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ABSTRACTS

1. Quantitative Ultrasound I

Quantitative Ultrasound Informed Simulation Guidance for Transcranial Ultrasound Therapy

Samuel Clinard; Randy Jensen; Douglas A. Christensen; Marie Muller; Taylor Webb*

Objective: Transcranial ultrasound therapies rely on numerical simulations to predict focal intensity through the skull. These simulations require spatial maps of acoustic properties derived from computed tomography (CT). However, our prior work demonstrates that skull attenuation is underdetermined by CT because clinical imaging cannot resolve sub-voxel microstructure or scattering losses. This project aims to incorporate Skull Quantitative Ultrasound (SQUS) as a subject-specific constraint on CT-derived attenuation models. We hypothesize that SQUS measurements will improve the accuracy of simulated focal-intensity estimates.

Methods: Preliminary SQUS data were acquired in two ex vivo human skull samples. Measurements consist of an Inter-element Response Matrix (IRM) obtained using a full synthetic-aperture transmit sequence, in which each array element is excited sequentially while backscattered signals are recorded on all elements. This acquisition enables the extraction of quantitative ultrasound parameters sensitive to scattering within the trabecular microstructure. We will initially evaluate the relationship between the backscatter coefficient and transmission loss to develop an SQUS-CT transformation for attenuation estimation.

Results: IRM acquisition was successfully demonstrated in both skull samples. Distinct front- and back-surface reflections are visible in the time traces, confirming full-thickness ultrasound propagation with sufficient signal-to-noise ratio for quantitative analysis. Between these reflections, diffuse scattering from trabecular microstructure is observed, indicating the presence of additional acoustic information that may inform attenuation modeling.

Future Work: Through-transmission measurements will be performed using a 650 kHz single-element focused transducer. Paired simulations using the Hybrid Angular Spectrum method will estimate focal intensity under existing CT-based attenuation models. Hydrophone-measured and simulated intensities will be compared to quantify baseline prediction error. SQUS-derived attenuation corrections will then be incorporated to evaluate improvements in focal-intensity accuracy.

Conclusion: Integrating SQUS with CT-based simulations establishes a subject-specific ultrasound guidance framework that addresses scattering-driven attenuation. This approach has the potential to improve focal-intensity prediction and treatment planning for transcranial ultrasound therapies.

Harmonic Tissue Characterization via Swept-Sine Technique: Leveraging Transducer Calibration Methods for Enhanced Quantitative Ultrasound

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Quantitative Ultrasound (QUS) aims to characterize tissue microstructure via frequency-dependent changes in the fundamental frequencies. Transfer functions in transducer design now utilize chirp signals, to estimate the higher harmonics over a broad-bandwidth. We propose a framework adapting this Swept-Sine Technique (SST) to evaluate both fundamental and harmonic backscattering behavior over a broad bandwidth.

The framework uses exponential chirp excitation to decouple the linear response from higher-order harmonics. Due to the monotonically increasing instantaneous frequency, convolution with an inverse filter maps each harmonic component to a unique time location. These kernels appear as temporally disjoint, compressed replicas of the impulse response. The temporal shift t(k) for the k-th harmonic ensures non-overlap, allowing direct windowing of each kernel h(k) without spectral separation. To demonstrate SNR gains, we evaluated varying signal lengths. To mitigate the "blind-zone" inherent in long-duration pulse-echo signals, we implemented a bistatic configuration using an RFSoC-based FPGA (Xilinx Zynq UltraScale+) with dedicated transmit/receive paths and separate transducers. This enables instantaneous signal acquisition without the dead-time typical for monostatic systems.

In ex vivo trials on bovine liver and muscle, the SST approach successfully quantified fundamentals and harmonics up to the third order (2–6 MHz). We observed a significant SNR improvement over conventional pulse excitation, correlating with signal length. The separation of harmonic components suggested distinct second- and third-order scattering properties, providing new dimensions for tissue differentiation inaccessible with standard methods.

Adapting SST for QUS enables high-sensitivity harmonic characterization, bridging transducer design and tissue analysis. By overcoming signal-duration limitations via a bistatic setup, this method offers a robust metric for nonlinear tissue analysis with increased SNR. Future work will focus on in vivo translation to prove its clinical stability.

Spatial Heterogeneity–Based Quantitative Ultrasound Biomarkers for Characterizing Testicular Spermatogenesis

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Background: Testicular spermatogenesis is inherently spatially heterogeneous, particularly in men with non-obstructive azoospermia (NOA), where focal islands of active seminiferous tubules are interspersed within globally impaired tissue. Conventional clinical predictors and grayscale ultrasound provide no spatially resolved assessment of this heterogeneity. Quantitative ultrasound (QUS), which models tissue microstructure from raw backscattered signals, may capture biologically meaningful variation in seminiferous tubule organization. We evaluated whether spatial heterogeneity of QUS parameters—rather than global tissue averages—reflects spermatogenic activity across complementary clinical cohorts.

Methods: High-frequency ultrasound data (30–46 MHz) were acquired using a VevoMD research system with access to raw in-phase and quadrature data. Quantitative parameters were derived from normalized envelope signals assuming a Nakagami scattering model. Three cohorts were analyzed: (1) an exploratory semen-analysis cohort evaluating associations between 92 QUS features and total motile sperm count (TMC); (2) a discovery cohort comparing fertile controls to men with NOA and globally negative microdissection testicular sperm extraction (mTESE); and (3) an independent validation cohort of men with NOA undergoing site-matched biopsy. Parametric maps of the Nakagami k-factor were generated using fixed-kernel local estimators. Spatial heterogeneity was quantified using the coefficient of variation within the superficial parenchymal zone (K_Zone1_Cv). Diagnostic performance was assessed using ROC analysis with bootstrap confidence intervals.

Results: In the semen-analysis cohort, K_Zone1_Cv showed the strongest association with TMC ($\rho \approx 0.50$, $q < 10^{-6}$), whereas global mean QUS parameters performed poorly. In the discovery cohort, K_Zone1_Cv distinguished fertile controls from NOA men with negative mTESE (AUC = 0.77). When this pre-specified feature was applied to the independent validation cohort, K_Zone1_Cv discriminated sperm-positive from sperm-negative biopsy sites (AUC = 0.83, sensitivity 81%, specificity 71%). Higher spatial heterogeneity consistently corresponded to preserved spermatogenesis.

Conclusions: Spatial heterogeneity of QUS scatterer statistics captures biologically meaningful differences in testicular microstructure obscured by global averaging. These findings support a heterogeneity-driven

framework for QUS assessment of spermatogenesis and motivate development of spatially resolved biomarkers for image-guided sperm retrieval in NOA.

Robust Data-Driven Parameter Estimation for Quantitative Acoustic Microscopy

Jinuan Lin; Jonathan Mamou*

Quantitative acoustic microscopy (QAM) is an advanced imaging technique that uses very high-frequency ultrasound to quantitatively characterize biological tissues at microscopic resolutions. Two-dimensional parameter maps are reconstructed by extracting acoustic and mechanical properties from radio frequency (RF) signals. Existing model-based parameter estimation methods, such as autoregressive and weighted Hankel approaches, degrade under challenging conditions (e.g., low SNR, thin tissue thickness, or small impedance contrast), yielding an increasing number of outliers and consequently reduced image quality and interpretability.

In this study, we propose a novel data-driven QAM parameter prediction framework that enhances robustness under challenging conditions and improves the interpretability of QAM images. We design a deep neural network consisting of a convolutional neural network (CNN) and a multilayer perceptron (MLP). We first conduct a simulation study in which the CNN is trained on simulated signals with known ground-truth parameters. Compared with model-based approaches, our method achieves consistently low prediction errors while substantially reducing outliers, even in challenging scenarios.

To enable applicability to experimentally measured QAM signals, we incorporate domain-adversarial training to extract shared feature representations between simulated and experimental data. In addition, a shallow MLP is appended to align network predictions with model-based priors using a small dataset of paired experimental signals and corresponding model-based estimates. This design allows the network to leverage labeled simulation data while adapting effectively to real experimental conditions.

We validate the proposed approach using experimental QAM data from thin sections of human lymph node and guinea pig eye tissue specimens. Our method produces significantly fewer (<1%) outliers compared with model-based approaches, which greatly improve the robustness and interpretability of the parameter maps. In addition, the network's inference takes moderate time. Our method's advantages make it a practical and effective approach for real-world biomedical QAM applications.

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2. Imaging I

Fourier-Domain Approach for Ultrasound Beam Design

Fan Feng; Stephen McAleavey*

Beamforming profoundly impacts diagnostic ultrasound performance. Conventionally, constructing a beam follows a forward principle: (1) define the amplitude (or apodization), and (2) define the phase delay for each transducer element. Focused beams are widely employed to concentrate acoustic intensity within the depth-of-focus (DoF) to improve image quality. However, a focused beam has an inflexible relationship between DoF, beamwidth and f-number.

To address this limitation, we consider a Fourier-domain beam design method for a linear array that provides a beam with the desired DoF, an arbitrary axial beam profile, and an adjustable beamwidth. The method enables beam construction with an inverse workflow: (1) define an arbitrary target beam, specifying its focal point, DoF and axial beam profile, (2) calculate the required transmit wave field at the probe surface in the Fourier domain using the angular spectrum approach, and (3) extract the corresponding apodization (i.e the magnitude of the transmit wave field) and phase delays to drive the transducer elements.. Simulation and hydrophone measurements are presented validating the proposed method.

In addition to axial beam profile design, we investigated sidelobe suppression, which effectively reduced sidelobe pressure by 5 dB. Furthermore, we proposed Fourier-domain attenuation compensation to enhance the beam's penetration. In B-mode, the compensated beam extended the -6 dB DoF by 10 mm compared to the non-compensated beam. For elastography, a compensated Acoustic Radiation Force (ARF) beam focused at 20 mm (with a 25 mm DoF) induced approximately 125% stronger displacement at a depth of 40 mm. Finally, inspired by previous work [1], we designed an ARF beam with a uniform axial beam profile and used it for quantifying the attenuation coefficient in an inhomogeneous phantom.

References

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Explainable Deep Learning of Longitudinal Breast Ultrasound for the Early Prediction of Late Radiotherapy Toxicity

*Jing Wang; Yuli Wang; Xiaofeng Yang; Yang Lei; Mylin Torres; Tian Liu**

Purpose Breast toxicity following radiotherapy (RT), including edema and fibrosis, often persists long after treatment and remains difficult to predict prior to symptom onset. Because ultrasound is highly sensitive to radiation-induced changes in tissue composition and acoustic interfaces, it offers a potential window for early detection of injury. This study investigates whether breast ultrasound (BUS) acquired pre-RT and at the completion of treatment can serve as an early, physics-based imaging biomarker for predicting late toxicity at 3 and 12 months post-RT using an explainable deep learning framework.

Methods Patients received hypofractionated whole-breast RT (40 Gy in 15 fractions) with a simultaneous integrated boost (8.1 Gy). Bilateral BUS scans were acquired at four standardized locations (12, 3, 6, and 9 o'clock) at four timepoints: pre-RT, final day of the 3-week RT course, and at 3 and 12 months post-RT. Paired pre-RT and end-of-RT images were jointly used as model inputs to predict binary toxicity outcomes at 3 and 12 months. A convolutional neural network–based classifier was trained, with class activation mapping (CAM) employed to identify the spatially relevant ultrasound regions and tissue interfaces contributing to model predictions.

Results Sixty-two patients (248 per-location samples) were included. At 3 months post-RT, prediction of any toxicity achieved an accuracy of 0.90 (AUC: 0.93), while moderate toxicity achieved 0.80 accuracy (AUC: 0.83). At 12 months post-RT, accuracy/AUC were 0.84/0.82 for any toxicity. CAM analysis consistently highlighted superficial skin and subcutaneous regions, reflecting ultrasound-sensitive manifestations of radiation-induced edema and subsequent tissue remodeling.

Conclusions Breast ultrasound acquired during the early course of treatment, combined with explainable deep learning, enables accurate prediction of late breast toxicity months to years after treatment. By linking predictive performance to spatially interpretable ultrasound features, this approach supports the development of BUS-based imaging biomarkers for objective toxicity risk stratification and physics-informed adaptive patient management.

An experimental platform for characterizing thermoelastic expansion of tissue under pulsed microwave

*Carissa Roper; Susan Hagness; Chu Ma**

The thermal expansion coefficient characterizes how a material's dimensions change in response to temperature variations, and accurate knowledge of this parameter is essential for predicting thermomechanical behavior under different heating conditions. For biological tissues, understanding thermal expansion during electromagnetic energy absorption is particularly important for assessing potential tissue injury risks associated with microwave exposures, as well as for advancing thermoacoustic monitoring techniques used in pulsed microwave ablation. However, the temperature dependent thermal expansion coefficient of soft tissues, especially under fast, pulsed heating, remains poorly documented. Rapid energy deposition from pulsed electromagnetic waves produces complex, transient thermal and mechanical responses that conventional slow-heating approaches (e.g., water-bath heating) cannot capture. To address these gaps, we investigate tissue thermoelastic behavior across both slow and fast heating timescales through combined experimental characterization and modeling.

In this talk, I will present a new experimental platform designed to quantify the thermoelastic expansion coefficient of tissue samples under pulsed microwave exposure. The system integrates a high framerate optical imaging module with a microwave delivery setup consisting of a transverse electromagnetic (TEM) waveguide and a pulsed microwave source. This configuration enables simultaneous high power (30 kW peak power), short duration (<1 μs) microwave irradiation and ultra high speed optical imaging at rates up to 10 million frames per second with micrometer-scale spatial resolution. The unique combination of ultra fast imaging and controlled pulsed microwave deposition allows the observation of tissue's thermoelastic dynamics under ultra-fast pulsed microwave heating, providing new insights into tissue expansion behavior that could benefit a wide range of diagnostic and therapeutic applications.

Estimating time-dependent stress fields from sparse ultrasound measurements and physics-guided machine-learning techniques

Will Newman; Michael F. Insana*

Background & Objective: Ultrasound is widely used to map material stiffness patterns within soft tissues by applying quasi-static compression and measuring the local strain developing between pre- and post-compression frames. Strain estimates are the primary indicator of material properties as the internal field stress cannot be directly measured. To estimate time-dependent constitutive properties, creep experiments are performed while assuming a constant spatial and temporal stress field. This assumption is almost always false in practice, and consequently strain images reveal material contrast but are not quantitative estimates of material properties. The objective of this research is to image the internal stress field that is applied to image quantitative spatial- and time-varying material properties.

Methods: We are adapting the Autoprogressive method to learn the internal spatiotemporal stress field. The method propagates force-displacement estimates measured in planes into stress and strain training data throughout a volume by imposing physical constraints through finite-element analyses. A neural network constitutive model extracts constitutive behavior from the stress-strain training data. Time-dependent material properties (e.g., viscosity) are estimated from the network weights after training.

Results: We provide images of the time-varying strain, stress and material properties from simulated and experimental phantom studies. Measurements of image contrast and spatial resolution are presented to assess the quality of the resulting shear modulus and viscosity images.

Conclusions: Embedding the physics of deformation into a machine learning process constrains the solution space to include only those that are physically realizable and consistent with the measurement data, thus allowing quantitative properties to emerge. This research serves as a building block for model-free, quantitative material property estimation using basic ultrasonic measurement techniques.

TV-Regularized Frequency-Domain Full-Waveform Inversion for Single-Sided Linear Ultrasound Array Data

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Quantitative speed-of-sound (SoS) imaging provides valuable information about tissue composition and pathology [1], [2]. Yet the conventional B-mode ultrasound is largely limited to qualitative visualization. In recent years, the concept of Full-waveform inversion (FWI) has emerged as a powerful approach for reconstructing quantitative SoS maps [3], [4]. However, many existing FWI methods for ultrasonography are developed for double-sided or ring-shaped transducer arrays, which restricts their applicability to routine clinical systems that primarily rely on single-sided linear probes. We present a frequency-domain FWI framework designed for single-sided linear ultrasound arrays that incorporates total variation (TV) regularization. Although this setup presents significant computational challenges, and increased illposedness of the inversion problem, we get around these restrictions by integrating multi-GPU parallelization, ADMM-based optimization, adjoint-state gradient computation, and effective frequency-domain forward

modeling into a single reconstruction framework. Based on numerical experiments conducted in clinically motivated scenarios, including liver-inspired tissue models, the proposed framework effectively reconstructs quantitative SoS maps from conventional linear-array acquisitions. When compared to traditional FWI without TV regularization, both the fluid-filled and solid inclusions are resolved with better contrast and structural fidelity. Additional 2D and 3D simulations across different array apertures and target configurations further clarify the performance characteristics and practical limitations of single-sided ultrasound FWI.

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Ultrasonic Decellularization and Imaging of Plant-Based Scaffolds for Subsequent Use as Vascular Grafts

Sleiman Ghorayeb; Ceren Karahan; Gabriella Lucas; Daniel Rivas; Nicholas Merna*

Plant-based scaffolds provide a sustainable and biocompatible platform for regenerative medicine. The objective of this study was to evaluate ultrasonic cavitation as a noninvasive decellularization method for Rumohra adiantiformis (leatherleaf) scaffolds. Two approaches were compared: a hybrid ultrasound–chemical protocol and a fully chemical-free ultrasound-only protocol. A secondary aim as to establish echogenicity analysis as a novel, non-destructive metric for assessing decellularization efficiency.

Leatherleaf samples were standardized and exposed to low-frequency ultrasound using a Qsonica Q500 system. The hybrid method alternated between 2% SDS exposure and sonication over 12 hours, while the ultrasound-only method applied identical acoustic conditions in deionized water. DNA content (ng DNA/mg tissue) was measured using the Omega BIO-TEK Mag-Bind Plant DNA DS Kit. Ultrasound C-scan imaging provided grayscale images that were processed in MATLAB using the Floyd–Steinberg dithering algorithm to calculate percent echogenicity. Mechanical properties were assessed via tensile testing.

The hybrid ultrasound–chemical decellularization protocol achieved a 94.7% reduction in DNA content, decreasing from 270 ng/mg to 14 ng/mg within 12 hours. This result meets established decellularization criteria (< 50 ng/mg) while preserving the scaffold's structural integrity and trichome features. The Young's Modulus decreased by 20%, indicating only a minor reduction in mechanical strength. Echogenicity measurements also demonstrated a substantial decrease, dropping from 67.1% to 3.7% (−94.4%), which closely correlated with the extent of DNA removal. In comparison, the ultrasound-only treatment achieved approximately 55% DNA reduction and a corresponding ~20% decline in echogenicity, indicating partial but consistent decellularization. Together, these findings validate echogenicity as a quantitative, noninvasive marker for scaffold purification and highlight ultrasound's potential as both a processing and imaging tool.

Ultrasonic cavitation significantly accelerates plant scaffold decellularization while maintaining structural fidelity. Hybrid ultrasound–chemical processing is efficient and timesaving, and ultrasoundonly decellularization shows potential as a chemical-free alternative pending optimization. Echogenicity provides a reliable, noninvasive biomarker for monitoring scaffold purification in real time. These findings highlight ultrasound's dual role as both a physical processing and analytical tool in the production of sustainable biomaterials

3. Elasticity

Estimating Arterial Nonlinearity and Anisotropy using Shear Wave Elastography

Shuvrodeb Adhikary*; *Charles Capron; Matthew W. Urban; Murthy N. Guddati*

Arterial stiffness is an established biomarker for cardiovascular health. Conventional shear wave elastography (SWE) techniques rely on linear isotropic material assumptions; however, arterial walls are inherently nonlinear and anisotropic, with the degree of nonlinearity evolving with aging and disease. The goal of this work is to develop an SWE-based framework capable of simultaneously estimating both arterial nonlinearity and anisotropy.

As the artery undergoes large deformations throughout the cardiac cycle, we hypothesize that variations in wave propagation characteristics across cardiac stages, such as phase velocity measured along the longitudinal direction, are sensitive to the overall mechanical response of the arterial wall, thereby capturing both anisotropy and nonlinearity. Additionally, since in-plane measurements do not resolve directional dependence, we utilize circumferential wave propagation characteristics to estimate anisotropic contributions. To account for both nonlinearity and anisotropy in our simulation, we introduced a simplified Holzapfel-Gasser-Ogden (HGO) hyperelastic model incorporating the relevant nonlinear and anisotropic parameters. Experimentally measured phase velocities across different cardiac stages are matched with forward simulations to characterize nonlinearity, while circumferential wave propagation is used to estimate anisotropy. The simulated response is obtained using the semi-analytical finite element (SAFE) method, with the effective modulus characterized by linearizing the hyperelastic model around the deformed configuration resulting from distension and residual stresses. The parameters of the reduced HGO model are identified by longitudinal and circumferential wave propagation across different cardiac stages. These results demonstrate the feasibility of the proposed SWE-based framework for characterizing arterial nonlinearity and anisotropy, providing a foundation for future in vivo experimental studies.

Longitudinal Evaluation of Muscle Stiffness in Healthy Volunteers and Preliminary Comparison to Neuromuscular Disease Patients Using 3D-Rotational Shear Wave Elasticity Imaging

Shruthi Srinivasan; Wren E. Wightman; Kaden D. Bock; David P. Bradway; Ned C. Rouze; Mark L. Palmeri; Lisa D. Hobson-Webb; Kathryn R. Nightingale*

Background: Previous work has shown the promise of 3D-rotational shear wave elasticity imaging (3D-RSWEI) to noninvasively characterize the anisotropic and nonlinear elastic properties of skeletal muscle [1]. Herein we quantify longitudinal consistency of SWEI-based metrics in healthy vastus lateralis. We also compare these metrics between healthy muscle and data collected in neuromuscular disease patient muscle.

Methods: 3D-RSWEI uses a linear-array transducer rotating about its central axis (the SWEI push axis) while collecting 2D planar SWEI data in 5-degree rotational increments. From acquired SWEI data, shear wave speed (SWS) along and across the fibers and fractional anisotropy are quantified. In an ongoing, IRB-approved study [2], in vivo data have been collected in ten healthy volunteers over three months and to date, one patient with Charcot-Marie-Tooth disease (CMT) with mild quadriceps weakness and one with fascioscapulohumeral muscular dystrophy (FSHD) with severe quadriceps weakness. Participants laid supine during 3D-RSWEI measurements in the vastus lateralis under varying degrees of knee flexion (~15-110° in volunteers, ~15-90° in patients). A nonlinear elasticity parameter ($\beta_{/\!/}$) was quantified by estimating an exponential growth constant between SWS along-the-fibers and knee flexion angle.

Results: In healthy volunteers, SWS along and across the fibers were consistent to 6% and fractional anisotropy to 7% coefficient of variation. Consistency of the $\beta_{/\!/}$ was within 8.3% coefficient of variation. Average $\beta_{/\!/}$ values were 0.010 ± 0.001 1/deg, and fractional anisotropy values were between 0.30-0.61 across knee flexion angles measured in volunteers. Measured $\beta_{/\!/}$ (0.012 1/deg) and fractional anisotropy (0.38-0.62) in one CMT patient were within the range of healthy muscle measurements. Data from one FSHD patient show higher $\beta_{/\!/}$

(0.021 1/deg) and lower fractional anisotropy (0.06-0.59) values than healthy volunteers. This preliminary comparison demonstrates feasibility of 3D-RSWEI to investigate clinical biomarkers for diagnosing severity of muscular dystrophies.

References

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Towards In-Vivo human brain shear wave imaging through sonolucent covers

Kaden Bock; Matthew Lowerison; David Bradway; Alexa Bramall; Pengfei Song*

Background: Intracranial Pressure Monitoring (ICP) is an established metric used for neurocritical care. Current clinical standards for ICP include either invasive pressure sensors placed in the epidural, parenchymal, or ventricular spaces of the brain, or less reliable, indirect methods such as transcranial doppler and optical nerve sheath diameter.

Recently, neurosurgeons have begun replacing sections of the skull removed during surgery with sonolucent covers to allow longitudinal monitoring of tissue health via ultrasound imaging. Current imaging use cases are largely qualitative. In this work, we present preliminary results of shear wave elasticity imaging (SWEI) through sonolucent covers, with the goal of using stiffness measurements to determine ICP and tissue strain state in a non-invasive manner.

Methods: First, we characterize the acoustic properties of the cover, using the through-transmission technique outlined by the AIUM standards. Next, using a Verasonics Vantage research scanner and GEM5ScD phased array, we demonstrate that we can generate and track shear waves through the cover, using an 800 μsec push at 2 MHz, and focused at 50 mm axially (F/2.25). Finally, we present preliminary in-vivo clinical imaging case studies from an IRB-approved clinical study, demonstrating early results and the challenges associated with imaging transcranial shear-waves through a sonolucent cover.

Results: The speed of sound of the cover slip was found to be 2300 m/s. Shear wave speeds (SWS) in calibrated reference phantoms were found to be within 9.4 +/- 2.5 % correspondence with and without the cover, with SWS speeds through the cover consistently appearing slower than without it. In a patient with an imageable shear waves, the SWS was found to be 2.03 +/- 0.34 m/s.

Using Ultrasound Shear Elastography with Expanded Bandwidth (USEWEB) to Evaluate Lymph Nodes in a Porcine Model of Lymphadenopathy

Matthew Urban; Piotr Kijanka; Benjamin Wood; Mackenzie Keown; Thomas Meier; Jeffrey Johnson; Gina Hesley; Christine Lee*

Background: Involvement of cancer in axillary lymph nodes (LNs) plays a critical role in cancer staging and treatment. Clinical determination of LN status after NST often involves ultrasound, the imaging modality of choice for the axilla, but the discriminatory capacity of ultrasound in detecting subtle treatment-induced changes in LN status limits early assessment of response to NST which could alter the subsequent chemotherapeutic regimen. Shear wave elastography (SWE) can provide quantitative mechanical property information, and it has been shown that malignant axillary LNs are typically stiffer than benign or normal LNs. While this approach is considered robust, imaging of small LNs is prone to bias in the measured wave velocity where the amount of bias is influenced by the size of the inclusion and mechanical properties of the LN and the surrounding tissue. In this study we used the Ultrasound Shear Elastography with Expanded Bandwidth (USEWEB) method to reconstruct the shear wave phase velocity, or wave velocity at specific frequencies.

Methods: To demonstrate the effects of size and mechanical properties on the reconstructed group and phase velocities, we performed simulations with varying inclusion sizes (10, 20 mm diameters) and Young's moduli values based on literature reports for suspicious axillary lymph nodes (Background: Eb = 7, 15 kPa; Inclusion: Ei = 10, 20, 30, 40 kPa). We conducted a study using a porcine model of induced reactive lymphadenopathy where lymph node size and mechanical properties changed over 4-6 months.

Results: With increasing frequency, the shear wavelength decreases and leads to reduced bias in wave velocity estimates. We evaluated the USEWEB method with longitudinal measurements of LNs as the LNs increased in size and subsequently normalized. Using phase velocity may provide more accurate assessment of mechanical properties within inclusions with small dimensions compared to the wavelength of the shear wave.

Deep-DoPIo Outperforms Conventional DoPIo for Detection of Renal Inflammation and Fibrosis in an In Vivo Porcine Ischemia-Reperfusion Injury Model

Sabiq Muhtadi; Keita A. Yokoyama; Timothy C. Nichols; Elizabeth P. Merricks; Rani S. Sellers; Gabriella de la Cruz; Caterina M. Gallippi*

Double Profile Intersection (DoPIo) is an on axis acoustic radiation force (ARF)-based elasticity imaging technique that applies a single ARF excitation and uses simultaneous narrow- and wide-aperture tracking beams to generate two displacement profiles whose intersection time is related to shear modulus. However, in stiffer tissue, DoPIo performance degrades due to increasing error in intersection time estimation. To overcome this limitation, Deep-DoPIo applies transformer based deep learning models to the full displacement profiles to predict modulus, eliminating reliance on accurate intersection time detection. We hypothesized that Deep-DoPIo would outperform DoPIo in detecting renal inflammation and fibrosis in an in vivo porcine ischemia–reperfusion injury (IRI) model. In an IACUC approved study of 18 pigs, 15 pigs underwent IRI and three served as uninjured controls. Injured animals were assigned to one of three cohorts: acute (imaged 3 days post IRI), chronic (imaged 90 days post IRI), or combined injury (repeat IRI at day 90, imaged 3 days later). Under general anesthesia, kidneys were imaged, and shear modulus was quantified using DoPIo and Deep-DoPIo within regions of interest spanning the outer and inner cortex and medulla. Modulus estimates from both methods were then used to train binary classifiers to detect injury presence (any IRI) and to distinguish injury subtype (acute, chronic, combined), with inflammation in acute injury, fibrosis in chronic injury, and both in combined injury confirmed by histology. DoPIo based classifiers achieved AUCs of 0.83, 0.68, 0.59, and 0.85 for detecting any injury, acute injury, chronic injury, and combined injury, respectively. Deep-DoPIo demonstrated significantly better performance, yielding AUCs of 0.93, 0.78, 0.74, and 0.98 for the same tasks. These improvements indicate that Deep-DoPIo provides substantially enhanced detection of renal inflammation and fibrosis—pathological features central to antibody mediated rejection (AMR). Overall, the findings support Deep-DoPIo's potential as a noninvasive tool for early identification of AMR relevant renal injury.

Combining ARFI Variance of Acceleration and Nakagami Parameters for Improved Automatic Segmentation of In Vivo Carotid Plaque

Shureed Qazi; Keerthi Anand; Jonathon W. Homeister; Mark A. Farber; Caterina M. Gallippi*

Background: Carotid plaque-associated stroke risk is often judged by stenosis; however, rupture risk is better reflected by plaque structure and composition. Clinical risk stratification would benefit from non-invasive, automated plaque feature segmentation. Acoustic Radiation Force Impulse (ARFI) imaging characterizes plaque via Peak Displacement (PD) and Variance of Acceleration (log(VoA)). Independently, Nakagami Quantitative Ultrasound (QUS) imaging assesses radiofrequency (RF) statistics linked to scatterer density, heterogeneity, and energy through the m (shape) and Ω (scale) parameters. We propose that combining ARFI and Nakagami-based metrics within a supervised learning framework enhances the automatic segmentation of carotid plaque components compared to ARFI alone.

Methods: In an IRB-approved study including 17 patients undergoing clinically-indicated carotid endarterectomy, ARFI-imaging was performed using a Siemens Acuson S3000 and 9L4 transducer. The acquired data were processed to extract cross-correlation coefficient (CC), PD, log(VoA), and signal-to-noise ratio (SNR) of the RF data. Frequency-compounded Nakagami imaging was performed to generate parametric maps of m and Ω. All permutations of these six parameters served as features in support vector machine (SVM) models trained to classify pixels as calcium (CAL), collagen (COL), lipid rich necrotic core (LRNC), or intraplaque hemorrhage (IPH) using spatially aligned histology. Classifier performance was assessed using receiver operating characteristic (ROC) analysis.

Results: Top-performing models achieved strong Sensitivity for CAL (>0.95), COL (>0.85), and IPH (>0.75), with lower Sensitivity for LRNC (>0.55). Notably, incorporating Ω improved discrimination, particularly for IPH (AUC = 0.75 vs. 0.50 without Ω). Specificity was high for all components (>0.90). These findings show that integrating ARFI and Nakagami parameters enhances automatic in vivo segmentation of carotid plaque components.

Deep Learning for Viscoelastic Property Estimation from Shear Wave Elastography

Ryan Pitsinger; Murthy Guddati*

Several methods exist for point estimation of viscoelastic properties from shear wave elastography (SWE) data, including attenuation matching, the two-point frequency shift method, and the recently proposed twin peak method, which estimates shear modulus (G) and relaxation time (τ) by matching peaks in the frequency-wavenumber domain. While these approaches have shown promise, they can be sensitive to noise, require careful selection of processing parameters, and rely on explicit wave-propagation models. In this work, we explore deep learning as an alternative approach to direct point estimation of viscoelastic properties from shear-wave displacement data. We train and evaluate multiple neural network architectures, including convolutional neural networks, Fourier Neural Operators, Vision Transformers, wavelet-based feature extractors, and template-matching methods, on noisy simulated shear-wave signals generated using a Voigt viscoelastic model. Preliminary results on simulated test data demonstrate that several architectures achieve high predictive accuracy for both G and τ, with performance competitive with or exceeding existing point estimation methods, particularly in the presence of noise. Validation on ex vivo pig liver samples shows predictions consistent with published literature ranges for hepatic tissue. We compare these data-driven predictions with existing point estimation techniques, examining the strengths of each approach in terms of accuracy, noise robustness, and computational cost. Building on the intuition gained from point estimation, we also present preliminary results extending these deep learning methods to full viscoelasticity imaging, where trained networks are adapted to reconstruct spatially resolved property maps from shear-wave data. The ultimate goal is to develop deep learning-based inversion methods that can approach the accuracy of full-waveform inversion at a fraction of the computational cost.

4. Quantitative Ultrasound II

Nakagami-Based Quantitative Ultrasound for Ultrasonic Characterization of Intracranial Pressure–Induced Brain Tissue Changes

Ladan Yazdani; Yibu Wu; Sophie Haddad; Aref Ghaderi; Katherine Luo; Todd J kilbaugh; Joseph Katz; Misun Hwang*

Noninvasive monitoring of intracranial pressure (ICP) remains a major unmet need in neurocritical care. This work investigates Nakagami-based quantitative ultrasound as an ultrasonic tissue characterization approach for detecting ICP-induced changes in brain microstructure. Ultrasound radiofrequency data were acquired from three porcine models under baseline conditions and following controlled ICP elevation (20, 30, and 40 mmHg) using invasive pressure monitoring as reference.

Backscattered echo envelopes were analyzed with a sliding-window Nakagami statistical model to estimate the shape (m) and scale (Ω) parameters, which quantify scattering statistics and effective scatterer concentration. Parametric maps were generated and spatially averaged within defined regions of interest to obtain quantitative biomarkers of tissue state.

Both parameters decreased systematically with increasing ICP. Spearman analysis demonstrated strong negative correlations between ICP and m ($\rho = -0.83$, $p < 0.01$) and Ω ($\rho = -0.93$, $p < 0.01$). Groupwise comparisons showed clear separation between baseline and elevated pressure conditions.

These results demonstrate that Nakagami-based backscatter statistics are sensitive to ICP-related tissue alterations and provide a purely ultrasound-based, noninvasive framework for pressure monitoring. The proposed approach highlights the potential of quantitative ultrasound and statistical signal processing for brain tissue characterization and real-time neuromonitoring.

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Experimental Characterization of Random Media for Lung Quantitative Ultrasound using Incoherent Backscattering

Shahriar Chowdhury; Sashank Gautam; Marie Muller*

An experimental approach to quantitative lung ultrasound is undertaken in the study by making use of the backscattering phenomenon of ultrasound wave propagation. The backscattered intensity is analyzed to identify the incoherent contribution, and the growth of the intensity halo of this incoherent backscattering intensity (IBS) is utilized to estimate diffusion coefficients [1]. The experimental procedures were carried out by obtaining the backscattered radio frequency data through a full synthetic aperture (FSA) acquisition (transmitting from each element and capturing the backscattered signal with all elements simultaneously for each successive emission).

Different phantoms were fabricated to emulate the scattering media mimicking lung tissue and several probes in conjunction with a Verasonics® Vantage NXT UTA were used for data acquisition. First, a ‘bubble tower’ was made with porcine gelatin and by making use of the buoyancy of bubbles introduced into the gelatin by means of high-speed stirring action. The corresponding trend in the diffusion constant along the height of the tower i.e. the direction in which the bubble density increases was evaluated. These values were then correlated to micro-CT images of the tower at different depths for comparison.

In a separate chain of experiments, Orgasol® particles were suspended in agar and cured to form uniform scattering media. The effects of particle size, particle concentration and the frequency of insonification were investigated for comparison.

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Fourier Neural Operator for Simulating Pressure Fields and Predicting Scattering

Hossein Ahmadian; Muller, Marie*

In a multiple-scattering medium, the measured wavefield contains rich information about the underlying structure and transport regime. In random media, pressure fields, as well as envelope- or intensity-based signals reveal how scattered energy evolves as the field transitions toward a diffuse state. Generating these signals through numerical simulations such as full-wave or pseudo spectral methods can be computationally prohibitive, particularly when one is interested in varying multiple input parameters. Experimental acquisition of such signals also presents significant practical challenges. The Fourier Neural Operator (FNO), a data-driven operator-learning framework, offers a compelling alternative. FNO excels at learning mappings from functional inputs (such as spatial distributions of speed of sound and density) to functional outputs (such as intensity signals) enabling a broad characterization of wave physics within the trained parameter space.

In this study, FNO was applied to rapidly predict intensity signals in a weakly scattering medium, where the speed of sound and density of scatterers was constrained to no more than 1.5 times the background values and the number density of scatterers did not exceed 4 mm^{-2}. A dataset of 2,000 k-Wave simulations with varying scatterer speed of sound, density, and number density was generated for training. The model takes spatial maps of speed of sound and density as inputs and predicts the resulting intensity field. Key hyperparameters including the number of Fourier modes and channel width were systematically tuned to maximize accuracy within practical computation times. The trained FNO achieved over 90% accuracy relative to held-out k-Wave test data, while providing intensity field predictions nearly instantaneously.

Microstructural Phenotyping of Nail Disease Using High-Frequency Quantitative Ultrasound

*Nuran Golbasi; Cameron Hoerig; Shari Lipner; Jonathan Mamou**

Background: Accurate diagnosis of nail disease is challenging due to overlapping clinical features, reliance on invasive biopsy, and limited access to nail specialists. Quantitative ultrasound (QUS) enables non-invasive assessment of tissues microstructure. However, its clinical applicability and ability to distinguish nail conditions is not well-characterized.

Methods: In this ongoing prospective study, patients with onychomycosis, inflammatory nail disease (psoriasis or lichen planus), and healthy controls underwent 15-MHz ultrasound imaging of fingernails and toenails (26 patients, 152 nails). Radio-frequency echo data from the nail bed region were analyzed to compute three QUS parameters based on envelope statistics and the backscatter coefficient: Homodyned-K parameter (α), reflecting scatterer number density; effective scatterer diameter (ESD), which relates to acoustic scatterer size; and effective acoustic concentration (EAC), corresponding to scatterer number density and relative acoustic impedance. Differences between affected diseased nails vs control nails were evaluated using t-tests and effect size was quantified with Cohen's d. Consistency was assessed across nail sites.

Results: In the fingernail cohort (33 affected vs 54 control nails), affected nails demonstrated significantly reduced α ($d=-1.11$, $p<0.001$). Onychomycosis showed the largest reduction ($d=-1.25$), while inflammatory nail disease showed intermediate changes ($d=-0.93$). ESD was increased in affected nails ($d=+0.85$, $p=0.02$). EAC was selectively elevated in lichen planus ($d=+1.30$, $p<0.01$). In the toenail cohort (16 affected vs 49 control nails), onychomycosis demonstrated similar reductions in α ($d=-0.9$, $p<0.001$) and increases in ESD ($d=+1.0$, $p=0.02$), confirming consistency to detect disease-related changes in the nail bed of both fingernails and toenails.

Conclusions: QUS is sensitive to microstructural alterations in nail diseases and may differentiate fungal from inflammatory nail pathology. These quantitative acoustic markers provide non-invasive characterization of nail tissue and support QUS as a diagnostic adjunct. This advances the application of ultrasonic tissue characterization in dermatology and establishes a foundation for microstructural phenotyping of nail disease.

5. Quantitative Ultrasound III

Dynamics Of Red Blood Cell Aggregation Under Arterial And Venous Flow Conditions: Simulation And Characterization Using Quantitative Ultrasound Parameters

Nasrin Akter; Deeba Farah*

Quantitative Ultrasound (QUS) can extract extract sub-resolution tissue properties [1] and is used to characterize red blood cells (RBCs), namely the hematocrit and reversible aggregation patterns. Pathological blood typically displays abnormally high RBC aggregation [2]. As a function of shear rate, increased aggregation results in an increase in frequency-dependent US backscattered power [3]. The goal of this study was to identify measurable QUS indices that reflect shear-dependent aggregation dynamics using both reference-phantom (RP) and phantom-free (PF) methods [4], [5]. Two parallel blood vessels [6], artery (0.8×0.25 cm) and vein (0.8x0.15 cm) with 500 μm separation were simulated with uniform RBC distribution. They were imaged in Field-II using plane US waves at 10 MHz center frequency and 10 raw RF data frames were acquired every 1 ms for 6 ms duration. The top artery was modeled having spatially varying shear rate [7]. Constant shear rates were considered for the vein mimicking vessel. In addition to shear flow, adhesive and repulsive forces between neighboring RBCs resulted in total vector displacement [3]. The Structure Factor Size and Attenuation Estimator (SFSAE) model [8] was used to extract RBC aggregation indices namely, attenuation coefficient (α_0), packing factor (W) and mean aggregate diameter (D). The formation and dispersion of aggregates was evident from the indices. In the vein, D (a.u.) decreased from 5.8±4.4 to 3.2±1.2 (RP method) with shear rate increase from 0.05 /s to 1 /s. Also, from 0.3 to 1 /s, α_0 decreased from 0.2±0.3 (dB/cm/MHz) to 0.14±0.3 (dB/cm/MHz). In the artery, the RP method gave decreasing D (3.3±3.1 to 2.4±0.66 a.u.) with increasing shear (6.5±4.7 /s to 9.3±7.4 /s). The PF method showed deviation from RP method mostly at higher shear rates, warranting further optimization. Overall, the QUS parameters captured the reversible aggregation and dispersion of RBCs under different flow conditions for both vessels.

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Towards quantitative ultrasound-based tissue characterization of breast tissue components

Alexander Gleed; Kemi Babagbemi; Michele Drotman; Kristy Brown; Jonathan Mamou; Cameron Hoerig*

In this study, we quantify the effect of breast Cooper’s ligaments on the envelope statistics of ultrasound (US) radiofrequency (RF) echo data of breast white adipose tissue (WAT) of subjects scheduled for an US-guided tissue biopsy. Cooper’s ligaments are connective tissue components which appear as hyperechoic lines in B-mode US images. We seek to quantify the effect of Coopers ligaments on the histogram of US envelope values, since their inclusion will influence downstream quantitative ultrasound-based tissue characterization of WAT. A total of 19 female subjects scheduled for an ultrasound-guided core needle biopsy of a suspicious lesion categorized as BIRADS 4b or greater were included in this study. WAT regions and Cooper’s ligaments were manually segmented in single 2-D RF echo frames (one per subject). First order statistics were computed using envelope values (in dB) in WAT regions containing Cooper’s ligaments, and from the same WAT regions after masking the Cooper’s ligaments (WAT - CL). A paired t-test was used to determine statistical significance. First order statistics included the mean, mode, median, range, standard deviation, interquartile range, skewness, kurtosis, minimum value, maximum value, and outlier count.
Differences in all first order statistics were significant (paired t-test, $p<0.05$) when comparing envelope values of WAT compared with WAT - CL.The highest mean absolute difference was 2.60 dB for the range, followed by 0.51 dB for the mean, both of which provide insight into histogram differences which may support downstream quantitative ultrasound-based tissue characterization such as speckle statistics.

This study provides evidence that inclusion of Cooper's ligaments affects the envelope histogram of WAT regions compared with WAT - CL. Future work will investigate ways to automate detection of the ligaments, and account for their inclusion in quantitative ultrasound-based tissue characterization methods specific to WAT.

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Vessel Density Characterization Using Quantitative Ultrasound

*Parniyan Norouzzadeh; Jadyn Cook; Irfan Ismail; Michael Daniele; Paul Dayton; Marie Muller**

Tumor vasculature differs from normal tissue, featuring denser, more isotropic, and randomly organized neo-vascular networks, now recognized as biomarkers of malignancy. When ultrasound contrast agents circulate through these vessels, they strongly scatter ultrasound waves. We exploit this phenomenon by measuring UltraSound Multiple Scattering (USMS) parameters to quantify the micro-architectural properties of cancer-related angiogenesis. We measured five different USMS parameters: SMFP (scattering mean free path) represents the average distance between scatterers and is expected to decrease with increasing vessel density. The remaining parameters (λ_max, E, ΔQC and R^2) are derived from random matrix theory (RMT) and characterize the eigenvalue distribution of the backscattered signals. We measured USMS and performed acoustic angiography (AA) in fibrosarcoma (FSA) tumors and control flanks in rats. Four rats with subcutaneously implanted FSA tumors were imaged at 7, 10, and 14 days post-implantation to capture tumor progression. Additionally, flanks from three control rats were imaged at a single time point for comparison. SMFP decreased with increasing tumor size in 3 of 4 rats, while other parameters exhibited weaker and less consistent trends.Rapid growth of FSA tumors was consistent with observed trends in tumor vascular remodeling, including increased vessel tortuosity over time. Using AA, comparison of 10 tumor volumes and 3 control flanks demonstrated a significant increase in tumor vessel density. A significant correlation (r=-0.87, p=1.2e-3) was observed between SMPF and tortuosity measured by AA.

Estimating the Diffusion constant of Multiple Scattering Media Embedded in an Aberrating Layer

Sashank Gautam; Marie Muller*

Biological tissues are inherently complex and heterogeneous, giving rise to multiple scattering phenomena that challenge conventional ultrasound imaging. Characterizing the diffusive behavior of acoustic waves in such media provides quantitative ultrasound (QUS) metrics that goes beyond structural imaging , enabling the extraction of microstructural tissue properties. In particular, the diffusion constant (D) encodes information about scatterer density, size, and organization, making its accurate estimation a key objective in multiple-scattering-based QUS. Toward this goal, we evaluate two complementary approaches for estimating D across three probe configurations: direct near-field, water-wall (WW), and an inhomogeneous , aberrating chest-wall (CW). Specifically, we compare exploiting Incoherent Backscattering (IBS) and enhanced Coherent Backscattering (eCBS) contributions as characterization tools. Using Fullwave simulations alongside experimental data, we demonstrate that distance-induced errors arising from far-field geometric divergence in the IBS method can be corrected through Gaussian beamforming. This numerical refocusing at the scattering medium surface restores the configuration needed to reliably compute D. While eCBS offers complementary advantages, namely probe-distance independence and relative robustness to phase aberrations, it is constrained by a narrower temporal coherence window and can become unstable in weakly scattering regimes where ballistic contributions obscure the backscattering cone. Taken together, our results indicate that IBS is better suited for stable, deeper measurements, whereas eCBS provides a more robust alternative when navigating complex anatomical barriers such as the chest wall. This dual-method framework offers practical guidance for selecting the optimal characterization strategy based on the acoustic environment encountered.

Quantitative Ultrasound for Lymph Node Metastasis Detection Using High-Suspicion-Frame Classification

Yasmine Guendouz; Kristie Huda; Cameron Hoerig; Kirk Wallace; Maoxin Wu; Jonathan Mamou*

Quantitative ultrasound (QUS) methods characterize soft tissue microstructure by analyzing backscattered radiofrequency (RF) ultrasound data. This approach reduces operator dependence and improves reproducibility. Currently, lymph node diagnosis in breast cancer relies on imaging suspicious nodes followed by biopsy. While the latter remains the gold standard, it is invasive and may lead to unnecessary procedures. In this study, QUS was used to detect in vivo lymph node (LN) metastasis from RF cine loops acquired with a GE LOGIQ™ E10 scanner and an L6–24 linear array (16-MHz center frequency). N=23 patients (7 metastatic, 16 benign) undergoing ultrasound-guided biopsy were included. In post hoc processing, effective scatterer diameter (ESD) and effective acoustic concentration (EAC) were estimated using the reference phantom method. QUS parameters were computed within segmented LN regions across 1-9 frames per patient. Frame-level predictions were aggregated to the patient level using a high-suspicion-frame (HSF) strategy defined as the maximum predicted probability across frames within each LN. Classification performance was evaluated using leave-one-patient-out cross-validation with L2-regularized logistic regression. The EAC+ESD model achieved an area under the receiver-operating characteristic curve (AUC) of 0.88 (95% CI: 0.71–1.00). This indicates that the EAC+ESD model yields a 88% probability of correctly discriminating between metastatic and benign lymph nodes. A linear support vector machine yielded similar performance (AUC = 0.88), and adding radiomic features did not improve classification. Additionally, a custom research software was developed to enable automated RF cine loop storage in DICOM format and rapid QUS parametric map generation at the bedside, establishing feasibility for scanner-integrated QUS analysis. These results demonstrate the potential of QUS for patient-level LN metastasis detection and support future integration of real-time classification within the clinical ultrasound workflow

6. Imaging II

Volumetric Power Doppler Imaging of Breast Tumor Vasculature Using Row-Column Arrays: Phantom Validation and Protocol Optimization

Ruoxuan Rosie Wang; Seongyeon Kim; Yangpei Liu; Shiqi Hu; Saachi Munot; Elisa Konofagou*

Introduction: The vasculature of the breast tumor microenvironment has been identified as a critical biomarker for monitoring progression and response to therapy. However, conventional 2D ultrasound lacks the volumetric context required to quantify angiogenic heterogeneity. Row-Column Arrays (RCA) provide a scalable alternative for volumetric imaging. This study aims to assess the performance of a high-frame-rate volumetric Power Doppler (PD) framework using RCA for longitudinal tumor perfusion monitoring.

Methods: A 6.25-MHz RCA transducer (128+128 elements, Vermon, France) driven by a 256-channel Verasonics Vantage system implemented a coherent orthogonal plane wave compounding sequence. We evaluated plane wave compounding strategies comparing total steering widths from 7.6° to 11° and volume rates of 150 Hz to 200 Hz. The framework was validated on tissue-mimicking gelatin-based flow phantoms (15 kPa) containing embedded channels (diameter 1.2 to 3.0 mm). Controlled flow rates (0.02 to 0.2 mL/s) mimicked velocities of murine tumor feeding arteries. Tukey and Kaiser apodization strategies were employed to mitigate orthogonal ghosting artifacts. Vascular geometry was quantified using Full-Width-at-Half-Maximum (FWHM), and the PD image quality was assessed via Contrast-to-Noise Ratio (CNR) in both lateral and elevation planes.

Results: Volumetric vascular reconstruction successfully resolved the channel architecture, though image quality depended critically on transmit beamforming strategy. We demonstrated that standard Tukey apodization is insufficient for clutter rejection in the lens-less orthogonal dimension. Conversely, Kaiser apodization suppressed integration side-lobes by 15 dB. Quantitative characterization revealed anisotropic image quality between orthogonal views: while the lateral-axial plane maintained robust resolution, the elevation-axial plane exhibited reduced contrast due to grating lobe artifacts inherent to the array geometry. However, optimizing the steering width to 7.6° mitigated artifacts. These results support the ongoing translation of this protocol to a longitudinal study of 4T1 murine breast tumor models to quantify vascular heterogeneity changes.

Single-frame Scatterer Localization Strategies for Diverging-Wave Ultrafast ULM

Kashta Dozier-Muhammad; Carl Herickhoff*

Ultrafast ultrasound localization microscopy (ULM) can resolve sub-wavelength microvasculature by localizing microbubbles, but this commonly involves compounding and filtering many frames of images, with significant computational burden. In this work, we propose and evaluate localization techniques using beamformed IQ data acquired from a single frame, for improved frame rate and efficiency. A 2.15-MHz, 64-element P4-2v array was simulated in Field II with point scatterers placed around z = 20 mm and 40 mm, and x = [0, ¼, ½, ¾]*(aperture width, D) with receive focus points $\pm 3\lambda_z/4$ axially and $\pm\lambda_x/4$ laterally. Each point scatterer was also moved at increments of $\lambda_z/4$ axially and $\lambda_x/16$ laterally. An 8-μs linear chirp (1.9- to 2.4-MHz) was transmitted using a single diverging wave, with virtual source at (0, -6.7) mm. Channel data was interpolated to the fourth harmonic (to mimic a microbubble's superharmonic response) and pulse-compressed, and four receive apodization profiles produced lateral oscillations in the beamformed PSFs, from which the scatterer locations were derived, either as an interpolation between adjacent focal points or as an angular position and radial offset from an arc centered on the virtual source through each focus. For both algorithms, the greatest RMS localization error among all locations was within 25μm axially and 37μm laterally; the algorithms' accuracy was reduced at farther-off-axis locations, as the PSF rotates and the transducer's angular sensitivity is reduced. The mean and standard deviation of the location errors were $\mu_z \pm \sigma_z$ = -2.85±7.57 μm and $\mu_z \pm \sigma_z$ = -3.95±14.35 μm axially, and $\mu_x \pm \sigma_x$ = -2.27±13.60 μm and $\mu_x \pm \sigma_x$ = -0.77±27.98 μm laterally, for the two algorithms. These results suggest that the achievable axial and lateral resolution limits are about 29μm and 56μm, respectively. This approach could offer fast, accurate, and robust ULM using diverging wave acquisition in limited-aperture contexts (e.g., neurovascular functional imaging).

Principle of Low Power Microwave-induced Thermoacoustic Imaging Using Leaky Coaxial Antennas

Yoshifumi Saijo; Masaya Shimizu; Yoshiki Mizuguchi; Takuro Ishii*

Microwave-induced Thermoacoustic Imaging (MTAI) is a hybrid acoustic imaging modality that, like photoacoustic imaging (PAI), detects broadband pressure waves generated by thermoelastic expansion following a rapid temperature rise caused by electromagnetic absorption. The underlying physics is analogous; however, whereas PAI relies on short-wavelength light and is therefore strongly limited by optical scattering and shallow penetration, MTAI uses longer-wavelength microwaves (e.g., 2.45-GHz band), for which scattering is substantially reduced, enabling deeper interrogation of biological tissues. Moreover, while photoacoustic contrast reflects spatial distributions of optical absorbers, thermoacoustic contrast is linked to microwave energy deposition, which is related to the effective electrical conductivity of the target. This provides access to complementary tissue information potentially related to hydration and ion homeostasis, thereby enriching the interpretation of ultrasound- and photoacoustic-derived functional readouts within a unified US-PA-TA imaging platform. Traditionally, microwave excitation for MTAI requires very high peak power (kW-MW range). For example, one study visualized cerebral hemorrhage in the mouse brain using a 55-kW high-power microwave source. However, it raised practical concerns regarding system size and safety. Consequently, recent efforts have shifted toward safe, compact, lower-power excitation strategies that still satisfy thermoacoustic generation requirements. In this direction, we attempted a tissue-proximal excitation approach by inserting a leaky coaxial antenna (LCX) near biological tissue and emitting 1-μs microwave pulses at 250 W. Using a single-element ultrasound transducer with a center frequency of 1.8 MHz, thermoacoustic signals originating from biological tissue were successfully observed. Mechanical scanning of the single element transducer enabled 2D imaging of a biological tissue phantom. This research demonstrated the principle of low-power, safe MTAI and established the foundation for future application for biomedical imaging.

From Light to Sound: Imaging, Treating, and Building Tissues at Depth

*Junjie Yao**

Integrating light and sound, our research weaves engineering innovations that map, treat, and ultimately engineer living tissues at depths unreachable by conventional optical methods—spanning scales from single cells to whole organs.

(1) Seeing deep with clarity and color. Our photoacoustic imaging (PAI) converts optical absorption into ultrasound emission, enabling multi-scale functional and molecular imaging. We accelerate photoacoustic microscopy (PAM) by 1000×, unlocking real-time observations of neural activity, placental development, and the remarkable transparency of glassfrogs. Using genetically encoded photoswitchable probes, we further enhance the molecular sensitivity of photoacoustic computed tomography (PACT) by 1000×, enabling reliable detection of cancer metastasis, tissue regeneration, and neuronal signaling in deep tissues.

(2) Treating deep with precision. We translate deep-tissue ultrasound technologies into clinical practice through super-resolution passive cavitation mapping (SR-PCM) integrated with laser lithotripsy. By localizing laser-induced cavitation with >10× sub-diffraction precision, SR-PCM provides real-time, closed-loop surgical guidance that significantly improves the efficiency and safety of kidney-stone treatments.

(3) Building deep with safety. Our ultrasound volumetric in-situ printing (UltraVIP) technology overcomes the penetration limits of light-based bioprinting by >100×, using focused ultrasound energy to fabricate intricate three-dimensional structures within deep-seated tissues. UltraVIP expands the possibilities of regenerative medicine, minimally invasive surgery, and in situ tissue engineering.

Together, these advances form a unified research pipeline that harnesses light–sound energy conversion and control for noninvasive imaging, image-guided intervention, and deep-tissue biofabrication—paving the way for next-generation diagnostic, therapeutic, and regenerative technologies.

FASTER-AIR: High-Volume-Rate 3-D Ultrasound with a 1-D Array Using Air-Backed Curved Reflection for Enhanced Elevational Resolution

Dongliang Yan; Matthew Lowerison, Jun Zou, Pengfei Song*

Three-dimensional (3D) ultrasound remains challenging for routine clinical deployment; current solutions rely on either 2-D matrix-array probes that require high-end scanners with multiplexing and large channel counts, or mechanically swept (“wobbler”) transducers that are inherently limited by slow volumetric acquisition rates [1], [2]. Fast acoustic steering via tilting electromechanical reflectors (FASTER) enables high–volume-rate 3D scanning using a standard 1-D array by steering the acoustic beam with a rapidly tilting reflector rather than mechanically moving the probe [3], [4]. However, elevational resolution is constrained by the fixed elevational focus of commercial 1-D arrays, such that imaging is largely performed outside the native elevational focal region.

We present FASTER-AIR, which integrates curved (concave) reflectors to refocus the elevational beam at a deeper target region. Using the paraxial oblique-incidence thin-mirror (Coddington) model for curved-surface reflection, the effective elevational focus is shifted from ~1.5 mm to ~34 mm away from the fast-tilting reflector. This refocusing is validated by k-Wave simulations and hydrophone measurements, demonstrating an elevational full width at half maximum (FWHM) improvement from 2.5 mm (FASTER 1.0) to 1.5 mm (FASTER-AIR). In vitro imaging with a standard CIRS general-purpose phantom further confirms improved elevational resolution: 80-μm wire targets exhibit an elevational FWHM reduction from 2.98 mm to 1.39 mm, and hypoechoic lesion analysis shows contrast-to-noise ratio (CNR) improvement from 1.57 to 2.24. We also demonstrate 3D Doppler imaging using a CIRS Doppler flow phantom (Model 069A). Volumetric flow is quantified using the power-weighted surface integration of vector velocity (SIVV) method [5]. Compared with FASTER 1.0 (flat reflector), FASTER-AIR improves flow measurement accuracy across pump settings, reducing MAE from 28.23 to 6.11 mL/min, RMSE from 32.14 to 7.63 mL/min, and MAPE from 21.83% to 4.29%, while increasing the percentage of measurements within 10% error from 25% to 100%.

Investigation of Dual-Frequency Transducer Array Element Design

*Timothy McDaniel**

Dual-frequency transducers offer the potential to provide improved harmonic imaging performance through their ability to excite a microbubble at a lower transmit frequency while capturing the bubble’s higher-frequency superharmonic response on receive. In this work, we investigate various geometries of piezoelectric transducer elements and their resonance behavior corresponding to the elements’ thickness and lateral dimensions. First, finite element modeling (FEM) of PZT-5H transducer elements ranging in size from 0.24 – 0.36 mm thickness and from 1.4 – 1.8 mm laterally were performed using ABAQUS CAE with a fixed boundary condition on one face and an applied electrical excitation of 100 V spanning a frequency range of 0.6 – 9.6 MHz. Peaks in the displacement vs. frequency plots resulting from the simulations revealed thickness- and lateral-mode resonances, which were tuned to 6.0 and 1.5 MHz, respectively. Based on these results, we used a DISCO precision dicing saw to cut pieces of 0.267-mm-thick PZT-5H to lateral dimensions of 0.8, 1.1, and 1.4 mm. Electrical impedance magnitude and phase were measured from 0.3 – 8 MHz at step intervals of 0.05 MHz using an impedance analyzer and a needle probe station, and these data were plotted vs frequency for each transducer element. MATLAB was used to identify local frequency minima and maxima, corresponding to individual series and parallel resonance frequencies; from these, the electromechanical coupling coefficient (kt) of each resonance mode was calculated. Preliminary results show thickness resonance modes to be between 6.86 and 7.16 MHz and lateral resonance modes to be between 1.49 and 2.39 MHz for the various element sizes, corresponding well to FEM simulations. Future work will entail characterization of additional piezoelectric materials, refinement of the lateral dimensions and resonance frequency, and the development of a flexible interconnect for fabrication of a dual-frequency transducer array.

7. Educational session on Motion Tracking

Principles and Applications of Ultrasound Motion Tracking

McAleavey, Stephen

Beamforming profoundly impacts diagnostic ultrasound performance. Conventionally, constructing a beam follows a forward principle: (1) define the amplitude (or apodization), and (2) define the phase delay for each transducer element. Focused beams are widely employed to concentrate acoustic intensity within the depth-of-focus (DoF) to improve image quality. However, a focused beam has an inflexible relationship between DoF, beamwidth and f-number.

To address this limitation, we consider a Fourier-domain beam design method for a linear array that provides a beam with the desired DoF, an arbitrary axial beam profile, and an adjustable beamwidth. The method enables beam construction with an inverse workflow: (1) define an arbitrary target beam, specifying its focal point, DoF and axial beam profile, (2) calculate the required transmit wave field at the probe surface in the Fourier domain using the angular spectrum approach, and (3) extract the corresponding apodization (i.e the magnitude of the transmit wave field) and phase delays to drive the transducer elements.. Simulation and hydrophone measurements are presented validating the proposed method.

In addition to axial beam profile design, we investigated sidelobe suppression, which effectively reduced sidelobe pressure by 5 dB. Furthermore, we proposed Fourier-domain attenuation compensation to enhance the beam's penetration. In B-mode, the compensated beam extended the -6 dB DoF by 10 mm compared to the non-compensated beam. For elastography, a compensated Acoustic Radiation Force (ARF) beam focused at 20 mm (with a 25 mm DoF) induced approximately 125% stronger displacement at a depth of 40 mm. Finally, inspired by previous work [1], we designed an ARF beam with a uniform axial beam profile and used it for quantifying the attenuation coefficient in an inhomogeneous phantom.

1.M.L. Palmeri, K.D. Frinkley, K.G. Oldenburg, K.R. Nightingale. Acoustic attenuation of homogeneous media using focused impulsive acoustic radiation force. Ultrasonic imaging., vol. 28, no. 2, pp. 114-128, Apr. 2006.

Motion Tracking Algorithms for Shear Wave Elasticity Imaging

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Background: Previous work has shown the promise of 3D-rotational shear wave elasticity imaging (3D-RSWEI) to noninvasively characterize the anisotropic and nonlinear elastic properties of skeletal muscle [1]. Herein we quantify longitudinal consistency of SWEI-based metrics in healthy vastus lateralis. We also compare these metrics between healthy muscle and data collected in neuromuscular disease patient muscle.

Methods: 3D-RSWEI uses a linear-array transducer rotating about its central axis (the SWEI push axis) while collecting 2D planar SWEI data in 5-degree rotational increments. From acquired SWEI data, shear wave speed (SWS) along and across the fibers and fractional anisotropy are quantified. In an ongoing, IRB-approved study [2], in vivo data have been collected in ten healthy volunteers over three months and to date, one patient with Charcot-Marie-Tooth disease (CMT) with mild quadriceps weakness and one with fascioscapulohumeral muscular dystrophy (FSHD) with severe quadriceps weakness. Participants laid supine during 3D-RSWEI measurements in the vastus lateralis under varying degrees of knee flexion (~15-110° in volunteers, ~15-90° in patients). A nonlinear elasticity parameter ($\beta_\parallel$) was quantified by estimating an exponential growth constant between SWS along-the-fibers and knee flexion angle.

Results: In healthy volunteers, SWS along and across the fibers were consistent to 6% and fractional anisotropy to 7% coefficient of variation. Consistency of the β‖ was within 8.3% coefficient of variation. Average β‖ values were 0.010 ± 0.001 1/deg, and fractional anisotropy values were between 0.30-0.61 across knee flexion angles measured in volunteers. Measured β‖ (0.012 1/deg) and fractional anisotropy (0.38-0.62) in one CMT patient were within the range of healthy muscle measurements. Data from one FSHD patient show higher β‖ (0.021 1/deg) and lower fractional anisotropy (0.06-0.59) values than healthy volunteers. This preliminary comparison demonstrates feasibility of 3D-RSWEI to investigate clinical biomarkers for diagnosing severity of muscular dystrophies.

[1] C. T. Paley et al., "Rotational 3D shear wave elasticity imaging: Effect of knee flexion on 3D shear wave propagation in in vivo vastus lateralis," Journal of the Mechanical Behavior of Biomedical Materials, vol. 150, p. 106302, 2024, doi: 10.1016/j.jmbbm.2023.106302.[2] Srinivasan et al., "Longitudinal Assessment of Quantitative Metrics for Skeletal Muscle Health using 3D Rotational Shear Wave Elasticity Imaging (3D-RSWEI) in in vivo vastus lateralis." In Review.

8. Wearables

A Wearable Sonomyographic Glide Interface for Continuous Multi-Degrees of Freedom Control in Upper-Limb Prosthetics

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Introduction: Surface electromyography (sEMG) is the standard noninvasive interface for prosthetic control, yet it often suffers from signal noise, crosstalk, and sensitivity to limb position, contributing to abandonment rates between 35% and 75%. Wearable sonomyography (SMG), which captures deep muscle deformation via ultrasound, offers a promising complementary biosignal. This study evaluates a wearable SMG approach using a four-channel, miniaturized time-delay spectrometry (TDS) M-mode ultrasound system designed for prosthetic socket integration. We introduce the "SMG Glide" framework to represent motor intent within a continuous control space, specifically accounting for transitions between rest and active motion.

Methods: Wearable ultrasound data were collected from three participants (DC03, DC04, DC05) at Med-Star Health Research Institute and Hanger Clinic with transradial upper-limb loss using a time-delay spectrometry (TDS)–based system, with sensors positioned using anatomical landmarks, muscle palpation, and voluntary activation. Participants performed repeated wrist and hand movements (flexion, extension, supination, and pronation), across multiple arm positions (neutral, shoulder level, cross-shoulder, and cross-body) while ultrasound M-mode images capturing muscle deformation were recorded. The recorded data were processed offline to extract mean depth features, which were used to estimate continuous motor intent through linear regression modeling to generate a proportional control signal. Spatial distinctness of the decoded motions within the continuous control space was evaluated using k-means clustering, with clusters corresponding to the four motion classes and the rest state, and validated using silhouette analysis. Performance was quantified using confusion matrices and F1-scores across all motion states. In addition, one participant (DC04) completed a virtual Fitts' law task to assess control performance and intuitiveness during 1DoF flexion and 1DoF pronation tasks as shown in .Results: The SMG Glide Control Map outperformed traditional threshold-based and majority voting methods.

For participant DC4, the Glide approach achieved an F1-score of 97.00% (a 7% improvement over baseline). Despite physiological variability in participant DC5, the Glide approach remained the most robust (F1: 71.40%). Silhouette scores (0.818 to 0.214) confirmed that the Glide framework successfully separated rest from active states across varying residual limb anatomies. In virtual testing, participant DC4 achieved high task completion rates (96.43% for flexion, 92.31% for pronation) with stable throughput and efficient path control.

Discussion and Conclusion: The SMG Glide framework provides a robust, spatially intuitive representation of motor intent by preserving the temporal and proportional information of muscle deformation, it enables stable transitions and clear geometric separation between movements, even in individuals with altered muscle anatomy. These findings highlight SMG Glide's potential as an intuitive interface for multi-DoF prosthetics control. Future work will focus on real-time integration with powered devices and clinical evaluation in daily living tasks.

Muscle-Resolved Tremor Characterization Using Wearable Ultrasound Tissue Displacement During Task-Evoked Tremor

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Background: Task-evoked tremor in Parkinson's disease (PD) and essential tremor (ET) is commonly monitored with inertial sensors or surface electromyography, which provide limited muscle specificity and can be artifact-prone. Objective, quantitative tremor measures that can be collected outside the clinic are needed [1]. Wearable ultrasound (WUS) can quantify muscle-level tissue micro-motion, providing tissue displacement (TD) as a physiologically interpretable signal linked to underlying muscle dynamics for tremor monitoring.
Methods: We used a wearable ultrasound sensing framework with two wearable 64-element arrays positioned over the flexor carpi radialis (FCR) and extensor carpi radialis (ECR) for simultaneous antagonist monitoring. During a cup-holding task, A-mode US was acquired at 100 Hz and tremor frequency was estimated from tissue-motion time series, with comparisons to a wrist-mounted IMU and commercial B-mode ultrasound. To quantify TD without continuous B-mode speckle tracking, we trained a machine-learning model to map compact raw A-mode features to B-mode-derived TD during calibration and then inferred TD from A-mode alone for low-latency monitoring.
Results: Across three participants (two PD, one ET) and multiple trials, wearable ultrasound tremor-frequency estimates showed approximately 10% variation relative to commercial B-mode ultrasound and IMU measurements and met statistical equivalence using a two one-sided test (TOST; ±0.5 Hz margin). TD estimation demonstrated strong agreement with the reference, with Pearson correlation coefficients of 0.84–0.99 and normalized RMSE below 11% across participant–muscle conditions, enabling identification of antagonist displacement signatures during task-evoked tremor. The learning-based workflow reduced offline model-development time by approximately 75% and enabled real-time inference with an update latency of approximately 17 ms and an effective processing rate exceeding 50 Hz [2].
Conclusion: Wearable ultrasound enables muscle-resolved tissue displacement and tremor-frequency metrics that complement distal kinematics, supporting quantitative, out-of-clinic characterization of antagonist tremor dynamics using physiologically interpretable tissue-displacement signatures.

[1] Crawford, Paul, and Ethan E. Zimmerman. "Differentiation and diagnosis of tremor." American family physician 83.6 (2011): 697-702.
[2] Xue, Xiangming, et al. "Wearable Ultrasound Sensing with Dual Arrays and Machine Learning for Real-Time Tremor Characterization and Antagonist Muscle Monitoring." IEEE Transactions on Instrumentation and Measurement (2026).

A Wearable Ultrasonic Cardiovascular-Twin System for Continuous, Non-invasive Blood Pressure and Hemodynamic Monitoring

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Background: Continuous BP waveforms can reveal cardiovascular dynamics beyond intermittent cuff measurements, but many cuffless methods lack physiologic grounding. Wearable ultrasound can directly sense arterial wall motion at depth, enabling waveform reconstruction and vascular characterization.

Methods: We developed a wearable ultrasound platform using a compact 6.5-MHz PZT-5A (lead zirconate titanate) transducer (2 × 2 mm^2 aperture) integrated into an arm strap to capture echoes from anterior and posterior arterial walls under low-intensity operation. A two-stage analysis pipeline converts RF data into beat-resolved BP waveforms via denoising, adaptive wall-peak detection, and inter-frame tracking of arterial diameter, followed by a pressure–area model anchored to reference values with signal-quality scoring. Stage 2 derives higher-order hemodynamic indices from the reconstructed waveform (e.g., ejection time, dicrotic-notch timing, diastolic decay behavior, rhythm variability, and reflection-related metrics).

Results: In vivo feasibility testing demonstrates robust wall-motion tracking and waveform recovery consistent with expected physiologic morphology. In prior work, the wearable system achieved 97.79% accuracy versus a commercial monitor across a measurement range [1]. In a cuff-instrumented session using the same transducer/setup, the reconstructed waveform produced session-level BP medians of 110/82 mmHg versus cuff 108/72 mmHg (ΔSBP +2 mmHg, ΔDBP +10 mmHg), while enabling extraction of waveform-based hemodynamic metrics (upstroke, diastolic decay, and rhythm indices).

Conclusion: By coupling a miniaturized wearable ultrasound front end with a quality-controlled two-stage analysis suite, this platform supports continuous BP waveforms and expanded hemodynamic monitoring on-body, enabling calibration-light ambulatory cardiovascular assessment.

[1] Y. Chu et al., "Wearable Ultrasound Blood Pressure Monitoring System for Cardiovascular Health," 2024 IEEE Ultrasonics, Ferroelectrics, and Frequency Control Joint Symposium (UFFC-JS), Taipei, Taiwan, 2024, pp. 1-6, doi: 10.1109/UFFC-JS60046.2024.10793899.