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MREureka!: Efficiently and Effectively Segmenting Brain Elastographs with nnU-Net

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INTRODUCTION

- Elastography is an imaging method focused on the visual representation of the mechanical properties of tissues in the body as measured through displacements of tissue in response to an external sinusoidal vibrating source, which can be equated to the palpation of internal organs using imaging [1].
- Magnetic resonance elastography (MRE) is the application of elastographic methods using magnetic resonance imaging (MRI).
- Clinically, elastography is used to measure the degree of cirrhosis in the liver where liver stiffness can be correlated with fibrosis [2].
- Recently, there's been a push to apply MRE to brain imaging in the detection of neurological diseases, potentially revealing abnormalities before conventional MRI images.

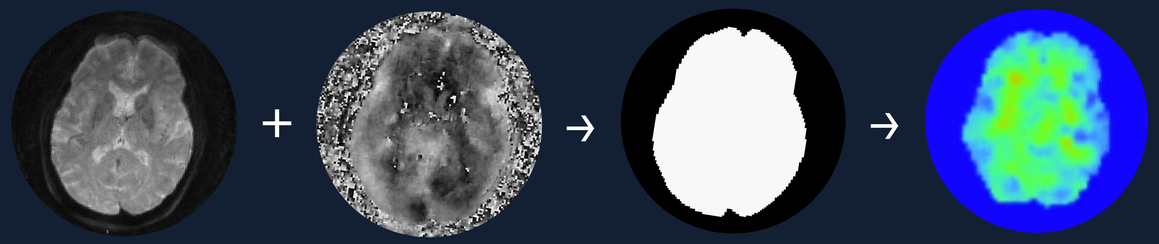
BACKGROUND

- Once the displacement data is gathered from the scan, a mechanical inversion must be performed to convert displacements measured in different directional encodings to images of tissue complex shear modulus, or elastograms.
- We use the nonlinear inversion (NLI) approach based on finite element modeling of brain mechanical behavior [3].
- One major barrier for MRE implementation in both research and clinical applications is the time needed to perform the inversion, which prolongs research time and makes it infeasible for the high-paced clinical environment.
- We aim to reduce the amount of time needed as well as improve the accuracy of generated elastographs.

UTILIZING NN-UNET

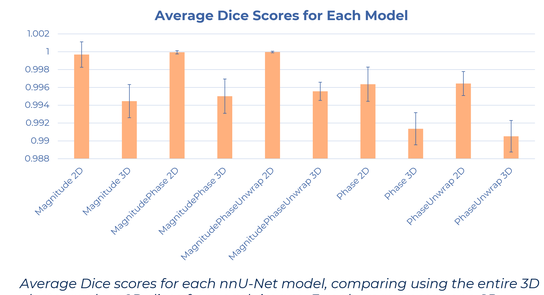
- Previous research has shown that conventional non-machine learning (non-ML) brain segmentation methods are not particularly applicable to elastographs, favoring more of an ML approach [4].
- Utilizing an ML approach has been shown to be superior in isolating brain tissue as compared to the non-ML-based gold standard MRI segmentation programs, especially in masking around cerebrospinal fluid and image distortion [4].
- nnU-Net is a segmentation model that adapts to a given dataset automatically, essentially automating the most time-consuming process optimizing model parameters [5].
- The framework relies on the classic U-Net, a convolutional neural network specifically designed for medical imaging [5].
- nnU-Net automatically configures an optimized U-Net model, a perfect fit for analyzing the complexity of displacement data, removing unusable data, and optimizing the data in preparation for mechanical inversion [5].

Magnetic resonance elastography (MRE), an advanced imaging technique that measures tissue stiffness, can **leverage machine learning** with models such as **nnU-Net** to significantly **improve the accuracy and efficiency** of tissue segmentation and mechanical inversion, **achieving near-perfect Dice scores** and paving the way for **broader clinical and research applications**.



RESULTS

- Dice scores were used as the measure for optimizing the U-Net, comparing the output to ground-truth manual masks.
- Combining non-ML standard segmentation programs with manually optimized ML methods produced the best Dice score of about 0.966 as compared to automatic optimization with nnU-Net alone, which produced Dice scores even higher of greater than 0.99.
- The models were further characterized in utilizing the entire 3D image versus 2D slices, which revealed high statistical significance between the 3D and 2D groups across all models ($p < 0.001$), with utilization of 2D data having better average Dice score.



Average Dice scores for each nnU-Net model, comparing using the entire 3D elastograph or 2D slices from each image. Error bars represent one SD.

CONCLUSION

Collaboration is crucial for advancing MRE into brain imaging applications, particularly in transitioning it from a research tool to a clinical modality. MRE holds promise for diagnosing and monitoring neurological conditions like tumors or Alzheimer's dementia in advance of conventional MRI, potentially changing the disease course with earlier intervention. With continued development and utilization of nnU-Net, we hope to even further optimize the outputs for a variety of situations and increase the reliability of elastograms across different research sites.

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