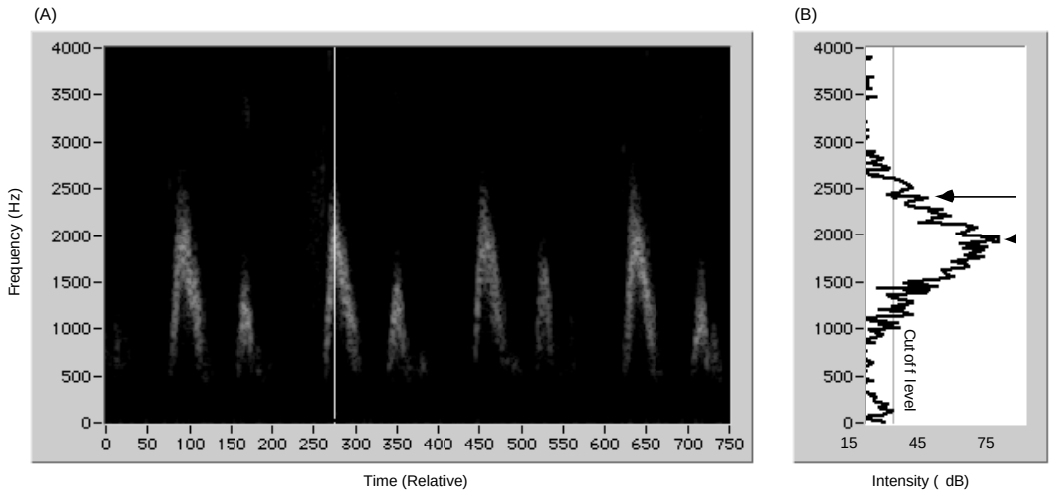


Figure 2. Calculation of audio Doppler measurements. Using a computer-based data acquisition system, interleaved audio Doppler data sets were analyzed for spectral content, displayed on a time-intensity plot similar to a typical Doppler video display (**A**). The E- and A-wave peaks were determined. The audio Doppler power spectrum at one instance was demonstrated in (**B**). The audio power peak frequency (velocity) was determined from the peak intensity of the audio Doppler power spectrum. The audio spectral peak frequency (velocity) was determined from the peak frequency of the audio Doppler power spectrum corresponding to the spectral cut-off intensity. The power peak intensity was determined from the Doppler intensity at the power peak frequency.

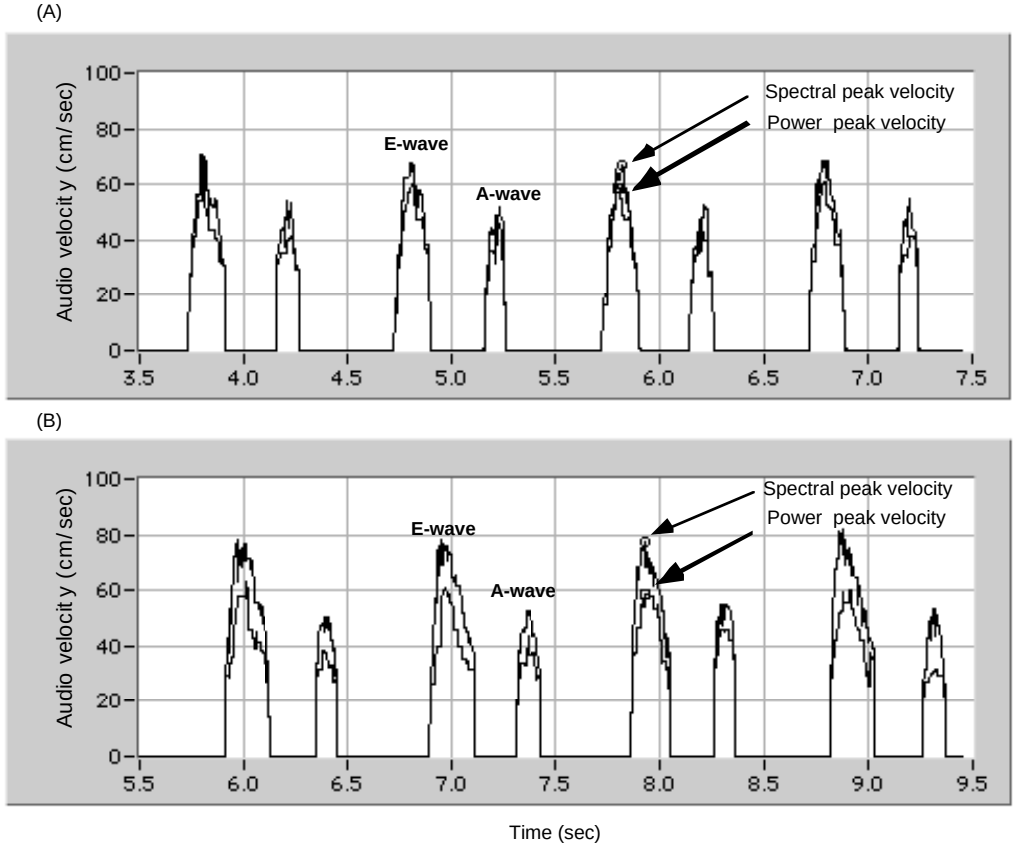


Figure 3. Example of audio Doppler quantitative analysis. Without echo enhancement (**A**), the audio power peak velocity (the modal velocity) and the spectral peak velocity were measured from the audio Doppler spectrum in a manner similar to the video spectral analysis, demonstrating the audio power peak velocity at the E-wave of 58.5 cm/sec (**arrow**) and the audio spectral peak velocity of 66.8 cm/sec in this example (**narrow arrow**). With contrast enhancement (B), repeat measurements were made at the E- and A-wave peaks, demonstrating the audio power peak velocity at the E-wave of 58.5 cm/sec (**arrow**) and the audio spectral peak velocity of 77.6 cm/sec in this example (**narrow arrow**). The audio peak power velocity did not change significantly. However, the audio spectral peak velocity increased significantly.

Stress Echo Outcome Study (SECOS)

by Karl Q. Schwarz, Naoyuki Yokoyama, Xucai Chen, and Sherry D. Steinmetz

Introduction. Exercise and pharmacological stress echocardiography has become one of the most widely utilized tests for the diagnosis of suspected coronary artery disease (CAD). The sensitivity of stress echo for detecting CAD has been reported to be in the 80%–95% range with test specificities in the 78%–94% range (1,2,3,5,6). However, stress echo is quite operator and patient population dependent, so these published figures may not be accurate in all laboratories or for all operators. Variations in ultrasound equipment, sonographers (ultrasound technicians), interpreting physicians and patient populations can all alter the accuracy of stress echocardiography. With this in mind, it is critical for ultrasound laboratories to have a continuous quality assurance program in place to monitor accuracy.

SECOS is a rolling quality assurance program to monitor the performance of stress echocardiography using clinical outcome variables. Patient demographics, clinical history and stress test results are collected prospectively at the time of clinical service. These are stored in the Pronto database system. The clinical outcome variables are collected using mailed or phone questionnaires under the auspices of the Cardiovascular Outcomes Monitoring Program at Strong (COMPS, RSRB #8725). The COMPS program allows for prospective and retrospective patient consenting. The quality of our diagnostic testing service will be measured against these clinical outcome variables.

Background. Stress echo relies on the assessment of regional and global LV systolic function under resting conditions compared to that at peak stress or just immediately post stress testing. New regional or global LV systolic dysfunction determines test positivity and is considered a sign of CAD. Abnormal regional function due to CAD may be mild and short-lived following stress. Thus, the most important weakness of the stress echo technique is the ability to adequately image all LV myocardial segments quickly and accurately. Other limitations include inadequate patient stress, irregular cardiac rhythms, technical failures, valvular heart disease and non-vascular cardiomyopathies. Left ventricular opacification (LVO) with transpulmonary contrast echo can improve echo imaging in many patients. There have been a number of studies addressing the safety, feasibility, and high diagnostic confidence of these agents (7,8,9), but the technique has not been validated using clinical outcome measures (10).

Study Objectives:

- Continuously monitor the clinical outcomes for patients undergoing stress echo.
- Establish the predictive value of the test (especially its negative predictive value) as it relates to hard and soft endpoints.
- Establish the baseline clinical and echocardiographic characteristics that affect the probability of these outcomes (How can we improve our stress testing procedures?).

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Research

Response of Tissues Containing Gas to Low Frequency Sound

by Diane Dalecki, Carol H. Raeman, Sally Z. Child, Sheryl M. Gracewski, and Edwin L. Carstensen

The biological effects of low frequency (100–3000 Hz) underwater sound are most pronounced in and near tissues that contain resonant gas bodies. Supported by the Office of Naval Research, our laboratory is investigating the effects of low frequency sound on biological tissues. 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 safety of sonar.

Two exposure systems were used to generate low frequency underwater sound in the laboratory. Acoustic fields at frequencies of 100–500 Hz were generated in the laboratory using an open, inertial impedance calibration system (G40 calibrator) capable of producing maximum pressure amplitudes of ~193 dB re 1 μPa. The second system used to generate acoustic fields for this project was a specially designed traveling wave tube system. This system is capable of generating maximum acoustic amplitudes on the order of 200 dB re 1 μPa over the 100-2500 Hz frequency range. The system can be driven in three modes of operation. The system can be used to generate a traveling wave field in the exposure chamber. The system can also generate a "pure pressure" field. In this mode of operation, the acoustic pressure is maximized and the particle velocity is minimized. Last, the system can generate a "pure velocity" field where the particle velocity is maximized and the pressure is minimized. The ability to generate these three different types of acoustic fields was instrumental in testing specific hypotheses regarding acoustic mechanisms for effects of low frequency sound on biological tissues.

Murine lung provided an excellent model to characterize the response of gas bodies *in vivo* to low frequency sound. Through several different investigations, we have shown that murine lung responds to low frequency acoustic fields as a resonant structure. Through measurements of acoustic scattering near murine lung, we demonstrated that the response of lung to low frequency sound fields can be described by a linear theory of a bubble in water. A pronounced resonance in the total acoustic field was observed at ~335 Hz for adult mice. Measurements of the displacement amplitudes of lung, using pulse-echo ranging techniques, were consistent with observations of acoustic scattering. Similar measurements of acoustic scattering with young mice and adult rats indicated that the resonance frequency of lung scales approximately inversely with the cube root of body weight.

Exposure to low frequency underwater sound at the resonance frequency of the lung can produce damage to the lung and surrounding tissues. For exposures of mice at frequencies near lung resonance, the area of lung damage increased with increasing pressure amplitude. At amplitudes well above threshold, nearly the entire lung was damaged, air was present in the pleural cavity, and areas of liver located near the lung were damaged. Effects on the liver are an indirect effect of the oscillation of the lung rather than a direct action of the sound on the liver. Thresholds for lung and liver damage are lowest for exposures near the resonance frequency of the lung. For adult mice exposed at the resonance frequency, the threshold for lung damage is ~188 dB re 1 μPa. The thresholds for lung hemorrhage were equivalent for exposures with the G40 calibrator, traveling wave field and "pure pressure" mode of operation. No damage to lung was observed for exposures in the "pure velocity" mode of operation. This indicates that acoustic pressure is the appropriate parameter for defining thresholds for lung damage induced by low frequency sound.

Similar investigations are underway to study the response of gas in the intestine to low frequency sound. Since the volume of a gas body in the murine intestine is less than the lung volume, the resonance frequencies of intestinal gas bodies investigated were within the frequency range of ~700-2500 Hz. Acoustic scattering techniques were used to determine the resonance frequency of intestinal gas bodies. Damage to the gas-filled intestine produced by exposure at the resonance frequency was less pronounced than that observed with the lung.

Research

Ultrasound Improves Tissue Perfusion in Ischemic Tissue Through a Nitric Oxide Dependent Mechanism

by Valentina N. Suchkova, Raymond B. Baggs, S. K. Sahni, and Charles W. Francis

Background. Ultrasound accelerates enzymatic fibrinolysis *in vitro* and in animal models and can cause vasodilation. We have investigated the effect of ultrasound on tissue perfusion in a rabbit model of acute muscle ischemia to characterize the magnitude and temporal course of vasodilation and determine its mechanism.

Methods and Results. After ligation of the femoral artery of rabbits, tissue perfusion in the gracilis muscle as determined using a laser Doppler probe declined by 53% from 13.7 ± 0.3 units to 6.4 ± 0.2 units. The tissue became acidotic, and pH declined from normal to 7.05 ± 0.2. Application of 40 kHz ultrasound at 0.75 W/cm^2 progressively improved perfusion over 60 minutes and reversed acidosis, but these effects were both completely blocked by pre-treatment of the animal with the nitric oxide synthase inhibitor L-NAME. Nitric oxide synthase activity in muscle was measured using an assay based on the conversion of radiolabeled L-arginine to L-citrulline and demonstrated an increase of 3.6-fold following ultrasound exposure. Histologic examination showed that capillaries in ultrasound exposed muscle were significantly dilated compared to unexposed tissue with no other histologic changes.

Conclusions. The application of 40 kHz ultrasound at 0.75 W/cm^2 improves perfusion and reverses acidosis in acutely ischemic muscle by increasing flow through collateral vessels through a nitric oxide dependent mechanism.

This work was supported by a Grant-in-Aid from the American Heart Association.

Butterfly Search Velocity Estimation: Analysis and VLSI Implementation Issues

by Stephen A. McAleavey

Color Doppler ultrasound is widely used for investigation of blood flow *in-vivo*. Conventional techniques suffer from shortcomings in resolution and velocity estimation range. The Butterfly Search has been proposed as an improved method for velocity estimation. Previous work considered only simplified target models, which do not take into account important characteristics of the echo from moving blood, most notably the loss of correlation between echo signals (decorrelation) over time. An extensive analysis of the effect of decorrelation on the Butterfly Search is presented. Approximate closed-form solutions are given for the expected peak value of the Butterfly L(v) function for several decorrelation models. Computer simulations of the echo from a moving fluid target are in agreement with the closed-form solutions. The solutions demonstrate that the peak value of the L(v) curve, which is related to the performance of the Butterfly Search method, that of subdividing the data into smaller ensembles with higher overall correlation, is shown to improve performance. Echo data gathered from *in-vitro* flow is used to confirm the results of the computer simulations. Doppler data gathered with a specially modified commercial scanner were used to produce the first *in-vivo* images of flow using the Butterfly Search method. The results are compared with standard processing methods, and conditions under which the Butterfly Search is superior are presented. Analysis of the sensitivity of the Butterfly Search to signal quantization and Doppler ensemble length is presented. Significantly, it is found that Butterfly Search velocity estimation with single-bit signal quantization yields comparable results to estimation on full-precision signal data when ensemble lengths of eight or greater are used. Issues for VLSI implementation are investigated. Two signal processing architectures are described and compared based on their memory requirements. A criterion for selecting the minimum-memory architecture based on system parameters is presented. Simplifications to the L(v) calculation that reduce hardware complexity are given. Finally, a single-bit data implementation is presented. Estimates of the area and power requirements for implementation in CMOS technologies from 180 to 70 nanometers are presented.

Research

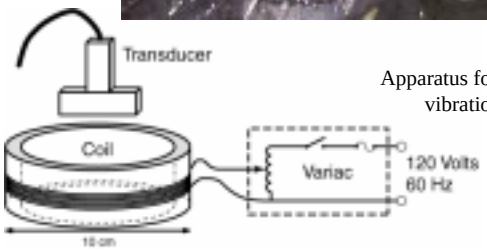
Doppler Technique for the Detection and Localization of Modified Brachytherapy Seeds

by Stephen A. McAleavey

A technique to improve detection of brachytherapy seeds in ultrasound images has been developed. Seeds modified to include a small ferrous or magnetic component are vibrated with an amplitude of a few microns within the tissue by an external magnetic field. The vibration is detected by standard Power Doppler or Pulse Wave Doppler systems, which pinpoints the source of vibration and thus the seed within the image. The results of *in vitro* experiments on agar and liver-tissue phantoms have been investigated to demonstrate the feasiblity of the method.

The *in vitro* experiments using a clinical scanner and simple apparatus demonstrate that the technique is feasible. MRI compatibility has been identified as an important issue for a permanent-implant application. Future work will attempt to quantify the problem and present an acceptable trade-off between MRI compatibility and coil size required for Doppler detection.

Agar phantom containing steel and copper seeds.



Apparatus for *in vitro* seed vibration experiment.

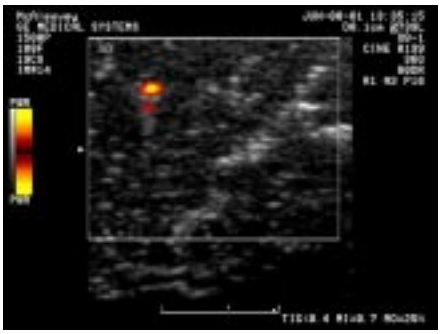
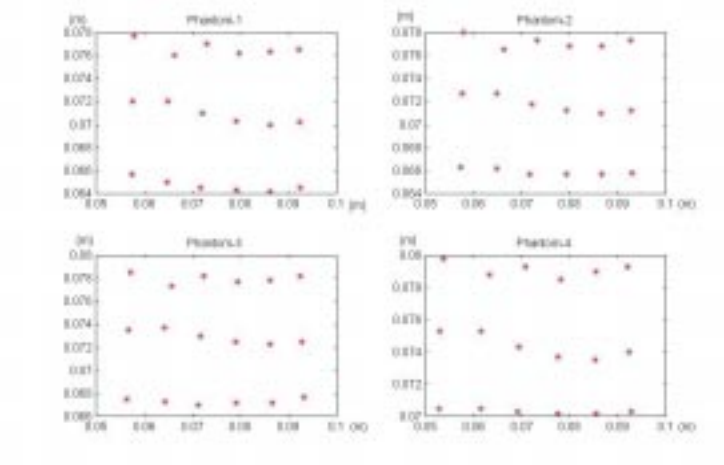


Image of liver phantom, coil on. The steel seed is highlighted by Power Doppler.

The Use of Simultaneous Optical and Acoustic Motion Tracking to Aid Resolution Enhancement in Sonoelastography

by Stephen Levinson, Sheryl Gracewski and Yixin Ren



One of the greatest challenges of quantitative sonoelastography is the reconstruction of elastic moduli at clinically useful spatial resolutions. Although higher-resolution images have been produced in *in vitro* preparations, the constraints imposed by *in situ* experiments have typically limited resolution to about 2 cm. Although higher resolutions can be demonstrated in simulations, displacement error and noise serve to destabilize the reconstruction algorithms, which contain higher-order differential terms. Improvements in spatial resolution can only occur with increased accuracy in ultrasonic soft tissue displacement estimation. Although there are multiple components that comprise displacement noise and estimation error, quantification of these is limited by the lack of a "gold standard" to which ultrasonic measurements can be compared.

To this end, we have developed a system that allows the simultaneous measurement of induced displacements in soft tissue phantoms using ultrasonic and optical means. By using thin (less than 2 cm) phantoms and constraining them between lubricated parallel plates, we can essentially reduce motion within the phantom to a two-dimensional problem. This is not unlike the cylindrical plane strain model used in our muscle studies; however, optical cross-sectional imaging can be employed. Each phantom is marked with a precision optical

cont'd, page 14

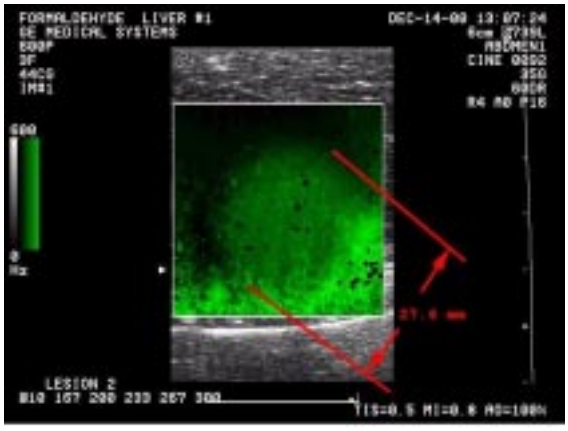
In Vitro Imaging Of Lesion Models Using Sonoelastography

by Larry S. Taylor, James G. Strang, Zhe Wu, Brian C. Porter, Deborah J. Rubens, and Kevin J. Parker

The use of sonoelastography for detecting lesion models in tissues was investigated. In the past, we have demonstrated the detectability of hard inclusions in gelatin and Zerdine phantoms over a wide range of frequencies and sizes. We now report extensions of this work to thermal lesions created by an RF ablation probe and by injection of formaldehyde as a localized bolus.

Thermal lesions were produced in fresh bovine calf livers using a surgical RF ablation device. Lesions were dissected after imaging to document their size and shape. All were found to be palpably hard and ellipsoidal in shape. During imaging, vibration was applied either at the surface of the liver or through the needle used for lesion production. In the best images the lesion was visible as a slightly darker region that matched the true shape of the lesion. Thermal ablation produced a gas bubble which degraded the acoustic path and had a negative effect on the quality of the B-scan and sonoelastography. When using higher frequency vibration (above 300 Hz), the vibration penetration and lesion detectability were poor. Reasons for this could involve the problem of excessive gas production and the high viscoelastic losses in liver (as compared to common phantom materials). We used the major axis of the ellipsoid as the metric for lesion size. Measurements of that axis in the sonoelastography images were within 15% for Lesion 1, 17% for Lesion 2, and 23% for Lesion 3 when compared to the true value. When vibration was applied through the needle, the lesion was brighter than the surrounding normal tissue but with lower accuracy of the lesion boundary.

Localized formalin lesions were produced by hypodermic injection of 37% formaldehyde solution in liver. Six palpably hard lesions were made using this method, two of which were dissected by slicing. The sliced samples revealed elliptically shaped lesions with good localization of hard lesion boundaries. We estimated that the lesion had a shear modulus of 13 times the untreated tissue. One of these lesions was imaged using sonoelastography. No problems were experienced with gas production and image degradation, unlike the case of RF lesion production. The lesion measured about 2% longer in the sonoelastography image than the maximum dimension found when dissected. As with the RF lesions, the vibration penetration and lesion detectability are poor above 300 Hz.



In this image the sonoelastography image of the lesion measures 26.7 mm in its maximum dimension. The maximum axis upon dissection was 27 mm.

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grid that can be imaged using a high-resolution digital camera. Digital optical images are then recorded during deformation of the phantom as simultaneous images are collected using ultrasound. Mesh-based speckle tracking is then used to estimate the induced internal displacements, which can be directly compared to the optical displacements measured at the surface. Initial tests demonstrate good correlation between the optical and acoustic displacement data. We are also investigating the use of imbedded optical markers that are acoustically invisible and can be located within the plane of the ultrasound scan, but that are still optically visible and trackable from the surface. Using these techniques, we hope to minimize sources of error in ultrasonic speckle tracking and to develop improved tracking algorithms that will permit improvements in the spatial resolution of elastic modulus reconstruction.

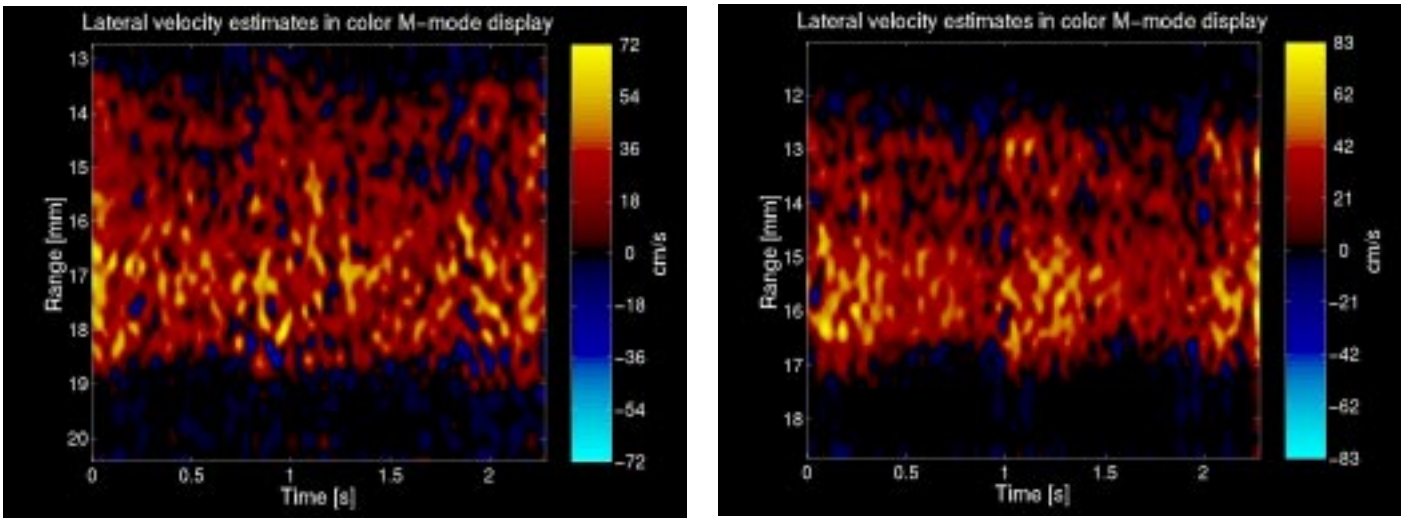
New Approaches to Vector Flow Imaging with Ultrasound

by Martin Anderson

Spatial quadrature is a method for quantifying the non-axial components of the blood velocity or tissue motion vector. The goal of our research is to extend quantitative blood velocity imaging beyond the current display of only the axial component of the flow vector.

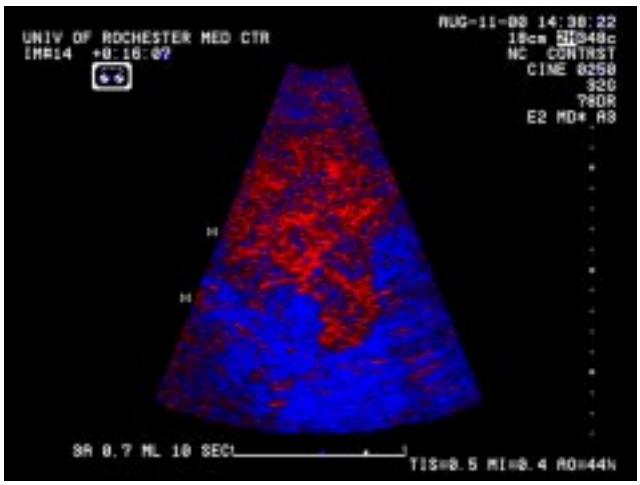
Spatial quadrature creates a lateral modulation in the ultrasound beam, and hence in the echoes of scatterers moving through the beam, that can be used to estimate the lateral component of the flow velocity. The first *in vivo* lateral blood velocity estimates made using a heterodyned spatial quadrature-based estimator were analyzed.

Digital summed I&Q data for sequences of image frames were captured during scanning the common carotid artery of an adult male with a 7.5MHz transducer. The ultrasound scanner used was programmed to generate spatial quadrature beams with 2:1 parallel receive processing. The scanner's B-mode scan line sequence was altered to place an ensemble of 16 lines for flow estimation within the field of view. The frame sequences captured were 2.3 seconds in length, encompassing just over 2 cardiac cycles. These data were processed off-line to produce M-mode style lateral velocity displays and mean velocity profiles. The results show pulsality in the lateral velocity profile coinciding with the pulsation of the vessel walls over the cardiac cycle. The associated velocity estimates show peak systolic velocities in the range of 60-80 cm/s and of mean velocities on the order of 20-30 cm/s. It is notable that these measurements were made at Doppler angles greater than 80 degrees, i.e., significantly above the practical Doppler limit of 60 degrees.

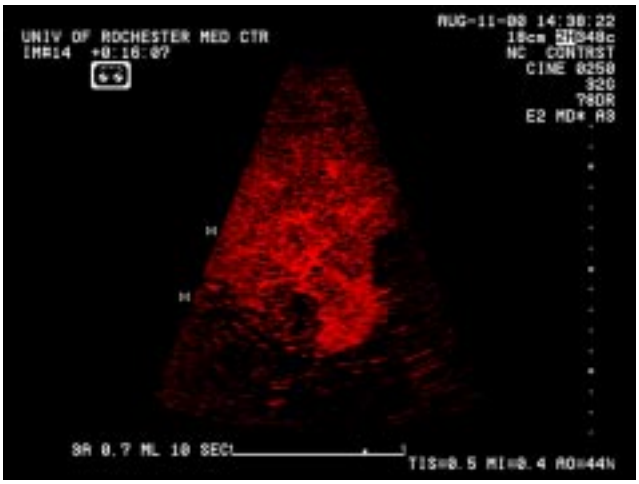


Lateral flow estimation results using heterodyned spatial quadrature in the right common carotid of a 33 year old male. These color images represent estimates of the lateral component of the blood velocity observed down a single beamline over a 2.3 second sequence of acquisitions. The velocity estimates are displayed with red hues corresponding to flow to the left (toward the head) and blue hues, flow to the right. The images show a roughly parabolic profile across the vessel and some pulsatility, consistent with carotid flow. In both cases the Doppler angle was approximately 85 degrees, i.e. at an angle at which conventional flow estimation is generally considered infeasible. These results are the first *in vivo* demonstration of spatial quadrature-based vector flow estimation.

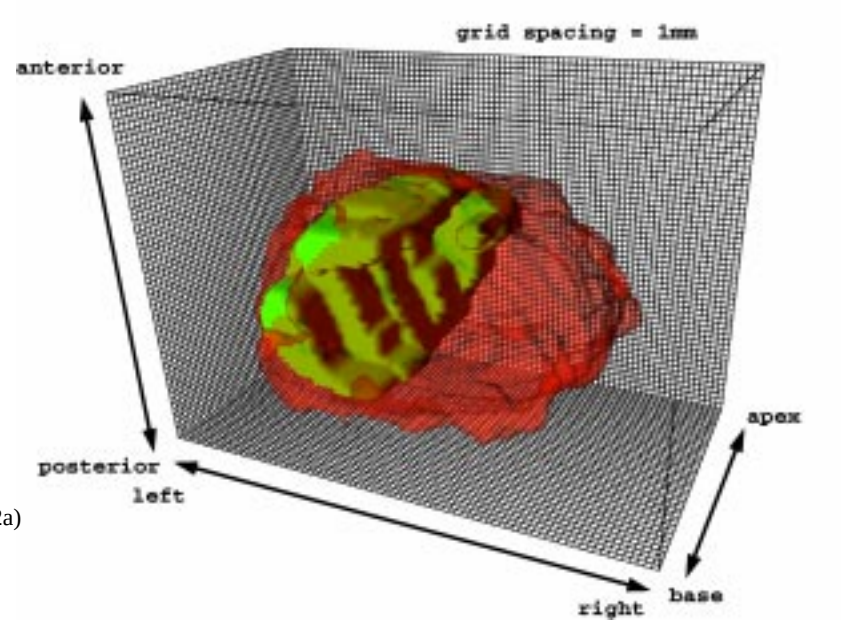
Research



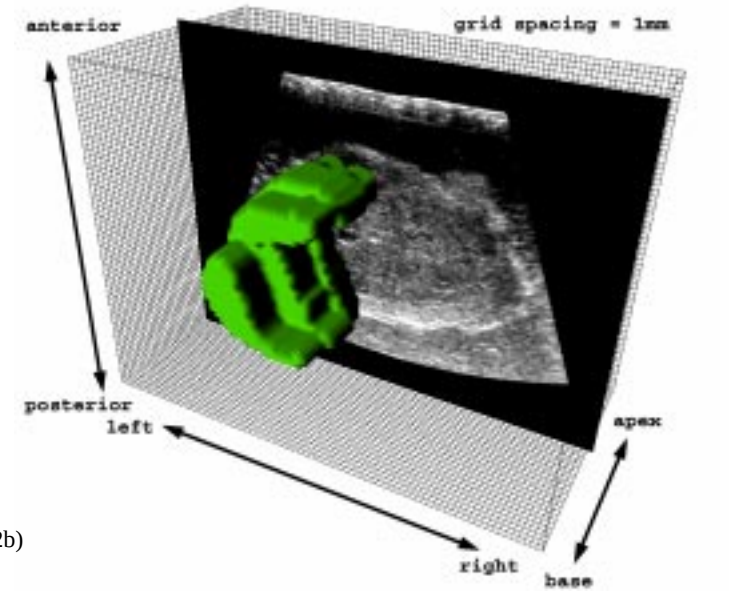
(1a)



(1b)



(2a)



(2b)

Figure Captions

1a. Subtraction image showing positive change in red and negative change in blue after contrast media injection.

1b. Subtraction image showing positive change in red after contrast media injection.

2a. Fusion volume showing B-scan surface (transparent orange) with reconstructed tumor (solid green).

2b. Fusion volume showing B-scan slice (grayscale) with reconstructed tumor (solid green).

Subtraction Imaging of the Liver for Contrast Kinetics

by Brian C. Porter, John G. Strang, Deborah J. Rubens, and Kevin J. Parker

Objective. Demonstrate the feasibility of image enhancement using subtraction and explain techniques and problems associated with generating images; including periodic and non-periodic motion artifacts, absolute difference results (dynamic range), and noise considerations.

Methods. Breathhold, time lapse CINE sequences of the liver (normal n=2, treated n=3) were obtained with non-Doppler imaging using B-mode, phase-inversion and harmonic angio, with and without contrast media (DuPont Definity) on GE Logiq 700. Three volunteers had been treated with RF ablation of malignant hepatoma. Mask frames were selected from each sequence and subtracted from subsequent frames to generate positive and negative difference sequences. The intensity change vs. time profiles were compared to find the optimal selection of the mask frame. Motion compensation was used to reduce alignment errors before subtraction. (See Images 1a and 1b on page 16).

Results. The greatest intensity increase for non-contrast, unregistered ROI is 8%. Large intensity changes (-6% to 16%) occured when the FOV moved out of the image plane. One RF treated lesion shows a large decrease (-47%) in signal intensity due to attenuation when contrast media is used. The anterior normal liver parenchyma shows a positive signal intensity change up to 31% after contrast injection. Intermittent imaging with contrast produced flashes up to 71% brighter than mask frame.

Conclusions. Subtraction can provide enhancement for non-Doppler ultrasound by finding the positive and negative changes in ROI intensities. These changes can be shown as an overlay on grayscale to highlight changing/unchanging regions of interest when using contrast media.

Histology and Ultrasound Fusion of Excised Prostate Tissue Using Surface Registration

by Brian C. Porter, Larry Taylor, Raymond Baggs, A. di Sant'Agnese, G Nadasdy, David Pasternack, Deborah J. Rubens, and Kevin J. Parker

We have developed a method for combining histological data with 3D ultrasound of excised prostate tissue using surface registration. With this technique, 3D prostate cancer lesions can be properly located and visualized within a B-scan volume for tissue characterization comparisons.

Three prostate specimens were scanned with a GE Logiq 700 (Expert series) to obtain 2D B-scan sequences. The prostates were manually segmented from each sequence and reconstructed into 3D volumes. Specimens were fixed, sectioned into slabs, then mounted whole onto slides. Cancerous lesions were outlined by a pathologist. The slides were photographed with an Optronics Spot digital camera, using Image-Pro Plus software on a PC. The gland surface was manually segmented from 2D histology images and reconstructed into a volume. Various reconstruction problems were addressed, such as specimen shrinkage due to the fixing and staining processes.

The fusion algorithm translates and rotates one surface volume in 3D to find the best surface overlap. The resulting geometric transform is used to re-orient the original image volume. (See Images 2a and 2b on page 16). The displacement error was determined by measuring the urethra offsets in final volume cross-sections. The offset distance ranged from 1.25mm to 3.45mm with an average of 2.36mm. Another measure to gauge volume alignment is to calculate the ratio of overlapping voxels to total combined voxels (intersection/union). For a perfect case, this ratio will be 1. The ratios for the three cases ranged in value from 0.774 to 0.845.

This work was supported by NIH Grant No. R01 AG16317-01A1 and GE Medical Systems.

Center Profile

Center Profile: Susan L. Voci, M.D.

Positive guidance of medical residents and sonographers will play a critical role in the future of clinical ultrasound. Susan Voci, M.D., looks forward to providing that guidance in her new position as Head of Ultrasound for the Department of Radiology at the University of Rochester.

In April 2001, Dr. Voci took the helm of ultrasound when RCBU Associate Director Deborah Rubens accepted a post as the Associate Chair of Special Imaging for the Department of Radiology.

Dr. Voci has been with the University of Rochester since 1994. She completed a one-year fellowship in Body Imaging and later became an Assistant Professor for the School of Medicine and Dentistry.

As Head of Ultrasound, Dr. Voci leads a dynamic team of individuals responsible for ultrasound at the University of Rochester Medical Center. She knows what it takes to optimize ultrasound effectiveness. She notes, "there are several factors that our success will be reliant upon, such as the recruitment of skilled sonographers, the continuing education of our staff, and the advances to equipment and technology to keep us in the forefront of medicine."

The Ultrasound Unit in the Department of Radiology performs vascular, body, neurosonography, and ultrasound-guided interventional procedures. This Unit is equipped with real-time, color flow Doppler, and other state-of-the-art equipment. The Unit moved closer to a fully digital electronic environment with its new picture archiving system (PACS). Additionally, a brachytherapy system was initialized recently and upgrades continue to be added to system software.

In addition to the management of a high-volume ultrasound clinic, Dr. Voci is Director of Medical Student Education for the Department of Radiology. She enjoys working with the students and developing new curriculum.

She teaches basic radiology courses to third-year medical students and provides instruction on body CT and body ultrasound for radiology electives. Hands on scanning responsibility for residents and fellows has traditionally been a strong aspect of training. Dr. Voci will continue the efforts to give the medical students a strong theoretical knowledge of medical imaging as well as providing experienced assistance as they practice clinical techniques.

The Ultrasound Unit has worked closely with Rochester Institute of Technology's Sonography program for many years. An internship is offered each semester to students and Dr. Voci will play an integral part in helping the students learn proper scanning procedures.

Dr. Voci is a member of the American College of Radiology, the American Association of Women Radiologists, the American Institute of Ultrasound in Medicine, the American Roentgen Ray Society, the Radiological Society of North America, the Society for the Advancement of Women's Imaging, and the Society of Radiologists in Ultrasound.

She has authored or co-authored several articles including: "Doppler Respiratory Patterns in the Femoral Veins with Pelvic Vein Obstruction" (with RH Gottlieb, Clinical Imaging, 1999) and "Delayed Computed Tomography Characterization of Renal Masses: Preliminary Experience (with R.H. Gottlieb, P.J. Fultz, A. Mehta, R. Parthasarathy, D.J. Rubens, and J.G. Strang, *Abdominal Imaging*, 2000).

She received the M.D. degree from the University of Vermont College of Medicine. Prior to attending medical school, Dr. Voci was a nurse. She had a variety of assignments, including as a traveling nurse in Denver (Neurosurgical ICU, Denver General Hospital) and New Orleans (Surgical ICU). She received the B.S.N. degree from the University of Vermont.

With her wealth of medical knowledge and her desire to share that knowledge with others, Dr. Voci has the skills to lead the Ultrasound Unit into the future. We welcome her as a member of the Rochester Center for Biomedical Ultrasound.

People, Promotions, and Awards

Nancy Carson was named Chief Sonographer in the Ultrasound Unit for the Department of Radiology.

Jeanne Cullinan, **Shannon Campbell**, and **Deborah Rubens** won a *Cum Laude Education Exhibit Award* for a poster entitled "Slow Flow or No Flow? Color/Power Doppler Pitfalls in the Abdomen and Pelvis," at the 2001 Annual Meeting of the Radiological Society of North America.

Diane Dalecki became Chair of the American Institute of Ultrasound in Medicine (AIUM) Bioeffects Committee.

Ronald Gottlieb conducted clinical trials on coated needles for thyroid and liver biopsy and the assessment of the efficacy and improvement in needle visualization (vs. biopsy results). Additionally, he continued analyzing outcome data pertaining to ultrasound for lower extremity sutdies, which confirm the high negative predictive value of Doppler ultrasound for diagnosis of significant thrombosis.

Under the direction of **Amy Lerner**, Biomedical Engineering students Aaron Moskowitz and Michael Richards placed first in the Bioengineering Division's Bachelor's Level Student Paper Competition at the 2001 ASME International Mechanical Engineering Congress and Exposition. Aaron presented the work entitled, "Modeling the Viscoelastic Response of Bovine Liver Tissue" on November 12 at the conference in New York City. This work involved the characterization of material properties of soft tissues in collaboration with Center Members **Larry Taylor, Kevin Parker,** and **Deborah Rubens** who have interests in the use of sonoelastography. Aaron and Mike are now pursuing graduate degrees at Duke University and Boston University, respectively.

Calvin Maurer accepted a new position at Stanford University in the Department of Neurosurgery Image Guidance Laboratory. **Torsten Rohlfing** also made the move to continue collaborations with Dr. Maurer.

Morton Miller received a one-year renewal of the NIH Merit Award.

The National Council on Radiation Protection and Measurements (NCRP) Scientific Committee #66 has completed its third report ("Exposure Criteria for Medical Diagnostic Ultrasound: II. Criteria Based on All Known Mechanisms") and is 'in press'. The report was approximately 10 years in the making. The document is expected to be published later this year. The NCRP committee included several scientists who are members of the RCBU, including: **W. L. Nyborg** (SC 66 committee chairman), **Edwin L. Carstensen**, **Morton W. Miller**, **Horace Thompson**, and **Floyd Dunn**.

Stephen McAleavey completed the Ph.D. degree in Electrical and Computer Engineering. **Kevin J. Parker** served as his advisor for a thesis entitled, "Butterfly Search Velocity Estimation: Analysis and VLSI Implementation Issues." Dr. McAleavey is now working at Duke University with Gregg Trahey.

Under the direction of **Navalgund Rao**, Di Lai, received the Ph.D. degree for work on "Model Based Effective Cell Volume Calculation in Ultrasound Tissue Characterization."

Deborah Rubens was named Associate Chair of Special Imaging for the Department of Radiology and promoted to full Professor.

Susan Voci was named Head of the Ultrasound Unit and Director of Medical Student Education for the Department of Radiology.

Naoyuki Yokoyama joined the Cardiology Unit as a Post-Doctoral Research Fellow. He will be working with **Karl Schwarz** and **Xucai Chen**.

Center Members Serve as Mentors for Undergraduate Summer Students

Students recently completed the first year of the Rochester Research for Undergraduates in Biomechanics and Imaging(RUBI) program. Sponsored by the National Science Foundation, RUBI is designed to provide research experiences for students in a variety of educational activities related to the integration of imaging and biomechanics research. Research areas included: Cell mechanics, Bioeffects of Ultrasound, Orthopaedic Biomechanics, Magnetic Resonance Imaging, Image guided surgery, 3D / 4D Medical Image Processing, Musculoskeletal Kinematics, and Sonoelastography. Faculty members from the Bioengineering Department provided mentorship on a variety of projects. The following faculty and students participated in ultrasound research:

Faculty Mentor	Student	School	Research Area
Diane Dalecki	Candace Pullen	UR	Bioeffects of Ultrasound
Diane Dalecki	Genoa Dickson	UR	Bioeffects of Ultrasound
Martin Anderson	Anant Mathur	UR	Ultrasound Image Processing
Martin Anderson	Torrence Welch	Tulane	Ultrasound Image Processing

Selected Publications

Anderson ME
"Vector Flow Estimator Isomorphism and Wall Filter Requirements"
Proceedings of the SPIE International Symposium on Medical Imaging, 4325, 215-226, 2001.

Anderson ME and **Kerr RF**
"*In Vivo* Lateral Flow Estimation with Spatial Quadrature"
Proceedings of the IEEE International Ultrasonics Symposium, accepted for publication 2001.

Anderson ME, Soo MSC, and Trahey GE
"*In Vivo* Breast Tissue Backscatter Measurements with 7.5 and 10 MHz Transducers"
Ultrasound in Medicine and Biology, 27, 75-81, 2001.

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IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 45, 392-408, 2001.

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"Perspectives on Prostate Cancer Diagnosis and Treatment: A Roundtable"
Urology 53(2):135-140, 2001.

Dalecki D
"Effects of Ultrasound on the Heart"
J. Acoust. Soc. Am. 109:2432; 2001.

Dogra VS, **Gottlieb RH**, **Rubens DJ**, and Liao L
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RadioGraphics: 21: S273-S281, 2001.

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Eichel L, Scheidweiler K, Kost J, Shojaie J, Schwarz E, **Messing E**, and Wood R.
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Fultz PJ, Feins RH, **Strang JG**, **Wandtke JC**, Johnstone DW, Watson TJ, **Gottlieb RH**, **Voci SL**, and **Rubens DJ**
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Radiology, accepted for publication 2001.

Hah Z, McAleavey S, and **Parker KJ**
"Tissue Mimicking Materials for Thin Film Phantom"
Acustica 88, 2002, accepted for publication 2001.

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"Distributed Aberrators for Emulation of Ultrasonic Pulse Distortion by Abdominal Wall"
Acoust. Res. Lett. On-Line. 3(**2**): 47-52, 2002, accepted for publication 2001.

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"Time-Shift Estimation and Focusing Through Distributed Aberration Using Multirow Arrays"
IEEE Trans. Ultra. Ferro, Freq. Contr. 48(**6**): 1606-1624, 2001.

Li Z, Na X, Wang D, Schoen S, **Messing EM**, and Wu G
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"Effect of Decorrelation on Butterfly Search Velocity Estimator"
SPIE Medical Imaging Proceedings, 2001.

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Ultrasound in Medicine and Biology 27: 419-425, 2001.

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"Alveolar Macrophage Cluster Formation: A Clearance Mechanism for Large Particles in Mouse Lungs?"
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Pakin SK, Gaborski R, Barski L, Foos D, and **Parker KJ**
"Segmentation of Bone and Soft Tissue Regions in Digital Radiographic Images of Extremities"
SPIE Medical Imaging 4322, 1296-1301, 2001.

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"3D Fusion of Ultrasound and MRI Using Major Vessels as Fiducial Markers"
IEEE Transactions on Medical Imaging, 20(4), 2001.

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"Viscoelastic Effects in Sonoelastography: Impact on Tumor Detectability"
IEEE Ultrasonics Symposium Proceedings, accepted for publication 2001.

Wang M and **Parker KJ**
"A Metric to Evaluate the Texture Visibility of Halftone Patterns"
Human Vision and Electronic Imaging VI, (Eds: Rogowitz BE and Pappas TN), *Proceedings of SPIE*, Vol. 4299, 163-174, 2001.

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"Automated Non-Invasive Measurement of Cyclophosphamide-Induced Changes in Murine Micturition Frequency and Volume"
J. Urol. 165:653-659, 2001.

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Selected Presentations

Bettcher P, **Gottlieb R**, **Fultz P**, **Voci S**, **Strang J**, **Rubens D**, and Dombroski D
"Physicians Assistants: Can They Perform CT-Guided Biopsies?"
Radiological Society of North America's 87th Scientific Assembly and Annual Meeting
Chicago IL, November 25-30, 2001.

Cullinan JA, Campbell S, **Rubens DJ**
"Slow Flow or No Flow? Color/Power Doppler Pitfalls in the Abdomen and Pelvis"
Radiological Society of North America's 87th Scientific Assembly and Annual Meeting
November 25-30, 2001. *Cum Laude Education Exhibit Award Winner*.

Fultz P, Harrow A, Elvey S, **Strang J**, **Wandtke J**, **Gottlieb R**, and **Voci SL**
"Chest CT and Ultraound for Detection and Ultrasound-guidance for Biopsy of Non-palpable Enlarged Supraclavicular Lymph Nodes"
Radiological Society of North America's 87th Scientific Assembly and Annual Meeting
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Gottlieb RH, **Voci SL**, Syed L, **Erturk EN**, and Elmarzouky R
"CT in Detecting Urinary Tract Calculi: Influence on Patient Imaging and Clinical Outcomes"
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Oka M, **Rubens DJ**, **Strang JG**, Sternbach Y
"Ultrasound Contrast Agent in Evaluation of Abdominal Visceral Vessels"
AIUM 45th Annual Convention
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Lacefield JC and **Waag RC**
"Evaluation of Backpropagation Methods for Transmit Focus Compensation"
2001 IEEE International Ultrasonics Symposium
Atlanta GA, October 7-10, 2001.

Messing EM
"CAG Repeats Within the Androgen Receptor Gene in Black and White Men with Local Stage Prostate Cancer"
American Urological Association Annual Meeting
Anaheim, June 2001.

Messing EM
"Does Grade of Initial Bladder Cancer Predict that of Recurrences?"
American Urological Association, NorthEastern Section,
Boca Raton, December 2001.

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"Outcome of Surgical Treatment for Renal Cell Carcinoma (RCC) with Vena Caval Involvement: Results of EST2886,"
American Urological Association, NorthEastern Section,
Boca Raton, December 2001.

Pakin SK, Gaborski RS, Barski LL, Foos DH, and **Parker KJ**
"Segmentation of Bone and Soft Tissue Regions in Digital Radiographic Images of Extremities"
SPIE Medical Imaging
San Diego CA, February 19-22, 2001.

Parker KJ
"The Center for Electronic Imaging Systems"
2001 Industrial Physics Forum
Rochester NY, October 2001.

Presentations

Porter B and **Strang JG**
"Subtraction Imaging of the Liver for Contrast Kinetics"
AIUM 45th Annual Convention
Orlando FL, March 11-14, 2001.

Porter BC, **Taylor LS**, **Baggs R**, **di Sant'Agnese A**, **Nasasdy G**, **Pasternack D**, **Rubens DJ**, and **Parker KJ**
"Histology and US Fusion of Excised Prostate Tissue Using Surface Registration"
IEEE Ultrasonics Symposium
Atlanta GA, October 7-10, 2001.

Rubens DJ
"Sonoelastography: Clinical Reality vs. Research Tool"
AIUM 45th Annul Convention
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Rubens DJ, **Taylor LS**, **Dogra V**, **Wu Z**, **Porter BC**, and **Parker KJ**
"Vibration Sonoelastography: Defining Parameters for Clinical Imaging"
Radiological Society of North America's 87th Scientific Assembly and Annual Meeting
November 25-20, 2001.

Rubens DJ, **Taylor LS**, **Strang JG**, **Carson NL**, and **Parker KJ**
"2D *In-Vivo* Prostate Sonoelastography: Preliminary Results"
AIUM 45th Annual Convention
Orlando FL, March 11-14, 2001.

Strang JG, Arslan B, **Rubens DJ**, and **Erturk E**
"Pre-Operative Living Renal Donor Evaluation by MRI,"
International Society of Magnetic Resonance Annual Meeting
Glasgow, Scotland, April 23-27, 2001.

Strang JG, **Taylor L**, **Wu Z**, **Porter B**, **Rubens DJ**, and **Parker KJ**
"*In-Vitro* Imaging of RF Ablation Lesions in Bovine Liver using Sonoelastography Imaging"
AIUM 45th Annual Convention
Orlando FL, March 11-14, 2001.

Taylor LS, **Rubens DJ**, **Strang JG**, and **Parker KJ**
"*In-Vivo* Sonoelastography of the Human Prostate: System Improvements and New Results"
26th International Symposium on Ultrasonic Imaging and Tissue Characterization
Arlington VA, May 30-June 1, 2001.

Taylor L, **Rubens DJ**, **Strang JG**, and **Parker KJ**
"Viscoelastic Effects in Sonoelastography: Impact on Tumor Detectability"
IEEE Ultrasonics Symposium
Atlanta GA, October 7-10, 2001.

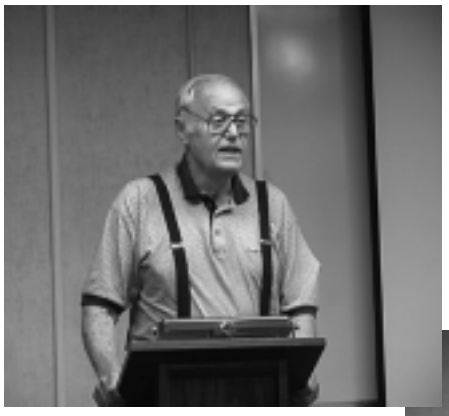
Taylor LS, **Strang JG**, **Wu Z**, **Porter BC**, **Rubens DJ**, and **Parker KJ**
"*In-Vitro* Imaging of Lesion Models Using Sonoelastography"
26th International Symposium on Ultrasonic Imaging and Tissue Characterization
Arlington VA, May 30-June 1, 2001.

Taylor L, **Wu Z**, **Strang JG**, **Rubens DJ**, and **Parker KJ**
"Vibration Artifact Reduction in Sonoelastography"
AIUM 45th Annual Convention
Orlando FL, March 11-14, 2001.

Wu Z, **Taylor LS**, **Rubens DJ**, and **Parker KJ**
"Vibration Sources for 3D Sonoelastography"
AIUM 45th Annual Convention
Orlando FL, March 11-14, 2001.

Presentations

2001 RCBU Meetings



(a)

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RCBU members gathered at the July 2001 meeting to celebrate 15 years of Center achievements and to reflect on the early years of ultrasound research. Pictured above are a few that gave presentations or tributes to Center founders, Drs. Gramiak and Carstensen.

a) Raymond Gramiak, b) Edwin L. Carstensen, c)Robert Lerner, d) Edwin Kinnen, and e) David Blackstock.

"Bee Brains, B-Splines and Computational Democracy: Generating an Average Probabilistic Atlas," presented by Torsten Rohlfing, Ph.D., of the UR Department of Neurosurgery, April 2001.

"3D Ultrasound: Quantitative Aspects," presented by Aaron Fenster, Ph.D., FCCPM, of the Imaging Research Laboratories at the JP Robarts Research Institute (London, Ontario, Canada), May 2001.

"Effects of Low-Frequency, Low Intensity Ultrasound on Fibrinolysis and Vascular Tone — An Update," presented by Charles Francis, M.D., of the UR Department of Vascular Medicine, June 2001.

"RCBU--A Historical Perspective".
presented by RCBU co-founders Edwin Carstensen, Ph.D.,(UR Department of Electrical Engineering) and Raymond Gramiak,M.D., (UR Department of Radiology). David Blackstock, Ph.D, of the University of Texas at Austin (adjunct member of the UR faculty and early pioneer on RCBU research) also contributed, July 2001.

"Elastography: Imaging the Elastic Properties of Tissues," presented by Jonathan Ophir, Ph.D., of the Ultrasonics Laboratory, Department of Radiology, University of Texas Medical School, October 2001.

"New Approaches to Vector Flow Imaging with Ultrasound," presented by Martin Anderson, Ph.D., of the UR Department of Biomedical Engineering, November 2001.

"Butterfly Search Velocity Estimation: Analysis and VLSI Implementation Issues," presented by Stephen McAleavey, M.S., of the UR Department of Electrical and Computer Engineering, as partial requirements for the doctoral theses defense. December 2001.

Selected Courses at the University of Rochester

Acoustic Waves (ECE433). Basic wave phenomena. Reflection, transmission, and excitation of plane waves. Radiation from vibration bodies. Scattering from simple objects and random media.

Image Processing (ECE447). Elements of image processing systems. Image model and imaging geometry. Image sampling and quantization. 2D Fourier transform and discrete Fourier and cosine transform. Image compression models and information theory basics. Error-free and lossy image compression. Image enhancement and filtering. Image degradation models and image restoration techniques. Image segmentation and applications. VLSI design and implementation of image processing algorithms. Image analysis and computer vision basics.

Pattern Recognition (ECE448). Statistical methods in pattern recognition. Bayes decision theory, hypothesis testing, linear classifiers, parameter estimation, feature selection, supervised and unsupervised learning-clustering. Applications from image recognition and image understanding. Hough transform. Texture modeling and image segmentation methods. Neural networks for pattern recognition.

Digital Video Processing (ECE449). Fundamentals of digital-video representation, filtering, and compression. Topics include popular algorithms for 2D and 3D motion estimation, object tracking, frame-rate conversion, deinterlacing, image enhancement, and the emerging international standards for image and video compression. Applications to digital TV, multimedia, videoconferencing, videophone and mobile image communications, advanced image compression techniques such as entropy coding, sub-band coding, and object-based coding.

Bioelectric Phenomena (ECE 450). Passive and active dielectric properties of biological materials including macromolecular solutions, membranes, cells, and tissues. Physical and biological effects of electric fields, including diagnostic and therapeutic uses and biological hazards of electrical fields and electromagnetic radiation. Effects of low frequency magnetic fields.

Biomedical Ultrasound (BME/ECE 451). The physical basis for the use of high-frequency sound in medicine (diagnosis, therapy, and surgery) and biology. Acoustic properties of tissues, sound propagationin tissues, including linear processes as well as finite amplitude sound propagation, and the developmentof shock waves, interactions of ultrasound with gas bodies, leading to the phenomenon of acoustic cavitation, thermal and nonthermal biological effects of ultrasound, ultrasonography, dosimetry, radiation diathermy, thermal surgery, lithotripsy.

Medical Imaging — Theory and Implementation (BME/ECE452). Fundamentals of x-ray, ultrasound, and magnetic resonance imaging and instrumentation. Special attention is given to Fourier transform relations and reconstruction algorithms of x-ray, ultrasonic tomography, and magentic resonance imaging.

Fundamentals of Biological System Analysis (BME/CHE 460). Introduction of the basics of biological system structure and function: molecules, cells, and tissues. Emphasis is on basic cell and mammalian physiology including respiration, cardiovascular, renal systems. Applications involving kinetics and transport phenomena to biological systems.

Reduction and Analysis of Noisy Data (ECE477). Basic ideas of sampling, statistics, inference, and deduction from noisy data. Properties of various distributions, testing of hypotheses, statistical inference, analysis of variance, regression analysis, curve-fitting and non-parametric statistics, using problems and examples drawn from areas of interest. Emphasis on appropriate use of statistical measures in reporting and drawing conclusions from data.

Continuum Mechanics (ME444). The mechanics of continuous media. Introduction to tensors. Study of stress and strain. Constitutive laws for solids and fluids. Balance of mass, momentum, angular momentum, and energy. Entropy production. Applications to boundary value problems.

Wave Propagation in Elastic Media (ME 446). Physical phenomena (reflection, dispersion) and mathematical techniques (Green's function, Fourier analysis, stationary phase) are studied for waves on strings. Concepts are then used to study waves in infinite, semi-infinite, and layered structures and waves in layers and cylinders.

Vascular Biology (BME 484/PHP 440). An examination of the microcirculatory systems and the transport phenomena that occur there. Topics include network architecture (adaptational and pathological changes, models); hemodynamics (roles of blood cell deformabilities, aggregation, cytocrits); mechanisms of vascular control; endothelial function; regulation of leukocyte-endothelial interactions; oxygen transport.

Cellular Mechanics and Transport (BME/ME 485). Equations of membrane equilibrium including bending, biological membrane elasticity in shear and area dilation, membrane curvature, thermal tensions in membranes, analysis of axisymmetric deformations of lamellar structures, white blood cell mechanics. Part II – Mass transport and diffusion in biological tissue, especially the interstitium.

All courses are not offered each semester. Some courses have prerequisites. See official University of Rochester bulletin for exact course information.

Patents and Software

Members of the RCBU continuously work 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 contact the Center office, the University of Rochester Technology Transfer office at (585) 275-3998, or as otherwise indicated.

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.

Finite Amplitude Distortion-Based Inhomogeneous Pulse Echo Ultrasonic Imaging

A method and system for imaging a sample. The method includes the steps of generating an ultrasonic signal, directing the signal into a sample, which signal is distorted and contains 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. For further information contact Eugene Cochran, Research Corporation Technologies, at (520) 748-4461.

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 also can be made faster and with higher quality by utilizing the Blue Noise Mask and new tonefac algorithm. The Blue Noise Mask invention received numerous patents, including: U.S. Patent Nos. 5,708,518; 5,726,772; 5,111,310; 5,477,305; and 5,543, 941. 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 which contain sub-resolvable 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 stimulating 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.

Patents

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 of membrane hydrophones do not have sufficient sensitivity at high frequencies to resolve the rapid risetimes (1-20 ns) of waveforms which may occur at a lithotripter focus. To overcome these limitations, we have developed a membrane-type hydrophone which costs hundreds (not thousands) of dollars and has disposable active elements which can be replaced easily when damaged. These elements, of 6-mm-thick PVDF copolymer film, incorporate an electrode pattern which 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 further 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) by first dividing the first image in the sequence of images 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 and then extrapolating the regions 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. U.S. Patent No. 6,169,817 was issued to co-inventors Kevin J. Parker, Saara S. M. Totterman, and Jose Tamez-Pena.

The Acoustic Filter

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 by passing a stream of blood from the patient through an ultrasonic traveling wave which 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 disposed at an end of the chamber opposite to the end into which the ultrasonic beam is projected. U.S. Patent No. 5,334,136 has been issued to co-inventors Karl Schwarz, Richard Meltzer, and Charles Church.

Multiple Function Infant Monitor

Piezoelectric polymer sheets made of PVDF, placed on the floor of the crib can output voltage that provides information about the heart and breathing rates of an infant in a 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. U.S. Patent No. 5,479, 932 has been issued for this invention. For more information, contact Carr Everbach (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. U.S. Patent No. 6,106,464 was issued on August 22, 2000, for this invention.

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 which may not be accessible to palpation can be imaged regardless of subtle changes in echogenicity. U.S. 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

A computational model for the nonlinear propagation of acoustic beams has been developed. 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. U.S. patent allowed.

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 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 the present-day techniques, such as the stringent tradeoff criterion between imaging resolution and velocity resolution implicit in Doppler techniques, and the need for computations. U.S. 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. A first ultrasound transducer connected to the tube near its distal end is in intimate contact with the forward inner wall of the patient's trachea at substantially its midpoint. A second ultrasound transducer is disposed in intimate contact with the forward outer skin surface of the patient's neck. Either the first or the second transducer can be a transmitter of an ultrasound signal provided by ultrasound transducer excitation, to which it is electrically connected. The other transducer serves as a receiver, which is connected to an ultrasound detector situated externally to the patient.

Also, a process for monitoring the position of an endotracheal tube inserted in a patient utilizes an apparatus comprised of 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 is placed into contact with the forward inner wall of the trachea at substantially its midpoint, and a second ultrasound transducer is placed in intimate contact with the forward outer skin surface of the patient's neck at a position at least partially overlying the position of the first transmitter.

U. S. Patent No. 5,785,051 was issued July 29, 1998, to co-inventors Jack Mottley and Randy Lipscher for this invention.