Supplementary Material

The supplementary material provides a detailed examination of various aspects of the brain MRI registration methods and model components. Appendix A presents training curves for multiple MRI registration models, showcasing their performance in terms of SSIM scores and loss values across epochs. This analysis reveals that NestedMorph and TransMorph are the top performers, while VoxelMorph and MIDIR lag behind. Appendix B offers a comprehensive breakdown of the parameters in the NestedMorph model, highlighting a significant concentration in the Encoder and DAE-Former components. Appendix C includes further visualizations comparing eight registration techniques, illustrating their registered images, binary masks, deformation fields, and vector grids, with NestedMorph achieving the highest similarity score. Together, these appendices underscore the effectiveness of NestedMorph and TransMorph, detail the parameter distribution within NestedMorph, and provide a visual comparison of registration techniques to highlight their performance and alignment capabilities.

Appendix A. Comparison of Training Curves Across MRI Registration Models

Figure 1 shows the training curves for MRI registration models, including NestedMorph, TransMorph, CycleMorph, Vit-V-Net, VoxelMorph, and MIDIR, revealing significant performance differences. NestedMorph and TransMorph consistently outperform the others, achieving higher SSIM scores and lower loss values across training and validation phases, highlighting their superior learning efficiency and generalization capabilities. In contrast, VoxelMorph and MIDIR struggle with slower convergence and higher residual losses, reflecting difficulties in handling more complex tasks. CycleMorph and Vit-V-Net exhibit steady improvement, but their final SSIM scores and loss values suggest limitations in addressing intricate registration challenges. VoxelMorph and MIDIR further lag behind, demonstrating inefficiencies in capturing the complexity of medical images. Overall, NestedMorph and TransMorph emerge as the most effective models for accurate and robust brain MRI registration.

Appendix B. Analysis of Parameters in NestedMorph

From Table 1, the parameter distribution in NestedMorph reveals a significant focus on the Encoder and the DAE-Former components. The Encoder has the largest share, with 86.66 million parameters, reflecting its crucial role in feature extraction and transformation. The DAE-Former 1 contributes most of the remaining parameters (87.59 million), indicating its substantial role in the model's capability to perform denoising and feature refinement. The DAE-Former 2, LKA-Former 1, and LKA-Former 2 components, while still important, have comparatively smaller parameter counts, at 22.04 million, 4.05 million, and 2.08 million respectively. Overall, this distribution highlights the model's emphasis on robust feature encoding and transformation, with efficient processing managed by the more compact components.

Module	**Params (M)**
Encoder	86.66
Decoder	
DAE-Former 1	87.59
DAE-Former 2	22.04
LKA-Former 1	4.05
LKA-Former 2	2.08
Total	**202.41**

Table 1. Parameter count for each module in the model.

Appendix C. Further Visualization Results

Figure 2 presents a comprehensive comparison of various state-of-the-art brain MRI registration methods. The top row displays the moving (Im) and fixed (If) reference images, providing a baseline for subsequent analyses. Below, eight different registration techniques are evaluated: NiftyReg, SyN, MIDIR, VoxelMorph, CycleMorph, TransMorph, VIT-V-Net, and NestedMorph. Each method is represented by a row containing four key visualizations: the registered brain image, a binary mask highlighting the brain's contour, a 3D surface plot illustrating the deformation field, and a vector field grid depicting the transformation. Accompanying each method is a numerical value, likely representing a similarity or accuracy metric, with higher values potentially indicating superior performance. The registered images demonstrate subtle variations in alignment and detail preservation, while the deformation fields and vector grids offer insights into the underlying transformation mechanisms. Notably, NestedMorph achieves the highest score (0.923), suggesting superior performance in this comparative analysis.

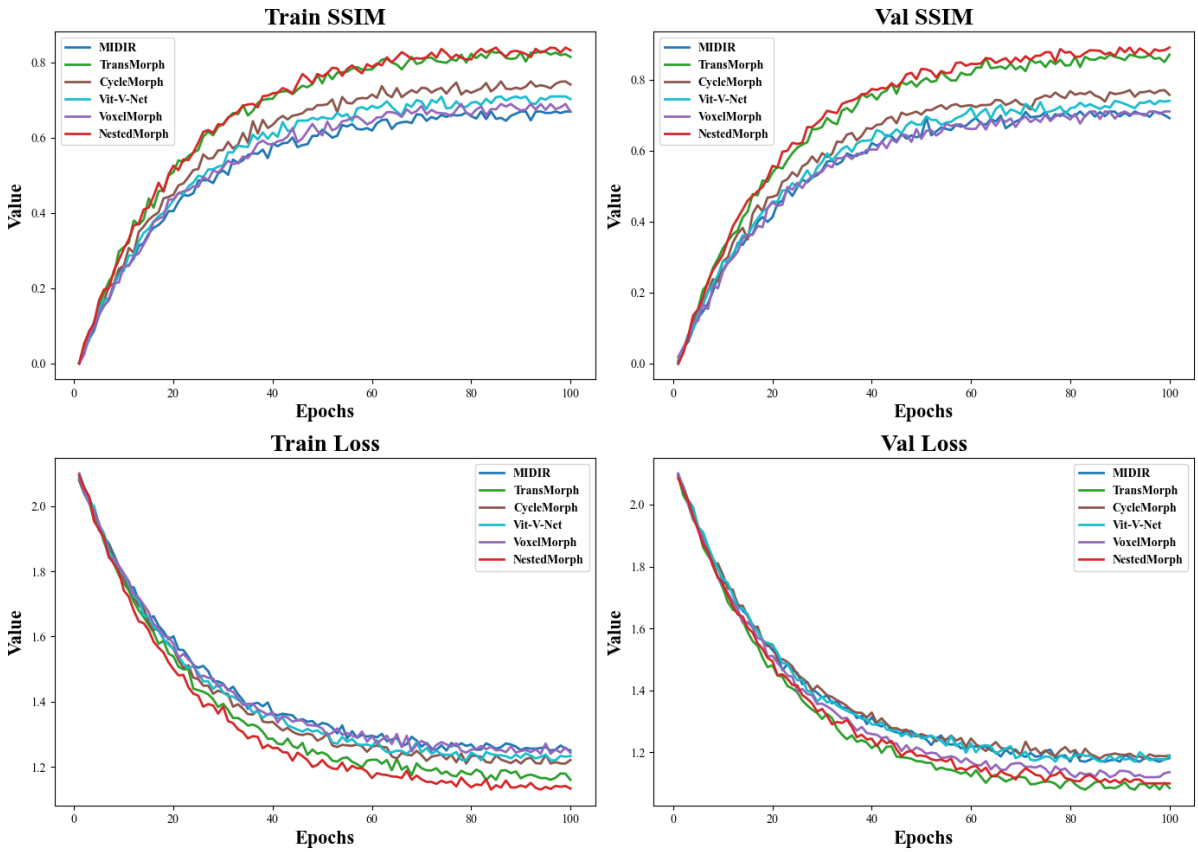

Figure 1. **Training curves for MRI registration models, showing SSIM scores and loss values.** NestedMorph and TransMorph perform best, while VoxelMorph and MIDIR lag.

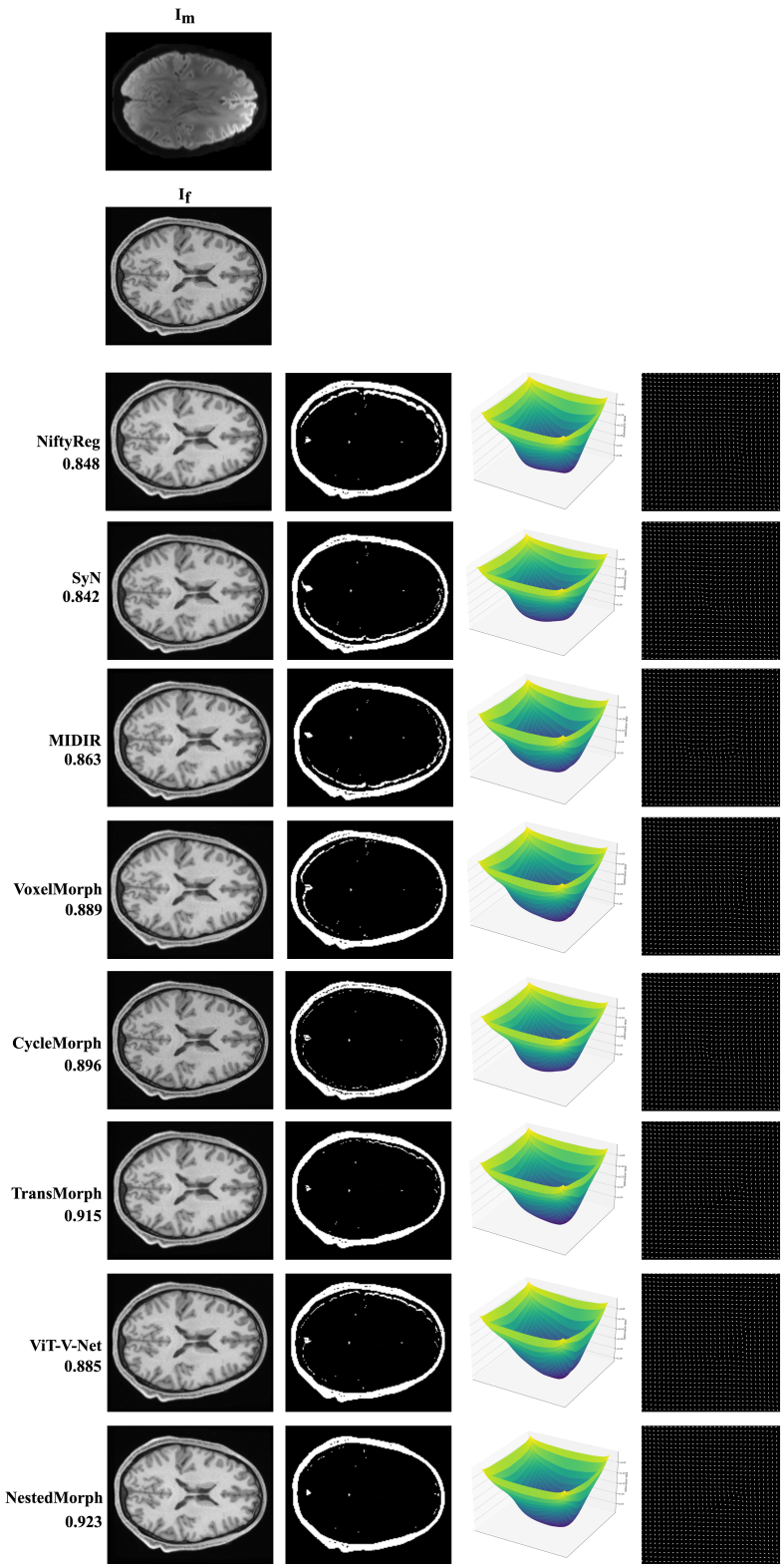

Figure 2. **Visual comparison of brain MRI registration methods. Top: Moving and fixed images.** Below: Results from eight techniques (NiftyReg, SyN, MIDIR, VoxelMorph, CycleMorph, TransMorph, VIT-V-Net, NestedMorph), with NestedMorph showing the highest similarity score (0.923).