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Bridging the Gap Between Anatomy and Structural Connectivity: Synthetic Generation of Fractional Anisotropy Maps from T1 MRI

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Introduction/Background
Diffusion tensor imaging (DTI) is a key technique for the evaluation of white matter integrity and structural connectivity. DTI-derived tractography is used clinically to avoid damage to white matter tracts in preoperative planning for brain tumor resection and radiation therapy planning. We hypothesized that generative AI could produce synthetic diffusion tensors and fractional anisotropy (FA) maps from structural T1-weighted images alone. We investigated (1) the accuracy of synthetic FA maps produced using a fully-supervised approach and (2) whether a generative adversarial network (GAN) could improve the perceptual sharpness of synthetic FA maps.

Methods/Intervention
We obtained 946 subjects with volumetric T1-weighted and DTI scans from the Human Connectome Project and transformed derived diffusion tensors to the log-Euclidian space for the ground truth. We trained a 3D transformer-based generator to predict the six unique log-tensor elements from T1 images. We conducted fully-supervised training using an image-based loss function and introduced a 3D discriminator network for adversarial training. We measured performance in five-fold cross validation using metrics including mean absolute error (MAE), angular error of the principal eigenvector (PEV), and sharpness ratio (synthetic/true) of color-FA maps. Sharpness improvements from GAN fine-tuning were analyzed per-subject using the Wilcoxon signed-rank test.

Results/Outcome
The fully-supervised model successfully predicted the log diffusion tensors and FA maps, with mean FA MAE of 0.0495±0.0008, log-tensor MAE of 0.100±0.002, and mean PEV angular error of 15.9±0.3 degrees (standard deviations, five-fold observations). The median sharpness ratio was 0.730 (IQR 0.717-0.744) using the fully-supervised model and 0.947 (IQR 0.931-0.962) using the GAN, representing a significant improvement ($p < 0.001$, $n=846$, $Z=25$, Holm-Bonferroni corrected).

Conclusion
Our model predicted accurate synthetic FA maps from a single T1-weighted image, and the sharpness of derived color-FA maps was substantially enriched using a GAN strategy. Increases in error in the GAN versus fully-supervised model reflect expected tradeoffs between strict conditional-mean accuracy and sharpness.

Statement of Impact
Diffusion tensors and color FA maps can be predicted from anatomical MRI using GAN models; this technique can aid with surgical and radiotherapy planning. This method also enables widespread availability of structural

connectivity information from anatomical data alone, particularly in resource-limited settings where specialized acquisitions are not feasible.

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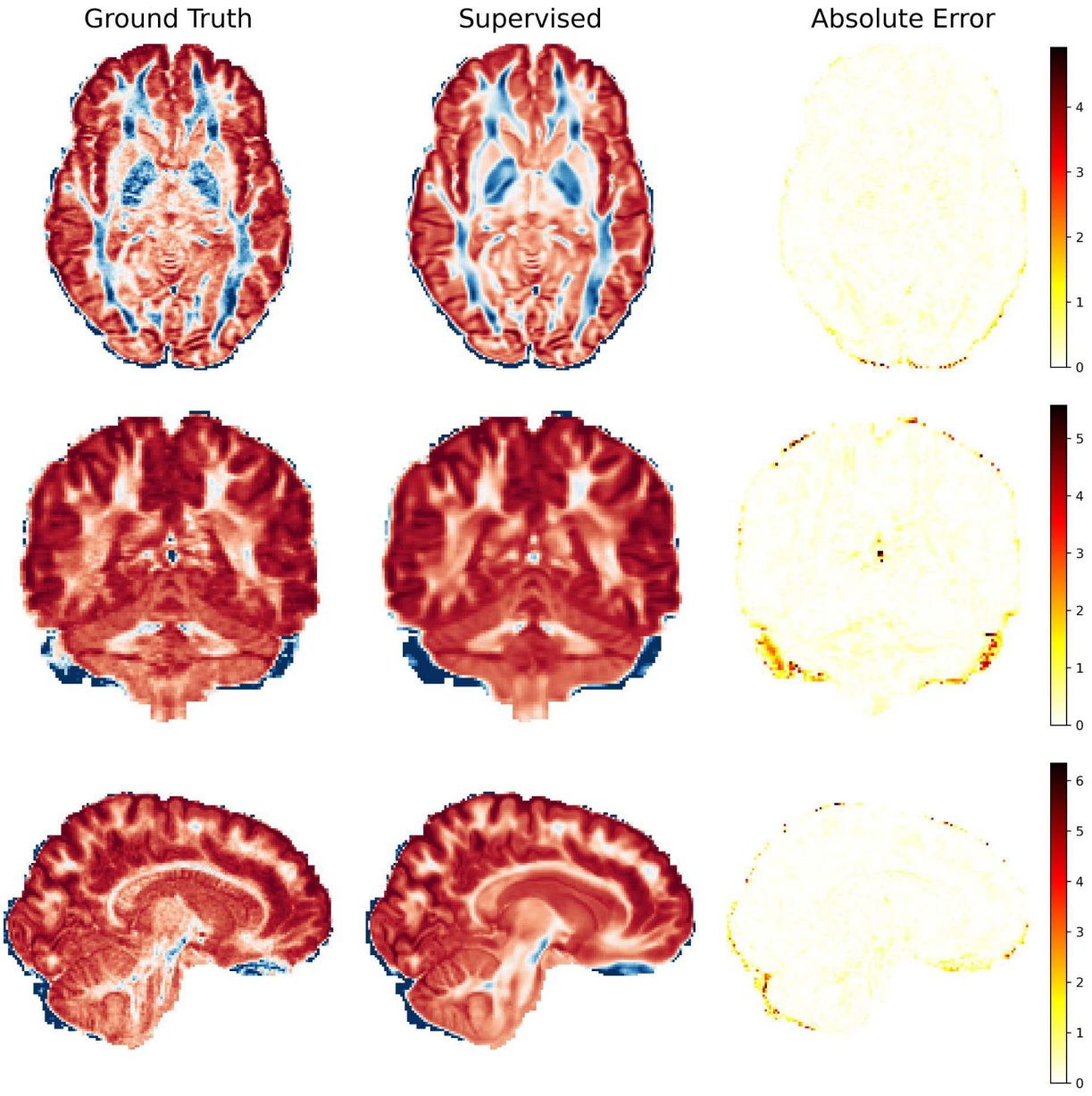

Figure 1. Representative axial, coronal, and sagittal slices of the S11 component of the log-diffusion tensor using the fully-supervised model on three subjects (rows). Columns show the ground truth (left), supervised prediction (middle), and absolute voxelwise error (right). A diverging color scale was used for the log tensor maps, i.e., blue/white/red corresponds to negative/zero/positive values respectively.

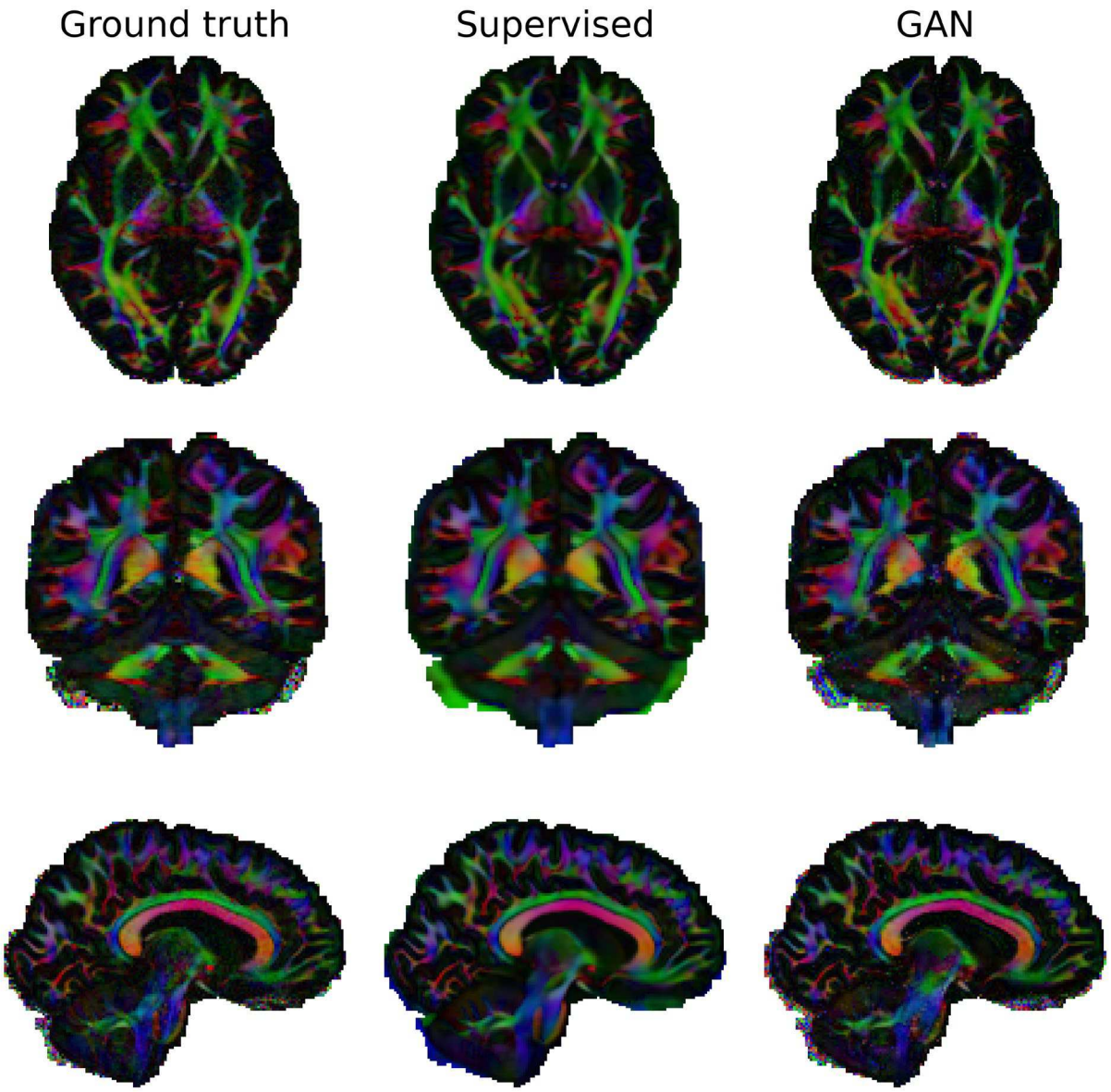

Figure 2. Representative axial, coronal, and sagittal slices of the fractional anisotropy map for three subjects (rows). Columns show the ground truth (left), fully-supervised model prediction (middle), and adversarial (GAN) model prediction (right). The color scale represents fiber orientation (red: left-right, green: anterior-posterior, blue: superior-inferior).

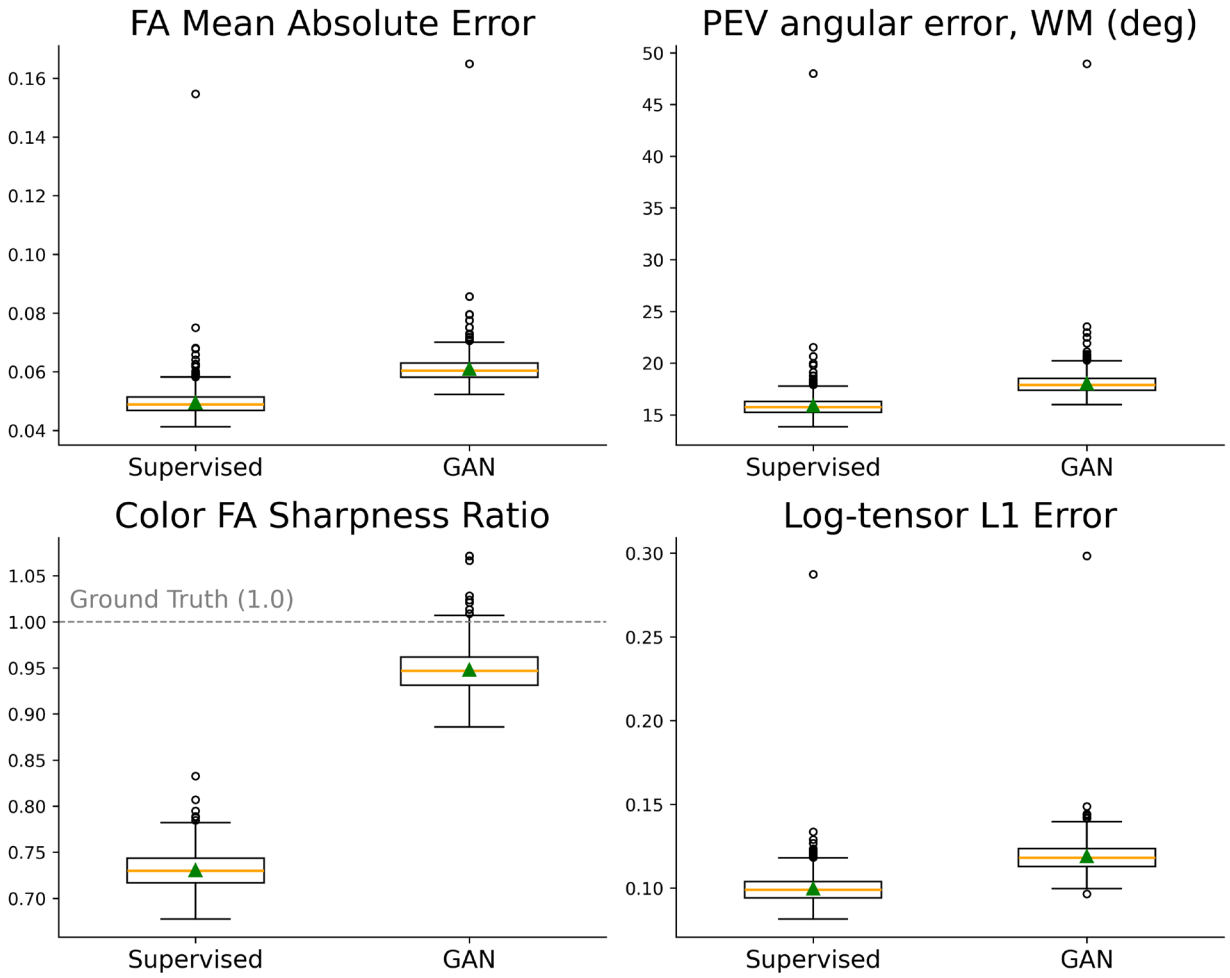

Figure 3. Boxplots of diffusion tensor reconstruction metrics for supervised versus adversarial (GAN) model predictions for held-out subjects. Panels show (A) fractional anisotropy (FA) mean absolute error, (B) principal eigenvector (PEV) angular error (degrees), (C) sharpness ratio of color-coded fractional anisotropy, and (D) log-tensor L1 error. Boxes span the interquartile range (IQR), with the orange line indicating the median and the green triangle indicating the mean. Whiskers extend to 1.5×IQR; open circles denote outliers.

Keywords
Brain MRI; Deep Learning; Generative AI; Radiology; Generative Adversarial Network