SWTV-ACE: Spatially Weighted Regularization based Attenuation Coefficient Estimation Method

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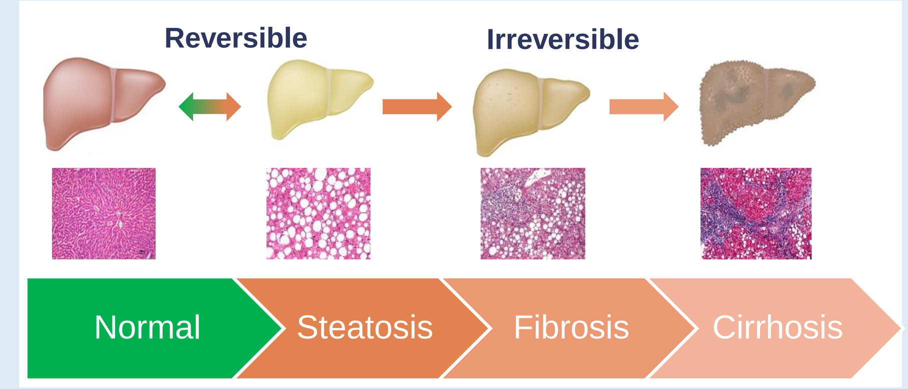
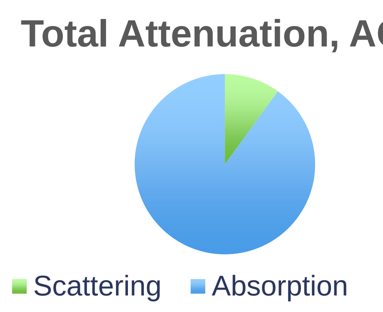
Highlights



- Non-alcoholic fatty liver disease (NAFLD) affects 1 in 4 persons, globally [1].
- Steatosis (excessive accumulation of fat in hepatic cells) is the first stage of NAFLD. This condition is reversible, but can progress into fibrosis and cirrhosis.
- Attenuation coefficient estimate (ACE), a potential screening tool to detect steatosis, is currently limited by large estimation variance and poor resolution.
- SWTV-ACE improves both the resolution and estimation precision and yield steatosis detection performance equivalent to MRI-PDFF, the current gold standard.

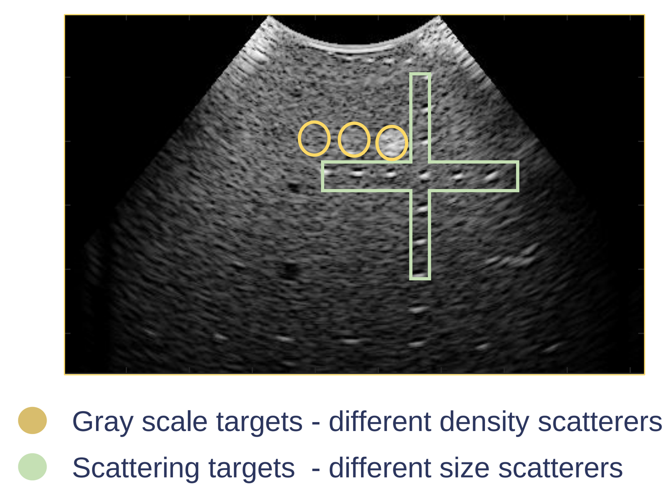
Why SWTV-ACE?

$$S = ACE + BSC$$



S = Power Spectrum term; ACE = Attenuation (ACE) term; BSC = Backscatter Coefficient (BSC) term;

A



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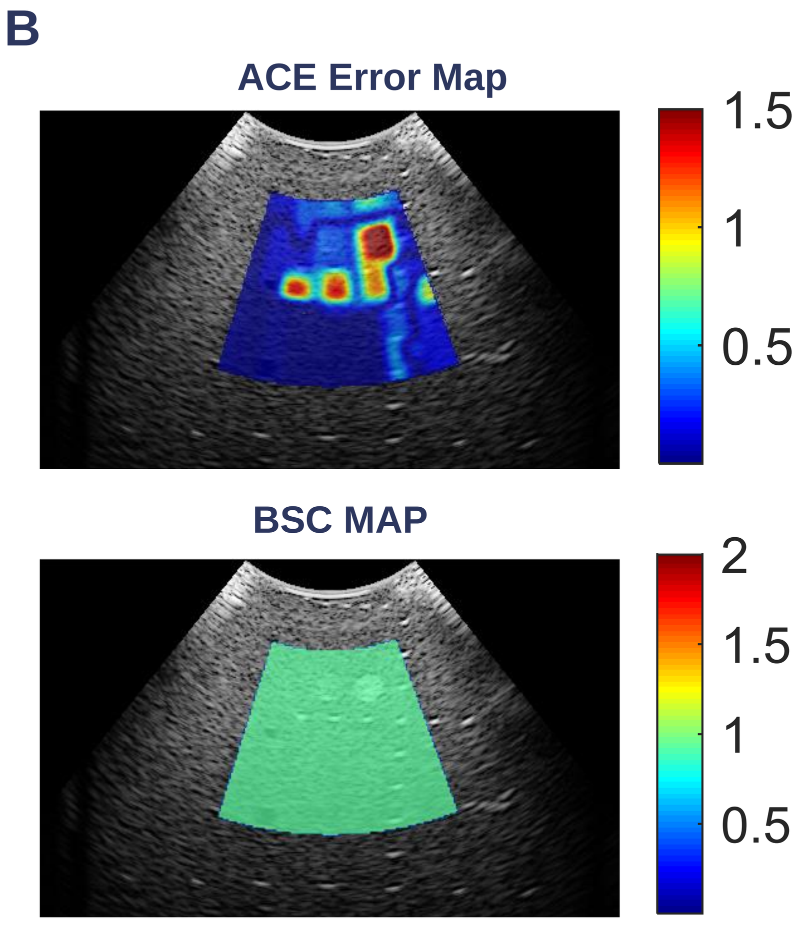
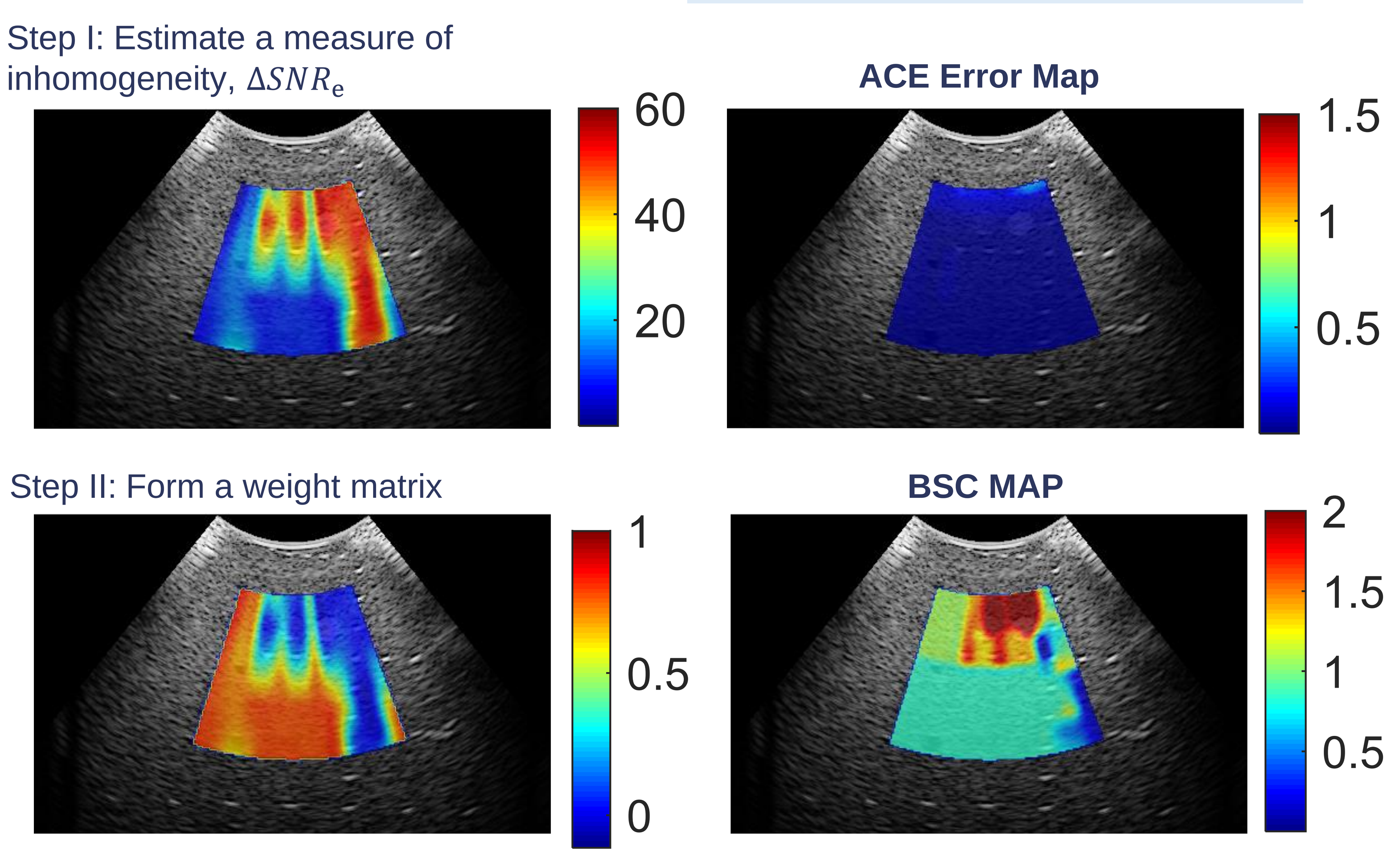


Uniform TV Regularization results in large error in the regions with backscatter variation.

C



The weight matrix modifies the regularization on BSC terms as a function of inhomogeneity.

SWTV significantly improves ACE measure and BSC map successfully captures the backscatter variation.

A. Ultrasound image of CIRS phantom (model 040) with backscatter variation; B. ACE and BSC estimation results with TV regularization; C. ACE and BSC estimation results using SWTV-ACE.

Introduction

- ACE is a measure of ultrasound amplitude dissipation due to scattering and absorption. The dissipation associated with the scattering is <10% for typical tissue.
- Traditional ACE methods assume a homogeneity (i.e. constant BSC) condition. Therefore, change in scattering, due to change in scatterer density and/or size results in a large bias in ACE measures.
- Proposed SWTV-ACE introduces an adaptive regularization, formulated as a function of ΔSNR_e, an indicator of homogeneity.
- SWTV-ACE yields accurate, precise and high resolution ACE irrespective of tissue inhomogeneity.

Methods

Proposed optimization problem:

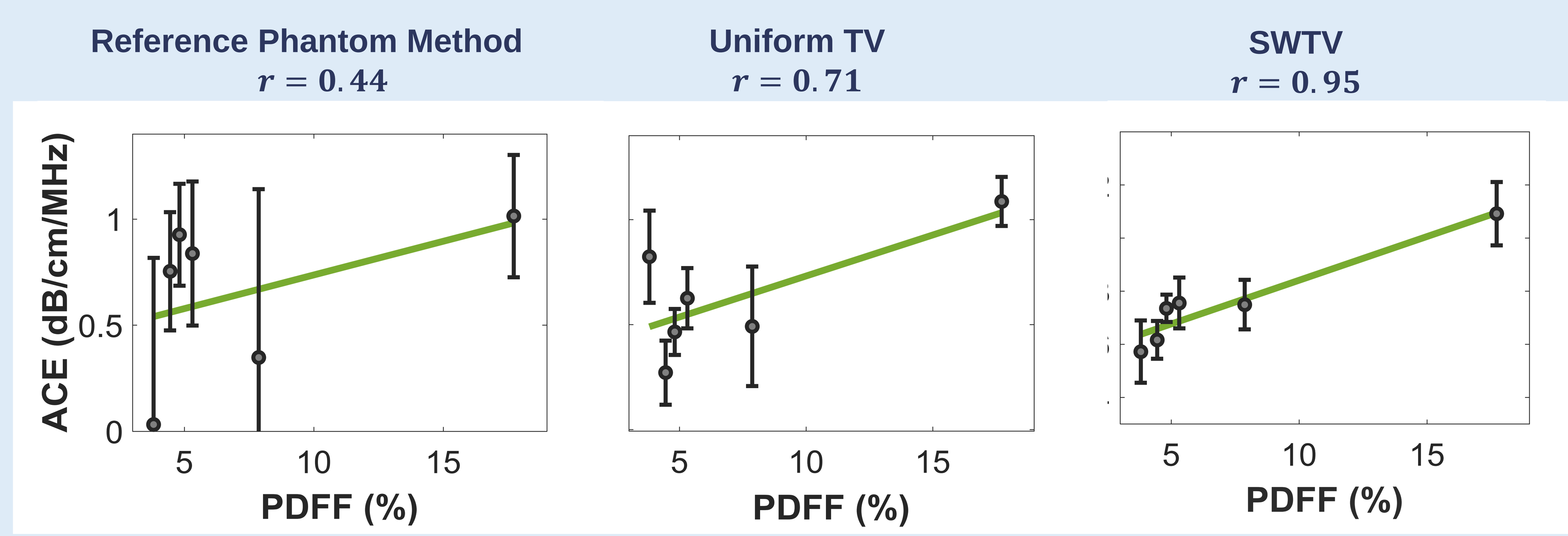
$$\arg\min_{x}\{\|y - Ax\|_2^2 + \lambda_1 TV(\alpha) + \lambda_2 SWTV(\beta)\}$$

- α: ACE; β: BSC;
- $SWTV(\beta) = \sum_{i,j} W_\beta^{i,j}(|\beta_{i+1,j} - \beta_{i,j}| + |\beta_{i,j+1} - \beta_{i,j}|)$;
- $W_\beta(\Delta SNR_e) = \frac{a}{1+\exp(b(\Delta SNR_e - \Delta SNR_e^{min}))}$

➢ Reference phantom method holds an assumption of constant BSC whereas uniform TV assumes a piece-wise homogeneity. Both methods fail to account for BSC variation.

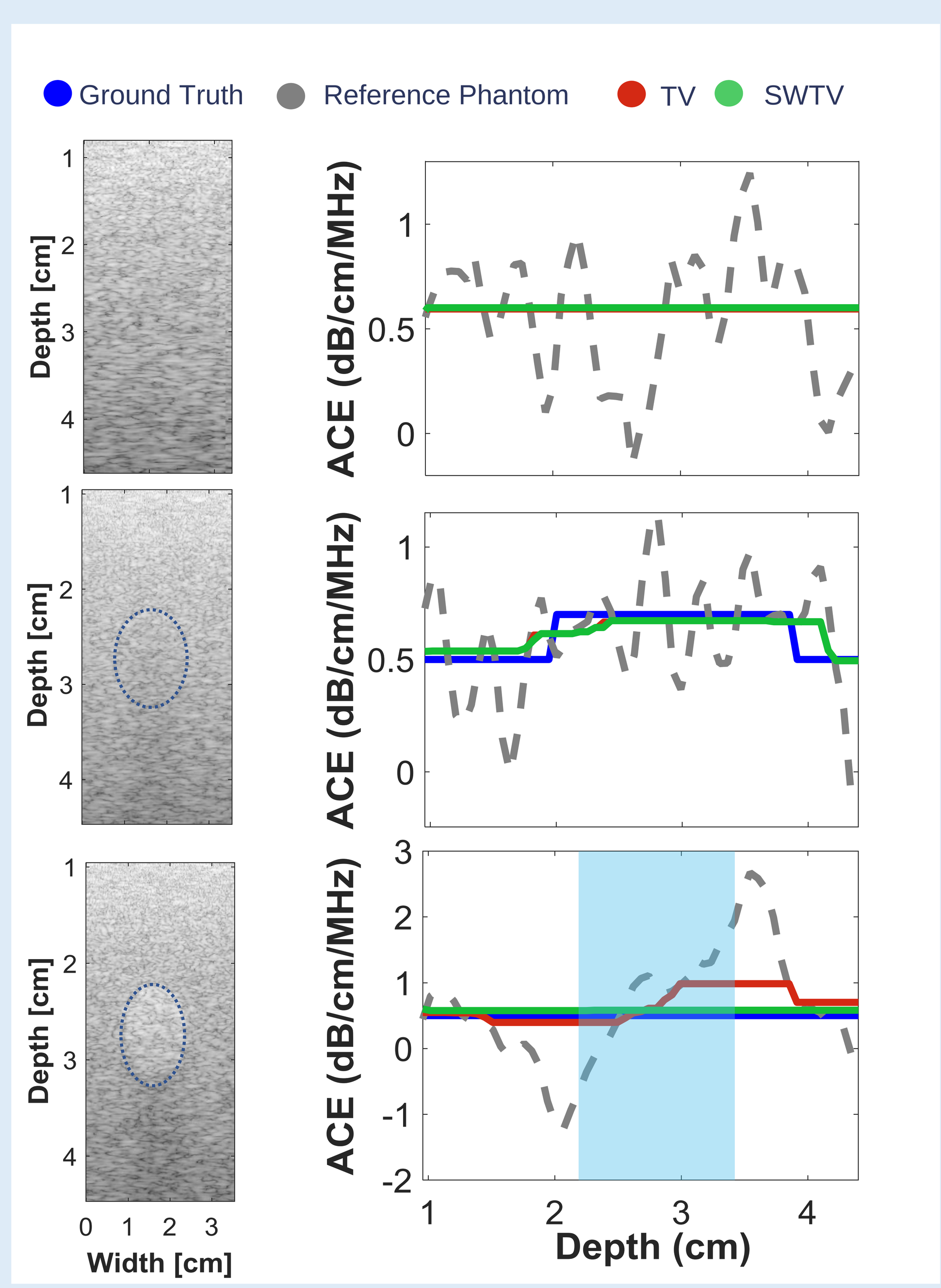
➢ SWTV-ACE reduces the regularization on the BSC term in inhomogeneous regions where $\Delta SNR_e > \Delta SNR_e^{min}$.

Results: Liver *In vivo* (Steatosis Detection)



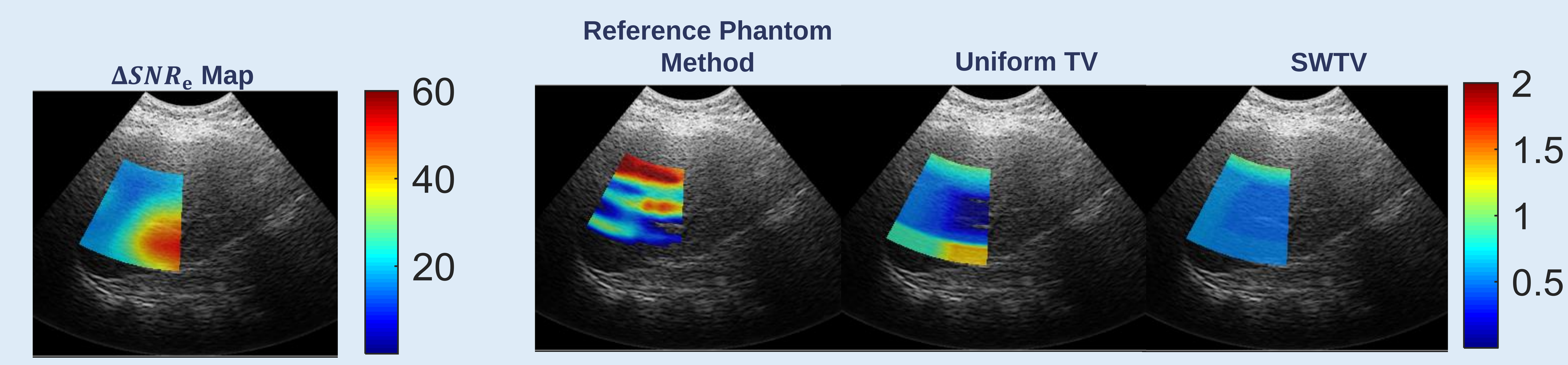
In vivo human liver ACE from patients (*n*=6) and their correlation with proton density fat fraction (PDFF). The error bars show the standard deviation whereas the circle represents the mean/

Results: Simulation



ACE results for simulation phantoms. **Phantom 1** : uniform ACE and uniform BSC; **Phantom 2**: variable ACE and uniform BSC; **Phantom 3**: uniform ACE and variable BSC.

Results: Liver *In vivo* (ACE Map Visualization)

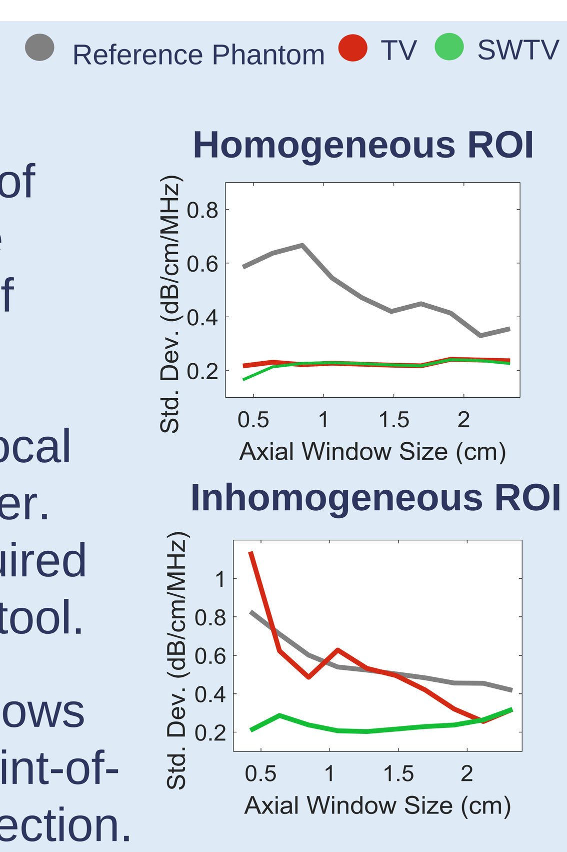


ΔSNR_e map depicting the variation in local homogeneity.

ACE map overlaid on human liver *in vivo.*

Conclusion

- SWTV-ACE improves the quality of ACE computation by reducing the estimation variance irrespective of window size and inhomogeneity.
- Improved resolution will provide local variation information within the liver. Improved precision would be required to qualify as a reliable diagnostic tool.
- The equivalence to MRI-PDFF shows that SWTV-ACE is a potential point-of-care tool for hepatic steatosis detection.



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