UITC 2024 Abstracts

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1 Ultrasound Imaging

1.1 Better attenuation imaging with full angular spatial compounding

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Abstract: Attenuation is used for tissue characterization in breast imaging. Ultrasound tomography is an imaging technique for the breast that can create maps of the sound speed and attenuation simultaneously. By use of full-wave inversion (FWI) methods, images of sound speed are of high quality, but the attenuation images are often of inferior quality. The Spectral Log Difference (SLD) is a technique based on the ultrasonic backscattered signal that can provide estimates of the attenuation coefficient slope (ACS). Due to the nature of tomography, the variance of ACS maps can be reduced by using full angular spatial compounding (FASC). Tissue mimicking phantoms were constructed, one with a high attenuation inclusion, i.e. 1.05 dB/MHz/cm for the inclusion and 0.76 dB/MHz/cm for the background, and one with a lower attenuation inclusion, i.e., 0.76 dB/MHz/cm for the inclusion and 1.05 dB/MHz/cm for the background. The phantoms were scanned in a commercial breast tomography scanner. The results demonstrated that the SLD technique with FASC could generate an accurate attenuation map with low bias and variance. Compared to the attenuation map reconstructed with the FWI method, the attenuation map generated with the backscattered signal had lower bias and variance. For the first phantom, the SLD produced values of 0.98 +/- 0.03 dB/MHz/cm (0.74 +/- 0.02 dB/MHz/cm) for the inclusion (background), while FWI produced values of 1.02 +/- 0.07 dB/MHz/cm (1.01 +/- 0.08 dB/MHz/cm) for the inclusion (background). For the second phantom, the SLD produced values of 0.70 +/- 0.03 dB/MHz/cm (0.91 +/- 0.05 dB/MHz/cm) for the inclusion (background) compared to the 0.32 +/- 0.05 dB/MHz/cm (0.32 +/- 0.04 dB/MHz/cm) for the inclusion (background) when using FWI. As a result, the SLD with FASC could be implemented on the ultrasound tomography imaging system to provide improved attenuation images.

1.2 3D Ultrafast ultrasound beamformer for plane wave imaging

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Abstract: 3D Ultrafast ultrasound beamformer for plane wave imaging with field programmable gate array. In this work, we propose a novel method of implementing a 3D ultrafast ultrasound beamformer for plane wave imaging (PWI) on a field programmable gate array (FPGA). First, a 2D interleaved channel mapping was proposed to distribute the analog channel connection and 3D beamforming computation load to multiple system on modules (SoM), which is composed of an FPGA and ARM processors. Second, a remote FPGA memory direct access (RFDMA) based ultrasound over Ethernet (UoE) protocol was proposed to allow the partial beamformed results from each SoM to be transferred to the central FPGA accelerator via Ethernet directly. Third, an IQ based volumetric beamforming algorithm was proposed to improve both the speed and the quality of the beamforming. In this algorithm, the input RF signal was down converted to baseband IQ signal with a decimation factor of 4 to reduce the input data size. A linear interpolation was performed on two adjacent IQ samples which were fetched according to the time delay. Then the linear interpolated IQ samples from all the channels were summed after delay compensation followed by a phase shift to complete the IQ based volumetric beamforming. The proposed design achieved a volume rate over 2000 Hz with an input data size of 32x32x1024 for each acquisition. The FPGA beamformers results were compared with Verasonics CPU beamformers result to verify that the image quality was not compromised for speed.
1.3 Limited-Aperture Diverging-wave Transmit Schemes to Maximize Field-of-View and Image Quality

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Abstract: Ultrafast pulse-echo ultrasound imaging can use unfocused diverging-wave transmit (DWT) wavefronts with multi angular coherent compounding to achieve high frame rates and image quality comparable to conventional focused-transmit ultrasound. DWT schemes can expand the Field-of-View (FoV) beyond the extent of a limited aperture depending on the placement of their virtual sources. In this work we compare algorithms for determining optimal virtual source placement, including one proposed that takes the transducer array elements angular response into account. Using Field II to simulate a 64-element, 2.75-MHz linear phased array (Verasonics P4-2v), the peak transmit pressure amplitude distribution was recorded for DWTs angled = [-20, 20] at 10 increments and a virtual source placed rvs = 10p behind the aperture, where p is the transducer pitch. To assess the pulse-echo image quality, the point-spread function (PSF) geometry and amplitude maximum (and their variance) was calculated for point targets placed regularly (every 5 mm, laterally and axially) over x = [0, 40] mm and z = [5, 50] mm for each DWT angle and the coherently compounded sum. For the compounded DWT sequence, the lateral resolution variance was L2 = 0.68 mm2, and the proposed algorithm determined the theoretical extent of the uniform FoV to be 32 beyond either side of the aperture width.

1.4 Exploiting Single and Multiple Scattering to Accurately Localize Pulmonary Nodules in Inflated Lung Tissue and Relationship to Staple Lines for Safe and Faster Pulmonary Nodule Resection

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Abstract: Introduction: Screening for lung cancer is finding millions of pulmonary nodules (PNs), and thousands to resect each year, often using minimally invasive surgery (MIS). PNs are often hard to feel, making resection challenging. Conventional ultrasound (US) is unsuitable for imaging lung parenchyma, because of US multiple scattering (USMS) from air-liquid interfaces due to millions of air-filled alveoli. PNs do not generate USMS. Methods: By separately mapping multiple and single scattering (MS/SS) we developed methods to detect and localize artificial PNs in inflated large animal lungs. We injected Vaseline (n=12) and dental impression (DI) materials (n=59) into 15 ex-vivo lungs (13 pigs, 2 dogs). A Philips ATL L7-4 128-element linear transducer array (central frequency 5.2 MHz) operated by a Verasonics Vantage 128 scanner was placed onto the lung surface. After processing, this generated a rendered image of the PN. After each experiment, lung blocks had CT scans. Two dental implant PNs instilled into airways were excluded. Results: 56 of 57 DI lung parenchyma PNs were detected by US. Pleural surface distance by US and CT was highly corelated (r=0.76, p=8.9e-12). Switching to B-mode prevented PN visualization but demonstrated the leading edge of a 6-cm surgical endo-stapler. Superimposing the rendered PN image and the B-mode image allowed measurement of the staple edge to the PN by US. Resection of 8 PNs placed in the CT scanner showed excellent correlation of lateral distance of PN to the staple line by US and CT (r=0.97, p=0.00021). During MIS, lungs are partly inflated, so we began to study lungs after PN insertion at different tidal volumes (600, 450 and 300 ml). In the first study, all 4 PNs were detected at all 3 volumes. Conclusions: Our data justifies making a steerable intra-pleural US probe with real-time data analysis to show surgeons PN and staple location.
1.5 3D Diffractive acoustic tomography

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Abstract: 3D Ultrasound (US) and photoacoustic (PA) imaging systems have many options for the method of ultrasonic detection. Linear-array transducers provide the benefits of low cost, large field-of-view, and fast scanning, making them a very popular choice. However, a traditional scanning linear-array system achieves low resolution and sensitivity along the scanning dimension (elevational axis) due to the fixed acoustic lens in both US and PA imaging. As a solution, we present diffractive acoustic tomography (DAT), a technique that employs an elevationally-focused transducer array with a secondary aperture (a single-slit) to alter the far-field acoustic beam pattern, ultimately allowing for US and PA volumes with isotropic resolution and sensitivity. Furthermore, we present a novel fast focal line (FFL) reconstruction technique, reducing the complete 3D reconstruction time by nearly two orders of magnitude in comparison with previously described methods. The DAT system presented in this study is designed with a dynamic slit allowing for accurate calibration and adjustment of the slit width and position, and further allowing for a thorough characterization of the relationship between slit width and image quality. The dynamic slit also allows for the transition between 3D-DAT and 2D imaging in traditional focused B-mode US and PA. We have applied our DAT system to three preliminary life science and biomedical studies. First, volumetric estimations of biliverdin binding serpin and hemoglobin concentrations in six species of South American glass frogs. Second, dynamic tracking of gold nano stars in a tumor mouse model. Third, longitudinal imaging of placenta and embryo blood oxygenation throughout pregnancy.

2 Elasticity I

2.1 Shear wave elasticity imaging via propagation invariant acoustic beams

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Abstract: Shear wave elasticity imaging is a crucial technique in medical diagnostics, particularly in noninvasive assessment of tissue stiffness. This imaging modality, often employed in Acoustic Radiation Force Impulse (ARFI) imaging, helps in identifying various tissue characteristics, which is essential in diagnosing diseases such as liver fibrosis. However, traditional focused beams used in ARFI imaging are limited by their narrow axial range, confining the effective imaging area. This constraint poses challenges in obtaining comprehensive and accurate tissue elasticity measurements. To address this limitation, our study proposes a method using propagation-invariant acoustic beams. These beams are designed to maintain consistent pressure over an extended range, unlike traditional beams that have a fixed focus point. By leveraging propagation-invariant beams, our method significantly expands the imaging area. This expanded range not only improves the detail but also enhances the accuracy of the images produced, facilitating better diagnostic capabilities. Additionally, the beam design not only achieves an extended depth of field but also supports versatile axial profile customization, allowing it to adapt to various
imaging scenarios. Our approach is grounded in both theoretical and experimental validation. We conducted extensive simulations to refine the beam properties and ensure their effective application in imaging. Following this, we carried out experiments to validate the advantages of using propagation-invariant beams. These experiments demonstrated a marked improvement in elasticity imaging quality compared to conventional methods, highlighting the potential of our approach in clinical settings.

2.2 Deep tissue transient elastography with focused shear waves

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Abstract: Liver tissue stiffness measurement with transient elastography (TE) is a popular method for fibrosis screening in the clinic, especially in the context of fatty liver disease where extent of fibrosis is the most predictive measure of patient outcomes. Current clinical devices utilize low-frequency vibration of a small, flat piston at the skin surface to generate shear wave motion in the liver, which is measured using ultrasound imaging. The shear wave resulting from vibration of such a piston spreads in all directions from the source, diverging from the liver, resulting in low shear wave signal in the liver stiffness measurement region, and contributing to high failure rates and unreliability of TE. Our group has developed the concept and technology of focused shear wave TE, which employs vibration of a concave shaped piston at the surface to generate shear waves that converge towards the liver stiffness measurement region, thereby increasing the signal amplitude available for tissue stiffness estimation. This presentation covers our initial investigations into the generation and propagation of focused shear wave beams along with recent translational efforts in the context of liver fibrosis screening. Focused shear wave generation and propagation is investigated in silico using a novel analytical model and on the benchtop in tissue-mimicking gelatin phantoms, where it is demonstrated that shear wave focusing is effective in the entire stiffness range seen in fatty liver disease. The effect of shear wave aberration during propagation between ribs is investigated in simulation and on the benchtop using anatomically realistic 3D printed human ribs, where it is found that the directionality of the narrow shear wave beam enables significant energy penetration through the intercostal space. Finally, we discuss the design and benchtop testing of a device for eventual application of focused shear wave TE in human fatty liver patients.

2.3 3D Rotational Shear Wave Elasticity Imaging (3D-RSWEI) in Multimodality Anisotropic Phantoms

Authors: Shruthi Srinivasan, Daniel Yoon, Margrethe Ruding, Philip V. Bayly, Ned C. Rouze, Mark L. Palmeri, David P. Bradway, Wren E. Wightman, Derek Y. Chan, Kaden D. Bock, Kathryn R. Nightingale
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Abstract: Background: Previous work has shown the feasibility of 3D-RSWEI for measuring the mechanical properties of skeletal muscle [1]. As development of elastography techniques across imaging modalities such as SWEI and magnetic resonance elastography (MRE) continues to advance, there is a growing need for anisotropic phantoms with tunable mechanical properties to validate these algorithms and methods.

Methods: We use 3D-RSWEI to observe shear wave propagation in 3D-printed, scaled lattice-structure phantoms. These phantoms have been previously shown to exhibit anisotropic elastic behavior through mechanical testing [2], [3], [4]. To acquire SWE planar data, a linear array transducer delivers a central acoustic radiation force
excitation and uses coherent plane wave compounding to track shear wave motion for \(\sim20\) ms. Using a Universal Robots co-bot arm (CIMTEC Automation, NC), our 3D-RSWEI system performs this procedure in 5-degree rotational increments, while also monitoring the real-time orientation of the transducer during data acquisition. Given the small size and lattice structure of these phantoms, it was necessary to optimize our imaging configuration, rotational acquisition speed, applied excitation configuration, and post-excitation ultrasonic tracking.

**Results:** We discuss the optimization of our imaging setup and post-processing of these acquisition data. We observed that signal-to-noise ratio of the reconstructed shear wave benefited from a higher imaging frequency (8MHz) and larger axial motion-tracking kernels (> 2mm). We have measured shear wave speeds of 6.3 0.7 m/s and 4.1 0.6 m/s parallel and perpendicular to an axis of rotational symmetry respectively, supporting the anisotropic nature of the phantoms.

We have estimated shear moduli of the lattice phantoms and compared our results to existing mechanical testing measurements. We have observed 114% and 129% difference in longitudinal and transverse shear moduli respectively between these characterization methods. This comparison offers a preliminary assessment of 3D-RSWEI to characterize the material properties of a multimodal lattice-structured phantom.


### 2.4 Viscoelasticity Estimation Using Physics-Informed Neural Network for Breast Shear Wave Elastography

**Authors:** Elisa Konofagou  
**Affiliation:** Columbia University  
**Abstract:** Background: Breast Shear Wave Elastography (SWE) is a non-invasive technique using acoustic radiation force to characterize tissue stiffness for breast cancer detection and thermal ablation monitoring. While conventional SWE faces challenges in heterogeneous soft materials due to wave diffraction, this study introduces a Physics-Informed Neural Network (PINN) based Inverse model[1]. Unlike computationally expensive Finite Element (FE) models, PINN solves the governing partial differential equation (PDE) without discretization, offering a promising alternative for estimating viscoelastic shear moduli.

**Method:** The proposed model’s PDE incorporates a spatial variation of elastic modulus, encoded in the PINN structure as a loss function. Since the soft tissues are nearly incompressible, we consider only the shear wave term in the Helmholtz PDE as the deformation due to the pressure wave is close to constant[2]. The Kelvin-Voigt model is employed to simulate viscoelasticity. The data loss term focuses on the misfit of particle velocity in the axial (Z) direction, aligning with conventional SWE experiments.

Utilizing wave motions, a PINN model infers viscoelastic moduli in a shear wave-illuminated region. The model comprises two deep neural networks (NN1 and NN2) with three hyper-parameters: 1, 2 (weight parameters), and (viscosity in Pa.s). NN1 predicts particle displacement in the Z direction based on spatial coordinates (X, Z) and time (T). NN2 predicts shear modulus (unit kPa) at each spatial coordinate (X, Z). NN1 has 6 hidden layers with 30 neurons each, while NN2 has 2 hidden layers with 15 neurons each, both using tanh as the activation function.

The PINN-based model has an advantage over conventional SWE methods in that it can seamlessly integrate multi-source data into the inverse model. Therefore, we analyze data from Pulse-SWE and Harmonic-SWE[3]
experiments and combine tissue deformations from excitations at different points. For validation, we perform FE simulations, tissue-mimicking phantom, and ex vivo experiments.

Results: In a homogenous medium, the proposed framework achieves a shear modulus of 13.16 kPa and viscosity of 0.20 Pa.s, closely matching FE simulation inputs of 14.3 kPa and 0.23 Pa.s. In a heterogeneous scenario, the shear modulus converges to 108.02 kPa at the stiffer inclusion, 12.88 kPa at the background, and shear viscosity converges to 0.25 Pa.s for both inclusion and background. The corresponding FE simulation inputs are 118.8 kPa for inclusion, 14.3 kPa for the background, and 0.23 Pa.s for both inclusion and background. In terms of efficiency, the PINN analysis completes in approximately 12 minutes for 3000 epochs.


2.5 High resolution estimation of shear wave speed and trajectory in arbitrarily sampled wavefields.

Authors: Wren E. Wightman, Derek Y. Chan, Shruthi Srinivasan, Ned C. Rouze, Kathryn R. Nightingale
Affiliation: Duke University
Abstract: Background: Myopathies and muscular dystrophies (MMD) are classes of neuro-muscular disorders that lack quantitative and non-invasive biomarkers for longitudinal treatment monitoring(1). Our group has developed and is investigating 3D rotational shearwave elasticity imaging (3D-RSWEI)(2) as a means to assess neuromuscular health. Despite the initial success of 3D-RSWEI-based biomarkers in healthy volunteers(2), the muscles of MMD patients often violate idealized assumptions used in shearwave speed estimation: specifically that the trajectory of the propagating wave is known and that the estimation region is homogeneous(2). Current algorithms that compensate for errors caused by these assumptions are only applicable to SWEI datasets sampled on a regular grid and are thus incompatible with our rotationally sampled datasets(2,3). In this work, we propose and validate the vectorized shear wave speed (vSWS) algorithm, a high-resolution least-squares approach to simultaneously estimate local shear wave speed and trajectory from estimated difference in shear wave arrival time (dSWAT) in arbitrarily spatially sampled 3D-SWEI datasets. Methods: Our algorithm inverts a forward model predicting dSWAT from the spatial location of datapoints and an assumed wave trajectory and velocity. We assess the effect of the algorithm parameters on the resolution, precision, and accuracy of vSWS reconstruction in simulated elasticity phantoms modelling isotropic, transversely isotropic, and heterogeneous spherical lesion elasticity phantoms. Results: In initial validation simulations of planar shear wave excitations, we found that the high resolution dSWAT algorithm estimated values of 0.940.074, 2.000.003, and 4.000.01 ms for expected values of 1, 2, and 4 ms respectively. We also demonstrated a spatial resolution of 0.91, 1.83, and 1.76 mm at an interface between two media. Future work will involve application in phantom and in vivo data.

2.6 Towards 3D Imaging with Shear Wave Elastography,

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Abstract: In shear wave elastography (SWE), acoustic radiation force (ARF) causes waves to propagate and scatter in a three-dimensional (3D) sense. The particle velocities are however measured only in a two-dimensional (2D) plane with no information in the elevational direction. Due to such measurements, existing SWE algorithms focus on providing 2D images within the measurement plane. In this work, we attempt to reconstruct an image of the entire 3D volume from planar SWE measurements. Further, to enhance the image, we utilize ARF pushes and associated measurements on multiple planes obtained by rocking the transducer at different elevational angles.

We utilize a Full Waveform Inversion (FWI) framework to convert SWE measurements on multiple planes to a single 3D image of elasticity using gradient optimization to adjust the elasticity map until the mismatch between simulated and measured particle velocities is minimized. Several ideas are brought together to ensure the robustness and effectiveness of the proposed FWI: (a) correlation-based matching between measurements and simulation, to mitigate the effects of imprecise knowledge of ARF; (b) high-fidelity finite element simulation of 3D shear waves in incompressible elastic media, unlike 2D scalar wave approximation used for existing SWE algorithms; (c) multi-resolution parametrization to help with convergence of FWI even with an initial elasticity map far from the true map; (d) further refinement of multi-resolution imaging by performing FWI first at low frequencies, followed by adding higher frequency measurements to obtain a refined image. In silico validation is performed by imaging a 2 x 3 x 2 cm³ block of liver-mimicking material with diffuse disease with noise laden synthetic data, illustrating the viability and robustness of the proposed approach. We also extend the idea to viscoelasticity imaging by examining a lower dimensional variant of the algorithm to image a prismatic inclusion, which indicates promise for eventually providing 3D images of tissue viscoelasticity.

3 Musculoskeletal

3.1 A Wearable Ultrasound System Using Time Delay Spectrometry for Musculoskeletal Imaging

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Affiliation: Musculoskeletal Imaging with clinical machines has shown its useability in applications such as monitoring muscle activity in moving subjects, force tracking and prediction, gesture classification and hand kinematics. Research on wearable ultrasound is focused on miniaturization and power optimization of ultrasound hardware, in addition to algorithm exploration to extract more information from reduced sensors. Time Delay Spectrometry (TDS) is a low voltage alternative to traditional pulse-echo ultrasound imaging. TDS utilizes long duration transmit chirps to reduce the transmit voltage requirements, as well as down mixing to reduce the sampling requirements. The excitation voltage, time duration, and bandwidth parameters of the transmit chirp affect imaging depth, imaging resolution, and SNR. Our objective is to show a prototype system and characterize its imaging capabilities. Method: We developed a prototype TDS system consisting of a function generator, transmit amplifier, a passive diode mixer, an output audio frequency amplifier, and a custom 1-3 composite transducer with a center frequency of 4 MHz and 50% bandwidth. A benchtop frequency generator was used to vary transmit parameters of chirp duration, chirp bandwidth, and excitation voltage to showcase their effect on imaging capability. The transducer was placed on a CIRS point target phantom was used to measure the effect of transmit parameters on SNR and resolution. The transducer was placed on a phantom with fully developed speckle to measure maximum imaging depth. Results/Discussion: A system utilizing low voltage transmit (3-5V) is capable of imaging up to 6 cm of depth with an SNR > 40 dB and a resolution of up to 0.33 mm. The data shows an increase in
transmit voltage results in increased SNR and larger bandwidth results in better resolution. Acknowledgements: This work was supported by NIH grant U01EB027601, Department of Defense grants W81XWH2010817 and W81XWH2010190, Medical Technology Enterprise Consortium Military Performance Advancement Initiative (MTEC-MPAI) under Grant W81XWH-15-9-0001.

3.2 First evaluation of an integrated sonomyographic prosthesis in individuals with congenital limb difference

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Affiliation:

Abstract: Abstract - Sonomyography (SMG) or ultrasound-based sensing of muscle deformation is an emerging modality for enhancing upper limb prosthesis control, offering the ability to spatially resolve muscle activity in both superficial and deep layers. Previous research, including ours, has shown the feasibility of SMG with both clinical and miniaturized ultrasound devices for prosthetic management by tracking muscle changes. However, its integration within prosthetic sockets using miniaturized sensors has not been explored. In our study, we fitted two individuals with below-elbow limb differences with these sensor-equipped sockets, evaluating control accuracy. Our results highlight SMG’s potential and outline challenges for advancement.

Method In our study with two below-elbow limb difference individualsone experienced with myoelectric prostheses, the other a novicewe evaluated our prototype. By palpating during muscle contractions, we located optimal sensor placements on the forearm, collected SMG data across grasps for accuracy assessment, and documented sensor placements after satisfactory outcomes. We tested our prototype using a supervised learning approach, incorporating a dynamic training protocol that captures data in various arm positions under 30 seconds. We then assessed performance through trials in different arm positions, employing Principal Component Analysis (PCA) for dimensionality reduction and Linear Discriminant Analysis (LDA) for motion classification, alongside Gaussian Process Regression (GPR) for enhanced classification and control.

Result: The first participant was able to perceive three distinct volitional motions which were mapped to power grasp, pinch, and tripod. The second participant was able to perceive two distinct volitional motions which were mapped to power grasp and tripod. In addition, both participants were able to perform wrist rotation. Therefore, including rest as a separate class, we had 5 distinct classes for the first participant and 4 distinct classes for the second participant. In our study, the first participant reached 81.6% accuracy in identifying five actions with dynamic methods. The second participant achieved 100% cross-validation accuracy in three arm positions, with static trials starting at 85% accuracy and reaching 100% by the fourth trial. Dynamic trials peaked at 94% accuracy but dropped to 60% over time due to sensor issues. Selecting optimal sensor channels, however, led to high accuracy in both static and dynamic settings.

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3.3 Simultaneous Musculoskeletal Assessment with Real Time Ultrasound (SMART-US) for Rehabilitation Monitoring after Injury

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Abstract: Introduction: Only 65% of patients return to preinjury activity levels following injury to the anterior cruciate ligament (ACL). Symmetrical quadricep activity, defined as the strength between the injured and non-injured limbs, should be stressed in ACL rehabilitation. This study shows that a wearable multi-site ultrasound imaging device can track quadricep symmetry after ACL injury over a rehabilitation period.

Methods: Subjects (2 control, 1 with a left ACL-III deficiency) performed 3 trials of 3 bilateral, bodyweight squats with SMART-US imaging sensors placed on the right and left rectus femoris on two separate days while wearing loadsol sensors. Controls sessions were 48 hours apart, and ACL-III was four weeks apart. ACL-III also completed functional assessment scores during each visit. Bilateral symmetry index (BSI) of rectus femoris muscle activation (BSI=1 - perfectly symmetric) was calculated for each subject by fitting a sine function to the fascia displacement caused by the muscle contraction during the movement and comparing the amplitudes between the left and right rectus femoris. The coefficient of variation (COV) was used to confirm the stability of BSI in controls.

Results: Imaging BSI for controls was 0.950.02 and 0.980.01 and a COV of 2.6%. Controls loadsol BSI showed 0.910.03 and a COV of 5.0%. ACL-IIIs imaging BSI improved from 0.50.06 to 0.890.03 over 4 weeks, correlating to a 25-point improvement in assessment scores. ACL-III loadsol BSI also improved over the four weeks from 0.560.07 to 0.760.03. These findings provide support that SMART-US can be used during squat tasks reliably and establish the potential to track rehabilitation longitudinally.

Conclusion: SMART-US offers the potential for assessing ACL recovery during rehabilitation periods by yielding new quantitative information on healing progression. Providing an objective method to monitor muscle performance during functional activity and exercises to inform return to activities of daily living in new ways.

3.4 Random matrix theory applied to fatty infiltration in muscle

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Abstract: Fatty infiltration (FI) within muscles is a critical marker for evaluating the progression of various musculoskeletal and neuromuscular disorders that impact decisions around surgical interventions. Ultrasonography (US) has been found to be comparable to magnetic resonance imaging (MRI) in detecting rotator cuff tears (RCT) and qualitatively grading FI in the rotator cuff muscles; however, highly skilled physicians are needed to evaluate US images. There is a need for an accessible, non-invasive quantitative and objective evaluation of FI for the diagnosis, treatment, and prognosis of RCT. We aim to leverage the behavior of ultrasound waves in complex, heterogeneous muscular structures to quantify FI in muscle. MRI scans of both uninjured and injured rotator cuff muscles were used to create maps for ultrasound simulations. We collected radiofrequency (RF) ultrasound data from finite-difference time-domain simulations. Through the application of singular value decomposition and eigenvalue thresholding, we can distinguish between single and multiple scattering (SS and MS) present in the RF data. This comprehensive approach allows us to explore how variations in FI in muscle influence both SS and MS-based quantitative ultrasound (QUS) metrics. As FI increases, we anticipate notable changes in the QUS parameters due to more multiple scattering.

3.5 Development of a Multimodal Ultrasound-based Imaging Biomarker for Myofascial Pain

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Abstract: Myofascial Pain (MP) is a prevalent public health concern, impacting 1124% of the global population, and 85% of individuals experience MP at some point in their lives. Chronic MP, often associated with chronic
low back pain, poses diagnostic challenges due to the absence of reliable biomarkers. Current research on Trigger Points using ultrasound imaging has shown some significant tissue abnormalities that could potentially be related to MP. However, there are no comprehensive studies combining multiple ultrasound imaging modalities to obtain a holistic understanding of MP.

To address this gap, we conducted a multimodal ultrasound analysis comparing healthy with Low Back Pain (LBP) subjects to identify MP-related factors. To acquire multimodal measurements, we developed 3D ultrasound imaging techniques using a Row-Column-addressed Array transducer, a pioneering approach for investigating MP. Volumetric images were captured around the thoracolumbar fascia, multifidus muscles, and erector spinae while a subject lay prone.

We first investigated the echogenicity measurements, which delineate the lower back anatomy and explore their connections with myofascial pain scores and pressure algometry readings. Then, an external vibrator generates shear waves that travel through the low back muscles. High-frame-rate ultrasound imaging captures tissue displacement reflecting wave propagation, allowing calculation of the propagation speed which provides valuable insights into the tissue elasticity. We also examined how thoracolumbar fascia deforms during controlled flexion. A motorized exam table induced 15-degree flexion, while high-frame-rate ultrasound imaging captured dynamic movements. Using 3D ultrasound speckle tracking algorithms, we quantified thoracolumbar fascia deformation to correlate it with clinical pain assessments.

The results with (n=5 healthy; n=5 LBP subjects) demonstrate echogenicity, static and dynamic mechanical properties related to MP can be compared between healthy and LBP subjects. These findings could offer clues for statistical analysis over a large cohort to develop a new surrogate imaging biomarker for clinical diagnosis of MP.

4 QUS Methods

4.1 Evaluation of Multiple Scattering in Glass Bead Tissue Mimicking Phantoms and the Impact on QUS Feature Estimation

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Abstract: Introduction: Tissue mimicking phantoms with different concentrations and sizes of micron-sized glass beads are commonly used to assess the accuracy and precision of backscatter coefficient estimates [1]. Estimation of the backscatter coefficient assumes weak scattering (Born approximation), leading to single scattering events by each scattering source. This condition is not usually tested in the design of these phantoms. This study assesses the validity of the single-scattering approximation in phantoms through multiple scattering analysis [2].

Methods: Four agar-based tissue-mimicking phantoms (1-4) were made with combinations of glass bead distributions of ranges 38-45, 45-53, 90-106, and 150-180 m. Radiofrequency echo signals were acquired through a full-matrix capture sequence from a Vantage Verasonics 256 scanner with a L11-5V transducer (7.6 MHz center frequency). Faran theory predictions of the backscatter coefficient at 7.6 MHz were 1.27E-2, 2.15E-2, 4.65E-2, and 3.96E-2 cm⁻¹ sr⁻¹ for phantoms 1-4, respectively. The single scattering assumption was tested following Aubry and Derodes [2] decomposition of the backscatter intensity into the single- and multiple scattering components. Evidence of multiple scattering came from (1) the presence of the coherent scattering peak arising from the acoustic reciprocity principle and (2) by calculating the proportion of the total backscattered intensity due to multiple scattering from a pulse sent and received from a single element, i.e., the multiple scattering rate (MSR).

Results & Discussion: The backscattered intensity of the four phantoms showed a coherent peak, serving as evidence of multiple scattering. At a depth of 30mm, the measured MSR was 0.16, 0.2, 0.34, and 0.54 for phantoms 1-4. We are currently assessing the correlation of the multiple scattering rate with the bias in the estimates of the backscatter coefficient.
4.2 Towards real-time backscatter coefficient estimation through automatic tumor segmentation

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Abstract: Quantitative ultrasound using spectral-based techniques, like the backscatter coefficient (BSC), have been used to characterize tumors for diagnostics and for monitoring therapy. Tumor segmentation in ultrasound images, which is crucial for BSC estimation, remains a labor-intensive and skill-dependent task. The advent of automatic tumor detection and segmentation methods, notably through advanced neural networks like the Convolutional Neural Network (CNN), You Only Look Once (YOLO), U-Net and Single Shot MultiBox Detector (SSD), can alleviate the manual tasks by automating segmentation. These methods have not only streamlined the segmentation process but also enhanced consistency and accuracy, particularly in cases with limited training data. This study utilized the U-Net model, widely used for its efficiency in biomedical image segmentation, to automate tumor segmentation in a rabbit tumor dataset where a calibration target, consisting of a titanium sphere of 2-mm diameter, was embedded in each tumor. Coupled with a cross-correlation method for identifying the calibration target in situ, the approach enabled real-time, automatic estimation of BSC. To quantify performance of the segmentation a similarity metric, i.e., the Dice Score, was calculated. The effects of the segmentation on BSC estimates and associated parameters (i.e., the ESD and EAC) were also quantified by comparing the manual segmentation with the automated segmentation. Overall, the U-Net demonstrated proficiency in estimating BSC parameters, achieving a relative error of 10.83% for ESD and 6.32% for EAC for automatically segmented tumors compared to tumors segmented by humans.

4.3 A Systematic Assessment of the Effects of Depth-dependent Power Loss on Speckle Statistics Estimation

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Abstract: Quantitative ultrasound based on speckle statistics relies on models linking signal envelope amplitude distributions with sub-resolution acoustic scatterers in order to characterize tissue microstructure. Power loss from beam diffraction and attenuation are not accounted for in such models, and therefore introduce bias in extracted features. The implementation of attenuation estimation in commercial scanners offers the potential to correct this bias. The purpose of this study is to quantify the expected errors in speckle statistics estimates from diffraction and attenuation within the parameter estimation region (PER), and to investigate methods for compensating for these errors. Experiments were performed with computational homogeneous diffuse-scattering phantoms simulated in Field II with attenuation of 0.5, 1, or 2 dB/cm/MHz. Images were created from linear-array transducers operated at center frequencies of 5 or 9 MHz. Speckle statistics were estimated in PERs of varying axial extent, both with and without applying compensation for power loss from diffraction and attenuation. Three time gain compensation methods were investigated: 1.) using the known attenuation to apply an exponential correction to the power loss, 2.) measuring and inverting the average depth-varying intensity along the length of the phantom and 3.) using the known attenuation plus a measured diffraction correction. Our results show that the exponential compensation using the known attenuation alone does not sufficiently eliminate the dependence of speckle statistics features on PER size. However, methods 2 and 3 effectively produce estimates that are PER size- and attenuation-independent, because these methods account for power loss from diffraction. Thus, we recommend the latter two methods to
reduce bias in speckle statistics estimates due to power gradients within the PER, so that speckle statistics estimates are more closely linked with the microstructure of the probed medium.

4.4 Test-retest repeatability of Quantitative Ultrasound in the neonatal brain: comparison of non-regularized vs regularized parameter estimators

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Abstract: We are investigating the use of backscatter Quantitative Ultrasound (bQUS) features, specifically the Effective Scatterer Diameter (ESD) and the Acoustic Concentration (AC), as potential biomarkers of acute tissue damage in the neonatal brain. To serve as biomarkers, QUS features must describe acoustic properties of tissue accurately and precisely. Novel regularized-QUS approaches (rQUS) have been shown to improve accuracy and precision in phantoms and to provide good to excellent repeatability and reproducibility when used in breast cancer. However, translation to in vivo neonatal brain imaging is challenged by the anatomical complexity and operator dependence of data acquisition. Here, we compare the experimental precision of rQUS in neonatal brain imaging over non-regularized approaches. We investigated two elements of precision, the intra-study, and the test-retest repeatability. Several frames of raw radiofrequency (RF) signals were acquired in 10 subjects by one of two sonographers at two-timepoints: 0 hrs (test) and 24 hrs (retest). ESD and AC were estimated from each frame using the reference phantom method with Gaussian form factors using either rQUS or literature-based attenuation values. Intra-study variability was assessed with the within-subject coefficient of variation (wCV) across frames acquired during one-timepoint by one sonographer. Test-retest variability was assessed through the intra-class correlation coefficient (ICC). Results indicate higher intra-study variability of rQUS vs conventional QUS (ESS wCV=9.1% vs 5.5%, AC wCV=13.1% vs 7.3%). For ESD, ICC indicated good to excellent test-retest repeatability with conventional QUS but poor to good for rQUS. For AC, both methods yielded poor to good agreement. We hypothesize that increased variability can be attributed to the simultaneous estimation of attenuation in rQUS (range: 0.03 0.78 dB/cm-MHz) versus using a single literature-based value (0.35 dB/cm-MHz) in the conventional approach. We are currently investigating the effects of regularization weights and recruiting more subjects to assess testing equivalence and inter-operator variability.

5 QUS Applications

5.1 Characterization of Muscle Microstructure in the Rabbit Anal Sphincter Complex Using the Angular Dependence of Integrated Backscatter

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Abstract: Anorectal malformations are congenital hindgut disorders that occur in 2-5 of 10,000 live births and impair development of the rectum, anal canal, anal sphincter complex, and colonic and rectal nerves. While, anorectal malformations can be surgically corrected in infancy, patients often experience continued fecal incontinence or constipation, leading to profound physical and psychosocial challenges. Muscle structure in the anal sphincter complex impacts contraction strength and plays a key role in fecal continence. Furthermore, collagen fibers in healthy muscle are ordered and aligned, while disorganization implies damage. Thus, there is a need to develop new non-invasive imaging technologies that characterize collagen microstructure in anal sphincter complex musculature. Here, we developed a high-frequency quantitative ultrasound spectral analysis technique to
characterize differences in collagen microstructure between muscle from healthy rabbit anal sphincter complex and liver. Backscattered echoes were acquired from ex vivo rabbit anal sphincter complexes and liver at multiple insonification angles. The integrated backscatter coefficient (IBC) is a quantitative ultrasound parameter, computed in the frequency domain, that estimates how strongly the interrogating pulse is reflected back to the transducer by scatterers within a resolution cell volume. IBC parametric images and the average IBC in a region of interest were computed at each insonification angle. The IBC exhibited angular dependence in anal sphincter complex musculature and angular independence in liver. These data suggest that the IBC as a function of insonification angle can be used to detect collagen fiber alignment in anal sphincter complex musculature. This work advances the utilization of non-invasive quantitative ultrasound for characterizing muscle structure and lays the groundwork for a tailored device to guide surgical approaches for anorectal malformation correction and rehabilitative techniques to optimize pediatric anal sphincter complex function.

5.2 Using Quantitative Ultrasound for Breast Cancer Detection

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Abstract: Angiogenesis is recognized as a marker of breast cancer aggressiveness. While current methods to diagnose breast cancer such as mammography and magnetic resonance imaging (MRI) pose drawbacks including radiation exposure, use of contrast, false positives/negatives, cost, and resolution issues, ultrasound emerges as a safe, portable, and cost-effective alternative. Ultrasonic imaging, super-resolution ultrasound, micro-Doppler, and acoustic angiography enable the imaging of vessel networks, but the information provided by these images is not quantitative. We propose to assess angiogenesis based on quantitative analysis of ultrasound scattering from raw ultrasound data. The experimental setup involves acquiring full synthetic aperture matrices (FSAM) using a transducer array connected to a Verasonics 128 Vantage scanner. We use microbubbles as ultrasound contrast agents to enhance scattering properties. In our prior study, we delved into quantitatively assessing angiogenesis in a rodent fibrosarcoma model, by employing signal processing techniques, focusing on the Scattering Mean Free Distance (SMFP) as a key parameter. To enhance the sensitivity of our analysis, we introduce a novel parameter, termed Single Scattering Intensity Decay Rate (SSIDR), which quantifies the decay of the single scattering contribution. This parameter was derived through the application of Single Value Decomposition (SVD) filtering, allowing for the separation of single and multiple scattering intensities. This separation method was expected to be highly sensitive to noise. By intentionally introducing noise to the raw data and comparing the resulting SSIDR values with those obtained from natural raw data, we observed a remarkable similarity. This finding underscores the robustness of the SSIDR method in the presence of noise, highlighting its potential reliability in practical applications. Additionally, we acquired FSAM from phantoms made of PDMS, simulating vascular structures. Subsequently, we apply the aforementioned signal processing techniques to analyze the acquired FSAM. Our study demonstrates the potential for developing biomarkers of cancer aggressiveness and improving ultrasound specificity by characterizing the microarchitecture of angiogenesis.

5.3 Quantitative ultrasound to characterize white adipose tissue in-vivo

Authors: Cameron Hoerig [1], Kemi Babagbemi [1], Michele Drotman [1], Kristy Brown [2], and Jonathan Mamou [1]
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**Abstract**: White adipose tissue (WAT) is a complex metabolic organ with wide-ranging roles in metabolic regulation and physiological homeostasis. Recent studies have identified relationships between changes in the microstructural properties of WAT and systemic or localized disease. For example, malignant breast tumors have been found to alter the microstructure of adjacent WAT. Measuring the microstructural properties of WAT may provide important clinical information for disease detection; however, current methods are time consuming, invasive, and inherently ex-vivo. Quantitative ultrasound (QUS) methods based on evaluating the backscattered echo signal could provide a tool for characterizing WAT rapidly, non-invasively, and in-vivo.

In this study, 51 patients with breast lesions scoring BI-RADS 4B or higher and scheduled for core needle biopsy were enrolled. Radiofrequency (RF) echo data were collected in two orthogonal planes through the lesions. One set of QUS parameters were computed by fitting histograms of envelope values to the Homodyned-K (HK) distribution. A second set of QUS parameters were computed by fitting the estimated backscatter coefficient to Gaussian scatterer and linear models. While no significant differences in QUS parameters were found within benign or malignant tumors \( (p > 0.34) \), significant differences in spectral slope, effective scatterer diameter, and HK parameters were observed within WAT near tumor boundaries for both benign and malignant tumors \( (p < 0.03) \) for all. Interestingly, HK exhibited significant differences near benign tumors \( (p = 0.01) \), whereas HK \( k \) differed near malignant tumors \( (p = 0.03) \). Considering QUS parameters corresponding to WAT within 2mm of tumor boundaries, significant differences were found for HK, midband fit, and effective acoustic concentration when comparing benign and malignant tumors \( (p = 0.01, p = 0.03, p = 0.008, \text{ respectively}) \). No significant QUS parameter differences were found beyond 4mm from the tumor edge. These findings provide encouraging evidence for the potential of QUS to characterize WAT microstructure non-invasively and in-vivo.

### 5.4 Quantitative ultrasound assessment of in vivo lymph node metastasis using a clinical scanner

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**Abstract**: Quantitative ultrasound (QUS) methods can characterize soft tissue microstructure by analyzing backscattered radiofrequency (RF) ultrasound data. Here, QUS methods were used to detect in vivo lymph node (LN) metastasis from RF data acquired with a GE LOGIQ E9 scanner and a 10-MHz linear array. \( N = 25 \) patients with known types of primary cancer were consented and included in this study. One LN was chosen in each patient and the LN metastasis status was assessed via cytology results of ultrasound-guided fine-needle aspiration. During imaging, the ultrasound transducer was manually translated in the elevational direction on the patients skin to acquire parallel RF echo frames throughout the LN. In post hoc processing, each RF echo frame was divided into overlapping regions of interest (ROIs), QUS parameters were computed within each ROI based on the backscatter coefficient and envelope statistics, and final mean QUS parameters were computed from ROIs located within the manually segmented LNs. According to Students t-test analysis comparing QUS parameters between metastatic and benign LNs, effective scatterer size (ESS), acoustic concentration (AC), spectral intercept (SI), and midband fit (MBF) values were significantly smaller in metastatic compared to benign LNs \( (p < 0.001) \), while the spectral slope (SS) parameter showed significantly larger values in metastatic vs. non-metastatic LNs \( (p < 0.001) \). Moreover, two linear discriminant analysis (LDA) models were trained: one on ESS and AC parameters, and another on SS, SI, and MBF parameters. Both supervised models achieved equal areas under the receiver-operating characteristic curves of 0.89 for classifying LN metastasis status. These results demonstrate the potential for QUS to differentiate metastatic from benign in vivo LNs using scanners operating at typical clinical frequencies.

This work was supported by NIH R01 CA277038.
5.5 Quantitative Ultrasound Assessment of Vitreous Echodensities using Double Nakagami Distribution

**Authors:** Ladan Yazdani (1), Cameron Hoerig (1), Justin H. Nguyen (2), Jonathan Mamou (1), J. Sebag (2), Jeffrey A. Ketterling (1)

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**Abstract:** Quantitative ultrasound (QUS) imaging characterizes vitreous echodensities, useful in assessing clinically significant visual floaters, known as Vision Degrading Myodesopsia (VDM). Previous QUS studies evaluating B-mode log-compressed envelope data found correlations between the QUS parameter energy (E, average squared pixel value in vitreous) and contrast sensitivity (CS). Access to raw radiofrequency (RF) data on clinical scanners facilitates enhanced processing of backscatter data, potentially providing more refined analyses. This study aims to analyze envelope statistics from RF signals using the Double Nakagami (DNK) approach to separate noise in the Nakagami (NK) distribution scale factor computation. Fourteen eyes from eight subjects underwent clinical measurement of CS and axial length (Axl). RF data of vitreous ultrasound scans were acquired using a clinical ophthalmic ultrasound machine (Absolu, Quantel, France) with a 20-MHz annular array transducer (B20, Quantel). QUS parameters including E and DNK were computed. The DNK distribution included one NK distribution fitting echodensities and another fitting noise. Two parameters, T90 and EP, based on the first NK scale factor’s map were computed over a region of interest (ROI) within the vitreous area. T90 represents a threshold where 90% of scale factors are T90, while EP is the ratio of the pixel count of echodensities computed from the DNK weighted factor to the total pixel count inside the ROI. There were significant correlations between T90 and Axl (R=0.76, p< 0.05) and between EP and CS (R=0.61, p< 0.05). These correlations surpassed those observed between E and Axl (R=0.56, p< 0.05) and CS (R=0.40, p=0.16). However, no significant correlation was observed between E and T90 (R=0.34, p=0.23). Our study highlights the potential of the DNK approachs QUS parameters (T90 and EP) as valuable indicators for assessing vitreous inhomogeneity beyond the capabilities of traditional parameters like energy. Additional datasets will be recruited to further validate DNK in characterizing vitreous echodensities.

(This work was supported by National Institute of Health grant EB032082.)

5.6 High-frequency Quantitative Ultrasound to Predict Myopia Progression In Vivo

**Authors:** Cameron Hoerig [1], Quan V. Hoang [2,3,4], and Jonathan Mamou [1]


**Abstract:** High myopia is a significant risk factor for pathologic myopia, a leading cause of blindness worldwide. Refractive error (RE) and axial length (Axl) are standard clinical ophthalmic measurements to identify myopia level but cannot predict myopia progression. Recent evidence demonstrates the microstructural properties of the anterior sclera may be altered by myopia. We developed a high-frequency point-of-care (POC) ultrasound instrument to utilize quantitative ultrasound (QUS) methods for characterizing myopia-induced microstructural and biomechanical properties of the anterior sclera that may be predictive of myopia progression.

Seventy-five subjects were recruited for this study. Standard ophthalmic measurements were obtained and both eyes were scanned with the POC instrument to collect radiofrequency (RF) echo data from the anterior sclera. RF data were processed with QUS methods to compute five parameters relating to the tissue microstructure and stiffness. Subjects returned one year later for RE and Axl measurements to identify myopia progression. Multi-linear regression revealed ophthalmic and QUS parameters correlated with change in RE (R0.52,p < 0.001),
but correlation with change in Axl was significant only when QUS parameters were included (R=0.33, p=0.006). Eyes were then categorized into two groups: eyes with significant RE change (RE0.5) or no change. A support vector machine was trained using the QUS parameters and ophthalmic measurements from the first time point to classify each eye and was evaluated by computing the area under the receiver-operating characteristic curve (AUC). Ophthalmic parameters alone were not predictive of significant RE change after one year (AUC=0.50), but the addition of QUS parameters significantly improved classifier performance (AUC=0.78). Results of this study suggest high-frequency QUS are sensitive to microstructure and biomechanical changes in the anterior sclera and may offer critical clinical information for predicting myopia progression.

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5.7 Ultrasonic Characterization of Printed Hydrogel Lung Phantoms

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Abstract: Conventional US is very challenging in lungs, as a phenomenon called US multiple scattering (MS) occurs, resulting in an unclear image. We aimed to evaluate 3D printed hydrogel phantoms made of polyethylene glycol diacrylate (PEGDA) and polyethylene glycol methyl ether acrylate (PEGMEA), designed to mimic the porous structure of lungs. We intended to determine if these phantoms are comparable to lung tissue (alveoli) from the point of view of ultrasound. By simulating the collection of an Impulse Response Matrix (IRM) data in a lung with the phantoms, we can study the synthetic images of the phantoms to determine how it compares to that of a lung. We were able to scan the phantoms, get ultrasound data and SMFP data, and see strut size, and we showed that there is speckle within the hydrogel, which can be further studied to determine if the material is an accurate representation of alveoli. We determined that the 3D printed hydrogel phantoms behaved like tissue. Furthermore, the scattering mean free path (SMFP) data demonstrated an interesting relationship between the amount of material and the SMFP value, which will have to be explored further.

Wednesday, May 30

6 Contrast and Markers

6.1 Evaluating the Performance of a Bioabsorbable Material, Applied Surface Modifications, and Autoclave Sterilization on In Vivo Doppler Twinkling: A Pilot Pig Study

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Abstract: Background: Some commercial breast biopsy markers and markers that our group have developed have shown strong color Doppler twinkling artifact in in vivo and ex vivo environments. We evaluated three marker propertiesbioabsorption, surface modifications, and autoclave sterilizationthat could affect twinkling after
implantation in a pilot pig study. Bioabsorption enables the clinical use of nonmetallic or non-permanent markers. Surface modifications can induce twinkling and improve ultrasound detectability of commercially-available markers that do not twinkle. Evaluating the effect of autoclave sterilization on twinkling is important to ensure that markers twinkle after sterilization. Methods: IACUC approval was obtained to implant markers made of bioabsorbable Stimulan (calcium sulfate) into a pig superficial inguinal lymph node and subcutaneously in the mid-abdomen. Additionally, control and laser-etched bowtie markers (Hologic) were implanted in different lymph nodes. Ultrasound of the markers was performed three times over three months. For a second pig, two polymethyl methacrylate (PMMA) markers, autoclaved and not autoclaved, were implanted in neighboring lymph nodes. These markers were scanned once after implantation. All scans were conducted on a General Electric Logiq E9 scanner with 9L, C1-6, and ML6-15 transducers. Twinkling was scored using a semi-quantitative scale from 0 (weakest) to 4 (strongest). Twinkling strength was also quantified using pixel counting of color Doppler pixels.

Results: The control bowtie did not twinkle at any time. The modified bowtie had robustly twinkled at the beginning, did not twinkle after one month, but twinkled again after two months. Both Stimulan markers showed strong twinkling in the lymph node and lesser twinkling subcutaneously after implantation. Stimulan did not twinkle in the subsequent months. The autoclaved PMMA marker had much stronger twinkling than non-autoclaved ones across all transducers. Surface modifications and autoclaving markers led to strong twinkling, while the bioresorbable markers that were tested did not have persistent twinkling.

6.2 Large-aperture arrays and null subtraction imaging for use in abdominal ultrasound

Authors: Mick Gardner, Michael Oelze
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Abstract: Abdominal ultrasound is a common medical test that doctors use to check patients for kidney stones, liver disease, tumors, and many other conditions. Creating an image with a wide field-of-view is necessary for this application in order to fit large abdominal organs inside a single image. The purpose of this study is to create a wide field-of-view by using a large-aperture linear array with a standard element count and a large pitch. A large linear aperture will provide a wide field-of-view and consistent resolution with depth. Also, while increasing the pitch would normally introduce grating lobes, Null Subtraction Imaging (NSI) is then used to mitigate the resulting grating lobe artifacts. Experiments were conducted in simulation, in phantoms, and in-vivo to test advantages and disadvantages of this approach. First, pitch and element factors were tested using an L14-5/60 and L14-5/38 probe with and without channel decimation and at various excitation frequencies. It was observed in phantom experiments that NSI combined with appropriate element factors completely eliminates grating lobes, providing a gCNR improvement of up to 0.52 for grating lobe regions and 0.06 for anechoic regions. Results were verified by scanning the liver and kidneys of a rabbit, where the resulting gCNR improvement due to NSI reached 0.11 for contrast and 0.16 for grating lobe regions. Lastly, k-wave simulations were done to explore the possibility of a much larger aperture, 160 mm, for abdominal imaging. Based on the results, this approach towards large linear arrays is an attractive option for improving abdominal imaging.

6.3 An Adaptive Ultrasound Sequence for Activation and Monitoring of Phase-Changing Nanodroplets

Authors: Charles R. Dyall[1], Dmitry Nevozhay[1], Trevor M. Mitcham[2], Yunyun Chen[3], Stephen Lai[3], Konstantin Sokolov[1, 4, 5, 6], Richard R. Bouchard[1, 4]
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Abstract: Perfluorocarbon-cored phase-changing nanodroplet contrast agents (PNCAs) can be molecularly targeted and used for extravascular molecular ultrasound (US) imaging. To monitor the activation and behavior over time of these nanodroplets, we propose an adaptable scheme for activation and imaging comprised of plane-wave B-mode imaging before and during the focused burst followed directly by high-frame-rate (HFR), co-registered B-mode, and nonlinear Pulse-Inversion (PI) imaging. By understanding the behavior of the nanodroplets in both the short and long-term after activation, we can better optimize their future in vivo performance. The adaptive sequences for performing the activation and imaging of the PFC nanodroplets were designed on a Verasonics Vantage 128 US system (Verasonics Inc., Kirkland, WA, USA) using both a Verasonics L11-4v transducer (6.25MHz-fc) and a Kolo L22-8v CMUT transducer (15MHz-fc; Suzhou, Jiangsu, China). Both dodecafluoropentane (C5) and dodecafluorohexane (C6)-cored nanodroplets were used. The Diluted PNCAs (1% concentration) were cast in a tissue mimicking polyacrylimide (PAA) phantom (25% acrylimide, 1% ammonium persulfate) for imaging. These phantoms were attached to a gelatin base with cyanoacrylate glue and maintained at a temperature of ~37°C. B-mode images were acquired before and during the activation while HFR (13k frames/second), B-mode, and PI imaging were performed post-activation. Contrast enhancement in ROIs (0.32 x 0.9mm) around each nanodroplet was measured by the contrast-to-noise ratio (CNR) with reference to the background of the phantom. Activation visualization demonstrated significant echo response that can be used to ensure optimal nanodroplet activation. HFR acquisition captured the behavior of microbubbles in formative moments, with an adaptable number of plane-wave transmits to achieve better image quality (at the expense of frame rate). Activated PFC nanodroplets provided a CNR of 0.8-1.5. The results of this study demonstrate that this sequence provides a strong platform for further in vitro and future in vivo study of PNCA activation and behavior.

6.4 Photoacoustic-based PAtrace biodistribution assessment with independent cryo-fluorescence tomography validation

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Abstract: Background: Many cancer subtypes do not respond to standard therapeutics, implying the need for real-time, noninvasive imaging to monitor therapy response and direct non-responders to alternative treatments. We previously demonstrated photoacoustic (PA) imaging for quantitative assessment of in vivo accumulation of a targeted contrast agent, PAtrace (liposome-encapsulated indocyanine green [ICG]), in an ovarian cancer model[1]. There is a need to further assess PAtrace biodistribution to further optimize systemic delivery.

Methods: Twelve wild-type athymic NCr mice were imaged on the MSOT inVision 256-TF PA imaging system. Multi-wavelength volumetric PA imaging was performed pre-injection, and PA imaging was repeated for 30-min following injection of EGFR-targeted PAtrace. Additional PA images were acquired at 1-day (N=9), 3-days (N=6), and 6-days (N=3) post-injection. Fluence-corrected images were unmixed for oxy-/deoxyhemoglobin, ICG, and PAtrace within liver and spleen ROIs. To independently verify ICG distribution postmortem, mice (N=3 per group) were processed for cryo-fluorescence tomography (CFT; Xerra imager) at 1-hour, 1-day, 3-days, and 6-days post-injection.

Results: Liver and spleen PAtrace signal increased through 30-min post-injection. 1-day post-injection, PAtrace signal dropped significantly, implying substantial probe clearance. ICG signal in both organs peaked immediately post-injection, then decreased within 30 min. Liver ICG signal remained low through 6-days post-injection; however, spleen ICG signal increased from 1 day to 6 days. These trends were confirmed with CFT,
which indicated measurable liver ICG signal at 1-hour and 6-days and increasing spleen signal from 1-hour to 6-days.

Conclusions: High PAtrace signals in the liver and spleen, assessed with PA and CFT, imply that PAtrace is taken up and cleared by the hepatic system, which is consistent with previously demonstrated liposomal clearance dynamics. Further studies will continue to evaluate PAtrace biodistribution in tumor-bearing subjects to evaluate safety for future clinical translation.


6.5 Advancing Near-Infrared Photoacoustic Imaging with Novel ICG-Based Contrast Agents

Authors: Marzieh Hanafi, Giovanni Giammanco, Shrishti Singh, Remi Veneziano and Parag V. Chitnis

Affiliation:

Abstract: Near-infrared photoacoustic imaging (NIR-PA) can enable deep-tissue imaging. However, broad adoption and clinical translation are hindered due to a lack of biocompatible, targeted, and optically stable contrast agents. While indocyanine green (ICG), an FDA-approved NIR dye, represents a promising candidate, its concentration-dependent optical absorption and lack of facile targeting strategies restrict its use as a NIR-PA contrast agent. To address this unmet need, we examined two novel strategies for synthesizing ICG-based contrast-agent platforms, which are DNA-ICG nanoprobes (1D and 2D) and ICG J-aggregates (JAAZ). Our results demonstrate that all contrast agents produced a PA signal stronger than that from whole blood at concentrations above 45 \text{ M} and as low as 7.5 \text{ M} for JAAZ. Surface plasmon resonance was used to confirm molecular targeting. In comparison to free ICG, DNA-ICG nanoprobes remained in monomeric form at all concentrations, resulting in a predictable optical absorption signature in vivo. JAAZ showed a robust and red-shifted absorption peak with a profile distinctly different from endogenous chromophores. JAAZ exhibited reduced fluorescence signals, which makes them particularly conducive to PA-based sensing and imaging. Similar to free ICG dye, DNA-ICG probes are bimodal and can be used for optical fluorescence and PA imaging. In vivo imaging indicated that JAAZ constructs produced a stronger PA signal in whole-body mouse imaging compared to free ICG, and the signal persisted for over 90 minutes.

7 Elasticity II

7.1 Single Track Location Shear wave Spectroscopy & Imaging for Biomechanical Characterization of Tissues

Authors: Siladitya Khan, Fan Feng, Stefanie Hollenbach, Marvin Doyley and Stephen McAleavey

Affiliation: University of Rochester

Abstract: Ultrasound shear wave elastography (USWE) provides contrast based on tissue stiffness which is complimentary to conventional US imaging. However, all commercially available USWE systems assume tissue is elastic. Yet, tissue elasticity alone is not reliable discriminant of many pathologies. We hypothesize that incorporating viscoelasticity will improve pathological characterizations. To this end we developed a moving Acoustic Radiation Force (ARF) source shear wave spectroscopy and imaging technique to probe viscoelastic biomechanics of tissues. Elastography scans and processing was performed to capture 3D particle data frames, performed with an ATL L7-4 linear array that is driven by a Vantage 64LE ultrasound system. Shear wave dispersion and attenuation was initially estimated from the cross-spectral power density (CPSD) estimate of the spatiotemporal shear wavefield induced by the two ARF pushes for each spatial location of estimated displacement location. Spectroscopic estimation was performed over an ROI of 5 mm axial length 10 mm in the lateral
direction around the focal depth of the ARF push. Imaging reconstructions were performed pixel-wise over the entire field-of-view that resulted in shear wave dispersion and attenuation maps resolved over multiple frequencies. We report viscoelasticity measurements across a range of imaging configurations on test phantom objects by varying acquisition parameters and study the sensitivity of such parameters to our estimated apparent viscoelastic modulus. We performed local rheological reconstructions on custom-made oil-in-gelatin viscoelastic phantoms to test viscoelastic imaging performance. We evaluated the sensitivity of the reconstruction approach to capture mechanical modulation in ex-vivo porcine and rabbit tissues and demonstrate imaging feasibility in post-delivery human placentae. We show that our spectroscopic imaging approach can better capture viscoelastic dynamics in tissues.

7.2 Ultrasound Thermal Strain Imaging for Characterizing Atherosclerosis Plaques

Authors: Ran Wei, Zhiyu Sheng, Mengyue Chen, Tara Danielle Richards, Megan Smith, Matthew Wielgat, Dhanansayan Shanmuganayagam, Alan M Watson, Julie A, Phillipi, Edith Tzeng, Xuecang Geng, Xiaoning Jiang and Kang Kim

Affiliation: University of Pittsburgh, North Carolina State University, University of Wisconsin-Madison, Blatek Inc.

Abstract: Background: Strokes often result from atherosclerotic plaque (AP) rupture; rupture-prone AP is associated with a lipid-rich core. The ability to diagnose rupture-prone AP would better guide decisions for surgical intervention and avoid unnecessary surgeries. To characterize AP and identify lipids, we use ultrasound thermal strain imaging (US-TSI) with a custom-built probe that integrates heating and imaging arrays. US-TSI contrasts the plaque lipid content (positive strain) from the surrounding water-rich tissue (negative strain) using differences in the change of sound speed with induced increases in temperature.

Methods: We conducted pilot in vivo studies in porcine (n = 1) and rabbit (n=1) models and ex vivo studies using human carotid endarterectomy (CEA) samples. In the pig, we sought to assess the effectiveness of acoustic energy delivery with controlled tissue temperature increase. We conducted US-TSI, measuring the post-heating temperature in a uniform muscle region that is expected to be primarily water-based tissue. In the rabbit, we sought to demonstrate the feasibility of using US-TSI to identify lipid content of AP in the femoral artery when cardiac pulsatile motion is present. In the CEA sample, we used histology to validate the identification of lipids within AP by US-TSI.

Results: In the pig, the thermal strain pattern indicated a peak (negative) strain of approximately -0.1% due to a 1.2 C temperature increase around the focus, while the temperature change and thermal strain were minimal off-focus. In the rabbit, US-TSI revealed positive thermal strain even when the pulsatile motion was present. In the CEA sample, the findings revealed a peak (positive) strain contrast, suggesting the presence of a lipid region consistent with histological analyses.

Discussion: The results demonstrate the feasibility of using US-TSI to detect lipid within AP in presence of pulsatile motion. The study also provided guidelines for future studies of US-TSI in human subjects.

7.3 Vector Flow and Adaptive Wall Shear Stress Imaging on Heterogeneous Pulsatile Flow Phantoms

Authors: Pengcheng Liang, Elisa Konofagou
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Abstract: Abnormal blood flow patterns and low or oscillatory wall shear stress (WSS) have been associated with atherosclerosis growth and vulnerable plaque developments. Cross-correlation based Vector Flow Imaging (CC-VFI) that estimates blood flow profile and adaptive method deriving WSS was previously developed by our group. Wall motions were assessed using Pulse Wave Imaging (PWI) on heterogeneous plaque phantoms in Mobadersany,
et al. In this study, five arterial phantoms with homogeneous (soft, intermediate, or stiff) and heterogeneous (soft or stiff core covered by intermediate wall) plaques were fabricated by pouring Polyvinyl Alcohol (PVA) solutions into 3-D-printed molds. Ultrasound sequences were acquired from these phantoms connected to a pulsating pump with blood mimicking fluid. Singular value decomposition (SVD) was applied to eliminate global and wall motion. A 1-D normalized cross-correlation (NCC) was applied to the SVD filtered frame with 2-D axially and laterally shifted kernel to estimate the 2-D blood velocity profile. Silhouette k-means clustering identified the optimally linear flow profile with the minimum variance in shear rate near the wall. The corresponding spatial derivative was then utilized for WSS calculations. The Young's modulus of the phantom materials was found to be E0 = 13 kPa for soft, E0 = 40 kPa for intermediate and wall, and E0 = 54 kPa for stiff plaques. VFI exhibited increase in peak flow velocity at lumen center as overall plaque compositions soften (179.111.2mm/s for plaque with stiff core and 185.28.9mm for soft core). WSS at peak flow exhibited more uniform profile across plaque as overall plaque compositions stiffen. A reduction in the span of high WSS at post-stenotic regions due to turbulence were also observed as plaque stiffen (from 10.2 mm to 6.8mm). Overall, CC-VFI and adaptive WSS demonstrated potentials in identifying flow characteristics and relating WSS to plaque stiffness in phantoms.

7.4 Frequency dependent crystalline lens elastography

Authors: Francois Legrand, Alice Ganeau, Gabrielle Laloy-Borgna, Cyril Lafon, Maxime Lafond, Stefan Catheline
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Abstract: Presbyopia, characterized by age-related stiffening of the crystalline lens due to protein aggregation, results in near vision loss. Ultrasonic cavitation, known to disrupt disulfide bonds in aggregated proteins, offers a promising research way for lens softening. However, shear wave elastography, effective in monitoring tissue softening, faces challenges in direct application to the lens due to the absence of speckle. Hence, our study delves into the impact of internal stiffness changes on observable surface waves through numerical and experimental exploration. We employed noise correlation of surface point displacements to derive dispersion curves and estimate viscoelastic properties. Finite Difference Time Domain simulations were run to evaluate elasticity in homogenous and multilayered media, findings of which were compared with experiments conducted on gelatin phantoms, naked eggs, and porcine lenses. Displacements on the surface were induced by a vibrator transmitting 0.1-3.5 kHz sweeps. Ultrasound images were acquired using a L22-14vX or L7-4v ultrasound array and a Verasonics Vantage (Kirkland, WA, USA). In homogeneous medium, the simulated dispersion curve exhibits a Scholte wave behavior above a frequency that depends on the ratio between shear velocity \(V_s\) and radius. Adding layers induced a gradient in the dispersion curves, indicating that higher frequency surface waves are less sensitive to deep layers. A similar behavior was observed experimentally: a plateau for high frequencies meeting Scholte wave expectation (0.84 \(V_s\)). At low frequencies, resonances and slow wave velocities indicate guided waves. This method successfully identified stiffness changes between 10% and 15% gelatin phantoms, fresh and aged naked eggs, and porcine lenses before and after heating. Numerical and experimental studies revealed the frequency-dependent sensitivity of surface waves to the viscoelastic properties of inclusions, highlighting the need for careful evaluation of stiffness changes. This challenges the reliability of measuring such changes using low frequency surface waves, as commonly done in literature.

7.5 Twin Peak Method for Measuring Shear Viscoelasticity of Soft Tissues

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Abstract: Estimating viscosity from shear wave elastography is often more difficult than elasticity because attenuation, the main effect of viscosity, leads to poor motion signal-to-noise ratio. In this work, we provide an alternative to existing methods of viscoelasticity estimation that is robust against noise. The key to our approach is the observation that the response in a viscoelastic medium, examined in the frequency-wavenumber domain, has a
peak with wider spread compared to that for an elastic medium, with the spread being a function of viscosity. We quantify the spread by examining two peaks, \( f(k) \) and \( k(f) \), which are distinct and robust against noise (\( f(k) \) peak represents the frequency \( f \) at which the motion is maximum, for a given wavenumber \( k \); \( k(f) \) peak is accordingly obtained by swapping \( f \) and \( k \)). We match these peaks from experiments with those from simulation. Simulation is performed with a Fourier method where the wave equation is solved in the frequency-wavenumber domain. The resulting waveform is sampled and windowed exactly the same way as the measurements and processed identically to experimental data to obtain the two simulation peaks. Viscoelastic parameters are then estimated by minimizing the least-squares error between the two simulation peaks and the two experimental peaks, leading to the name twin-peak method (TPM). The TPM is first verified using in silico data and compared with existing methods to illustrate the effectiveness. The method is then validated with data from ex vivo porcine livers, where the measured viscoelasticity matches well with independent measurements using a Rheospectris instrument which performs hyper-frequency viscoelastic spectroscopy, followed by in vivo application in liver that indicates robustness against significant noise.

8 Quantitative Ultrasound Simulations

8.1 Backscatter coefficient estimation and modeling: Successes, challenges, and opportunities

Authors: Aiguo Han
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Abstract: The backscatter coefficient (BSC) is a fundamental quantitative ultrasound (QUS) parameter that describes tissues ability to backscatter ultrasound energy. This system- and operator-independent parameter contains rich information about the acoustic properties and microstructure of the underlying tissue. The BSC plays a significant role in both basic science research and clinical applications. In basic science research, the BSC is essential for elucidating the mechanisms by which biological tissues backscatter ultrasonic waves and for interpreting the backscattered ultrasonic echo signals. In clinical applications, the BSC and parameters derived from the BSC are useful for medical diagnosis. Although the BSC has shown successes in QUS research and clinical applications, several challenges exist, such as the complexity of the BSC estimation process, the difficulty in attenuation and transmission compensation, and the lack of theory/models that accurately explain the observed BSC in various tissue types. These challenges also represent opportunities for future research in BSC estimation and modeling. In particular, accurate and realistic acoustic simulation is promising for addressing these challenges. This talk will review the successes and challenges in BSC estimation and modeling and discuss opportunities in developing and applying acoustic simulation tools to address the challenges. [Supported by NIH R01CA226528 and R21EB032638]

8.2 An Open-Source GPU-Based Acoustic Simulator for Fast and Accurate Simulation of Acoustic Scattering

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Abstract: Background: Acoustic simulations play a vital role in biomedical ultrasound research. Despite the availability of various open-source simulation tools, the capability to perform fast, accurate, and realistic acoustic simulations using multiple graphics processing units (GPUs) remains an unmet need. To address this unmet
need, we have developed an open-source GPU-based acoustic simulator for fast and accurate acoustic scattering simulations. This study's objective is to introduce our simulator and assess its performance by comparing against the widely used k-Wave toolbox.

Methods: Our simulator leveraged Devito, a cutting-edge domain-specific language designed for high-performance finite-difference solutions of partial differential equations (PDEs). The simulator was designed for simulating acoustic scattering in both fluid and solid media. Scattering in heterogeneous media was simulated by solving a linear system of coupled first-order PDEs using a finite difference framework. Spatial discretization was performed using a staggered grid scheme. The perfectly matched layer (PML) was integrated into the simulator. The simulator's accuracy was validated by simulating scattering from fluid spheres and elastic discs, and comparing the simulated waveforms with theory in both the time and frequency domains.

Results: For simulating scattering from a 0.5-mm-diameter fluid sphere, our simulator required 35 seconds to run versus 60 seconds for k-Wave on the same GPU, with both achieving relative mean absolute differences below 1% from the analytical solution. In two-dimensional elastic simulations of a 2-mm-diameter disc scatterer at 25 m resolution, our simulator achieved a mean absolute error of 3.5%, better than k-Waves 4.5%, and completed the simulation in 1 minute using multiple GPUs, significantly faster than k-Wave's 5 hours on a CPU (GPU capability for elastic wave simulation was unavailable in k-Wave as of this writing). These results demonstrate the robustness of our simulator. [Supported by NIH R01CA226528 and R21EB032638]

### 8.3 Simulation of ultrasonic scattering from scatterer size distributions using Field II

**Authors:** Ivan Rosado-Mendez Jonathan Hale Timothy Hall  
**Affiliation:** Department of Medical Physics, University of Wisconsin - Madison  
**Abstract:** Quantitative analysis of radiofrequency (RF) echo signals obtained from ultrasound scanners can yield objective parameters which are gaining clinical relevance as imaging biomarkers. Two parameters of interest are the backscatter coefficient (BSC) and the effective scatterer diameter (ESD). Parameter estimation method development and initial technical performance evaluation are typically performed with data from tissue-mimicking phantoms, although with limited flexibility to systematically vary scattering properties. Computer simulations, such as those from the ultrasound simulator Field II, can allow more flexibility. However, Field II does not allow simulation of RF data from a distribution of scatterers with finite size. In this work, we present a simulation method which builds upon previous work by including Faran theory models representative of distributions of scatterer size. These are systematically applied to RF data simulated in Field II. The method is validated by measuring the lateral correlation width, the root-mean-square error (RMSE) of the estimated BSC, and the percent bias of the estimated ESD from simulated data and comparing to matched results from experimental phantoms. As expected, the lateral correlation width increased with increasing scatter size. The RMSE of the BSC ranged from 0.24-0.46 dB and 1.15-2.23 dB in the simulated and experimental data, respectively. The higher RMSE in the experimental data could be due to the added sources of noise and physical phenomena (nonlinear wave propagation, multiple scattering) that may be present in experiments but not modeled in the simulations. The percent bias of the ESD ranged from -13% to 10% in the simulations and -28% to 3% in the experimental phantoms. These results indicate the method accurately simulates backscatter from phantoms with distributions of scatterer sizes imaged with clinical scanners. Because Field II is widely used by the ultrasound community, this method can be adopted to aid in validation of quantitative ultrasound imaging biomarkers.

### 8.4 Using SimSonic as a Tool for Simulating Ultrasound Backscatter

**Authors:** Brett Austin McCandless, Marie M. Muller  
**Affiliation:** North Carolina State University  
**Abstract:** As the number of potential practical applications for ultrasound continues to increase through additional
research and innovation, it is useful and necessary to understand relevant tools that can be used to simulate ultrasound backscatter. Different simulation tools boast certain benefits. SimSonic is a finite-domain time-difference (FDTD) freeware that can simulate ultrasound in backscatter. SimSonic allows for user control of any simulation media and relevant properties of the media that would influence ultrasound propagation, including elastic constants, density, and absorption. Intimate control of the simulation media easily enables users to simulate desired phenomena or isolate certain effects. In backscattering, for instance, the diffusion constant, and corresponding extinction length due to scattering, in porous, cortical bone has been studied using SimSonic simulations via acquiring IRMs. SimSonic is an effective tool for simulating and studying certain ultrasound phenomena, but is limited by the computational time needed and lack of incorporation of frequency-independent absorption.

Wednesday, May 31

9 Vascular Imaging and Super-resolution

9.1 Super-Resolution Ultrasound Imaging for Assessing Vasa Vasorum in Rabbit Atherosclerotic Plaques

Authors: Zahra Hosseini, Qiyang Chen, Tara Richards, Megan Smith, Julie Phillippi, Alan Watson, Kang Kim
Affiliation: University of Pittsburgh

Abstract: Background The main cause of strokes and acute coronary syndromes is atherosclerotic plaque (AP) rupture. It has been reported that the dense neovascularature of adventitial vasa vasorum (VV) is key evidence of AP progression and vulnerability. Super-resolution ultrasound (SRU) provides an adequate spatial resolution for VV visualization in the in vivo assessment of microvasculature of different animal models. However, the very small size of VV near the major vessel and the arterial pulsation make SRU challenging. To mitigate these challenges, we employed a high-frequency SRU operating at 30 MHz and implemented a cardiac cycle alignment algorithm to accurately assess the VV.

Method The rabbit’s left femoral artery AP was induced utilizing a balloon catheter injury followed by an 8-week high-fat diet under an approved animal protocol. Afterward, the SRU was applied on treat and control rabbits after the bolus injection of 0.2 ml microbubbles (undiluted). This scan procedure was done at weeks 0, 4, and 8 and 12 post-surgery using high frame rate ultrasound plane wave imaging using a 30 MHz probe connected to a Verasonics Vantage256 system. The deconvolution and spatiotemporal-interframe-correlation (STIC)-base methods were applied to further overcome fast physiologic motion and identify the VV.

Results/Discussion The SRU scan using the 30 MHz probe together with the cardiac cycle alignment algorithm enabled the identification of the abnormally populated VV near the injured region of the rabbit femoral artery. The estimated VV density from the SRU image shows a significant increase in the treated rabbits. Histology results of the collected artery sample confirmed the plaque formation and VV increase in the injured region. Overall, high-frequency SRU imaging presents the capability to visualize, quantitatively measure, and monitor the VV development in the rabbit AP model.

9.2 Simulation of a Novel 2D Array Transducer Design for Transcranial Doppler Signal Acquisition

Authors: Farraday Johnson, Carl D. Herickhoff
Affiliation: University of Memphis

Abstract: Acquisition of transcranial doppler (TCD) ultrasound signals is challenging due to the need to both find an acceptable acoustic window through the skull and intersect the beam with the middle cerebral artery. In this work, we investigate the design of a novel 2D array transducer intended to interrogate skull thickness and allow
steerability of the ultrasound beam to facilitate TCD signal acquisition. Field II was used to model multiple 2D array geometries using triangular transducer elements inscribed within a 2 cm diameter circle (comparable in size to conventional TCD single-element transducers). Using a 1 MHz center-frequency pulse, beam patterns were simulated in the xz-plane, the yz-plane, and two constant-z planes (5 mm and at the depth of the beam maximum) for focal ranges from 1 to 6 cm and steering angles up to 10 degrees. For a twelve-element array, the beam pattern in the z = 5 mm plane mirrored the array geometry, and the maximum depth for the peak pressure was found to be 35.0 cm (with depth of field = 57.0 mm) with -3 dB lateral beam-widths 4.5 mm in azimuth and 4.6 mm in elevation. When steered 10 degrees off-axis, grating lobes were shown to be < -6 dB from the peak. These results suggest that a simplified 2D array transducer could be made to provide TCD users with feedback to aid optimal signal acquisition.

9.3 StaBle: Staggered PRF with douBle Transmission for High-Frame-Rate Vector Doppler Imaging

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Abstract: Vector Doppler imaging (VDI) is an emerging method that enables estimates of low velocity and visualization of flow patterns and removes the angle dependency of conventional Doppler imaging. With advances in high-frequency ultrasound (HFU, > 20 MHz) and high-frame-rate plane wave imaging, the implementation of VDI in small animal models is gaining traction. However, the increased frequency of HFU results in a low Nyquist velocity limit, causing aliasing problem in analyzing fast blood flow in the heart and aorta. In this study, we propose a transmission scheme that combines a staggered PRF with a double-angle transmission to increase the velocity aliasing limit of conventional VDI by multiple folds. We performed an in vitro experiment with a 31-MHz linear-array transducer (MS550D, Visualsonics Inc., Toronto, Canada) connected to a 256 Verasonics Vantage system, scanning a spinning disc (~1 cm diameter) tissue mimicking phantom. The transmission scheme consisted of transmitting three repeated plane waves angles (-7.5, 1 and 7.5) with the first and third angles transmitted at a PRF of 10 kHz and the second (center) angle transmitted at a PRF of 7.5 kHz. The results show that we can extend the VDI Nyquist velocity limit of the conventional Doppler transmission scheme (4.1 cm/s) by nine-fold (37 cm/s). The significantly extended velocity limit has the potential to mitigate the aliasing obstacle that occurs in cardiac imaging with HFU VDI, especially in visualizing the flow in the aorta, which has the fastest blood flow in circulation. NIH: HL159869

9.4 Addressing the challenges in the development of a calibrated microflow phantom: evaluation of the acoustic properties of blood-mimicking fluids and channel diameter

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Abstract: A major challenge in the development of microflow phantoms for ultrasound imaging is mimicking the acoustic properties of blood and tissues. While several blood-mimicking fluids (BMFs) have been used, their acoustic properties have not been fully evaluated or reported. Here, we present the characterization of two custom-made BMFs and propose a method for measuring channel diameter and its impact on flow velocity estimates. The density and dynamic viscosity of the BMFs were determined using calibrated hydrometers and viscometers. Speed of sound and attenuation were measured with the through transmission technique. The backscatter coefficient (BSC) was evaluated with the reference phantom method. Wall-less channels with nominal diameters of 120, 150, and 250 m were cast in an agar-based tissue-mimicking material and scanned with a micro-computed tomography
(micro-CT) system over two weeks. The point-spread function of the micro-CT system was measured with a spatial resolution phantom. Micro-CT images were deblurred using a Wiener deconvolution approach. Channel diameter was measured as the full width at half-maximum of profiles in original (blurred) and deblurred images. Flow velocity was estimated from flow rate measurements and channel area. Results showed that both BMFs exhibited speed of sound and attenuation in agreement with those reported for blood [1], although one showed lower viscosity and the other, higher BSC. The differences found in channel diameter from original and deblurred images were not statistically significant. However, velocity estimates obtained with the diameter measured in deblurred images were significantly closer to the expected values for nominal diameters. In conclusion, the characterization of the microflow phantom components presented in this work will enable a more reliable estimation of flow velocity and quantitative ultrasound estimates. Funding for this project was provided by the UW School of Medicine and Public Health from the Wisconsin Partnership and the Centennial Scholars programs. [1] doi:10.1088/1361-6560/abbd17.