Optimizing SVRTK Input Parameters for High-Resolution Fetal Brain Reconstruction: A Technical Validation Study

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Background

- Fetal magnetic resonance imaging (MRI) functions as a second-line examination in prenatal care, performed after the detection of abnormalities in ultrasonography
- MRI is non-invasive and not harmful to pregnant individuals or fetuses (non-ionizing radiation)
- Non-invasive imaging technology is critical for the early detection of neurodevelopmental disorders.
- 2D stacks may be acquired in different orientations, at different time points, or become distorted due to fetal motion, resulting in poor image quality and motion corruption
- Slice-to-volume (SVR) reconstruction is a retrospective technique that reorients and repositions the motion-corrupted 2D stacks to create high-resolution 3D brain volumes

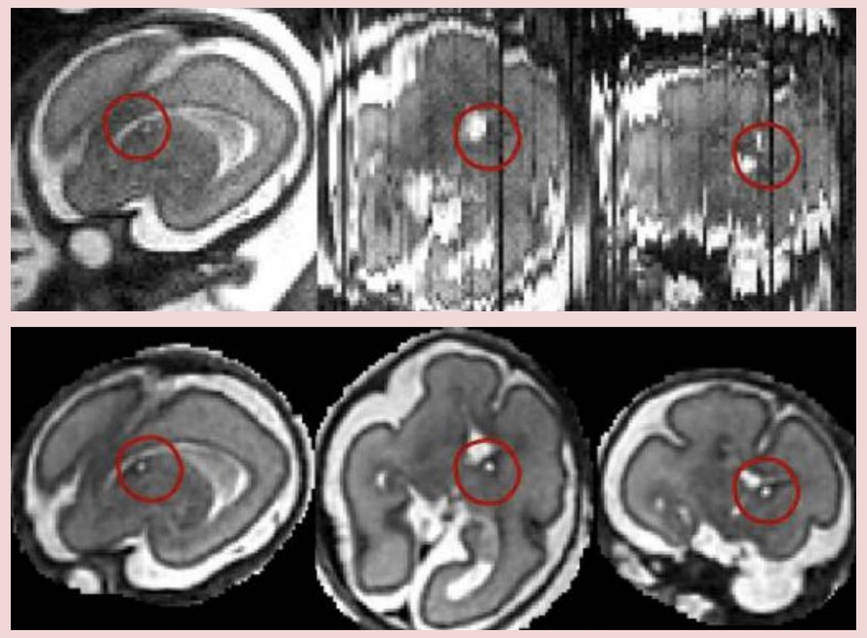
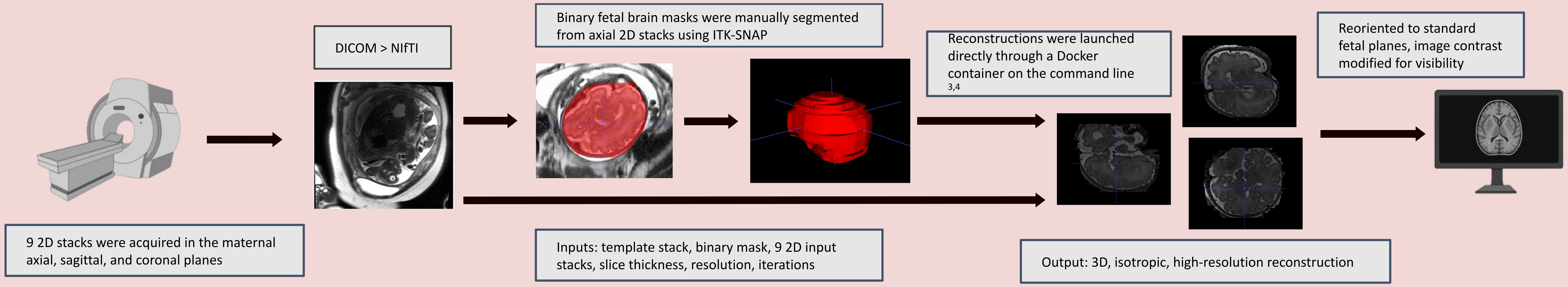


Figure 1. Motion-corrupted anisotropic 2D stacks (above), 3D SVR isotropic reconstructions (below) [1]

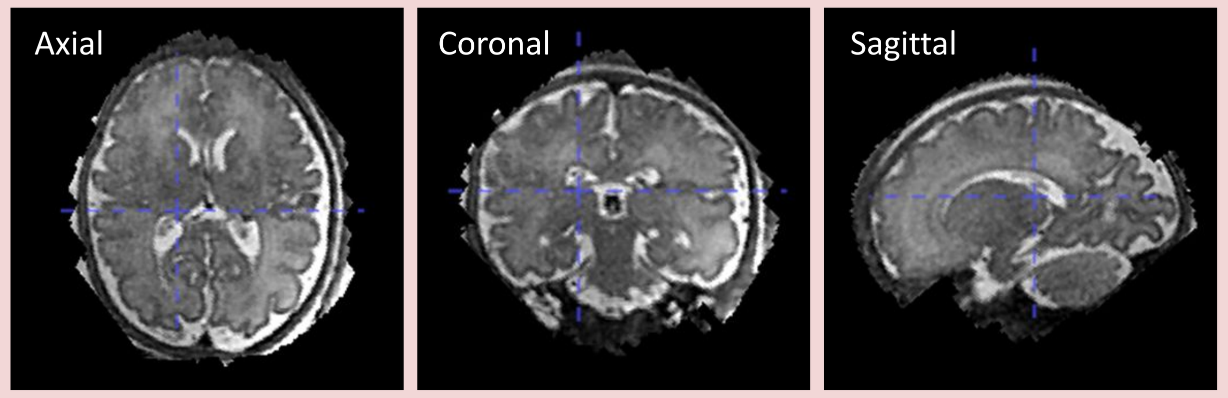
- The SVR ToolKit (SVRTK), is an open source software utilizing Medical Imaging Registration ToolKit (MIRTK)-based reconstruction.[1]
- With a strong IRTK foundation, SVRTK holds high potential for clinical utility, has a largely automated pipeline requiring minimal inputs, and has a fast processing time (due to C++ parallelization)[1]
- Minimal literature exists on optimizing SVRTK input parameters, suggesting a possible barrier to reconstruction consistency and reproducibility

Methods

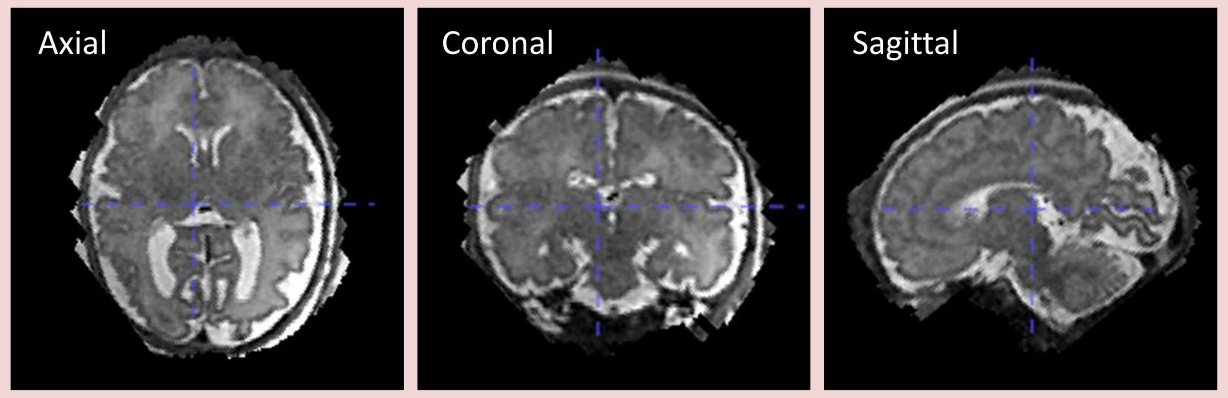
We conducted a retrospective analysis using fetal brain MRI data from a longitudinal study of pregnant participants conducted at OHSU.[2] MRI scans were acquired on a 3T Siemens Prisma scanner using T2-weighted HASTE sequences and muti-echo GRE sequences for T2* mapping. Data collection was IRB-approved, with informed consent obtained. We focused on the third scan time point (31-40 weeks gestational age) from a subset of OHSU participants.



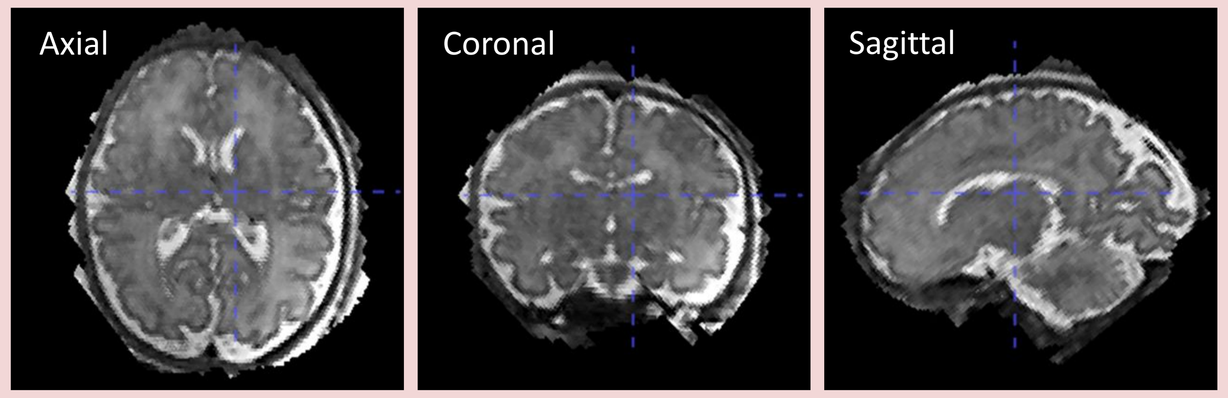
Results



Reconstructed volume voxel size: 0.50 mm, Processing time: ~24 mins



Reconstructed volume voxel size: 0.75 mm, Processing time: ~9 mins



Reconstructed volume voxel size: 1.00 mm, Processing time: ~5 mins

Example: Placenta Imaging Participant 328 (PIPO-328)

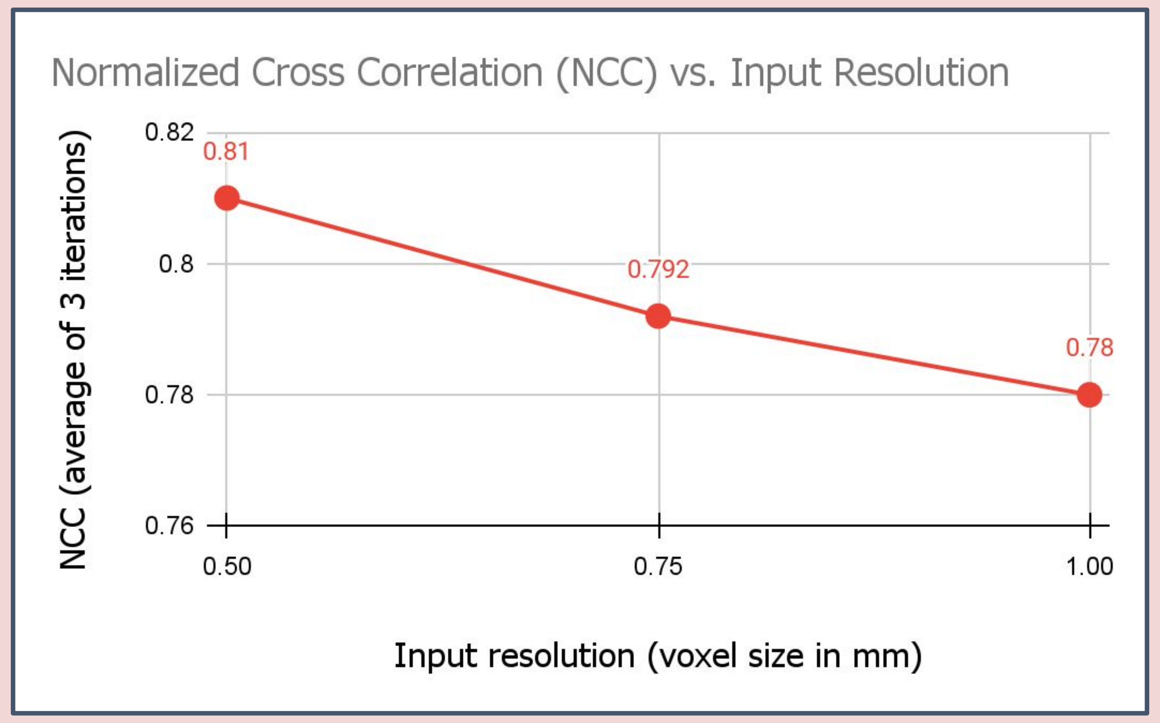
Reconstruction Quality Values:

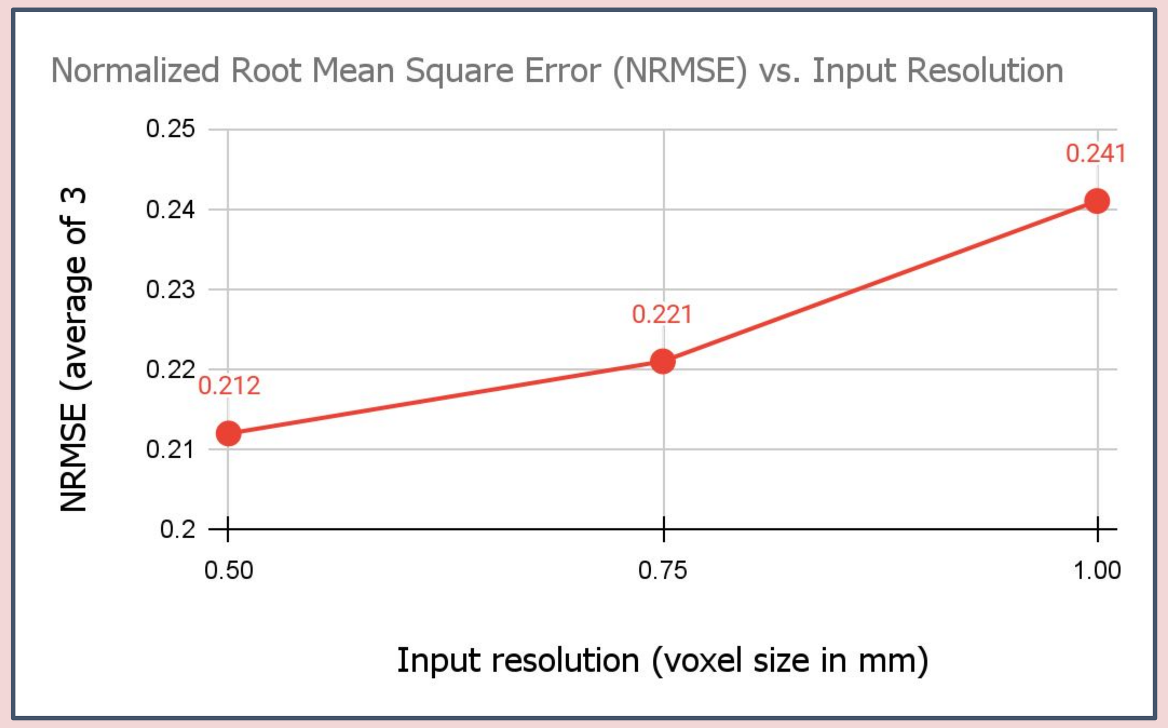
Normalized Cross Correlation (NCC)

- Measures how similar the reconstructed volume is to the template stack (more similar=closer to 1)

Normalized Root Mean Squared Error (NRMSE)

- Measures average error between reconstructed volume and template stack (less error=closer to 0)





Objectives

1) Identify the primary factors affecting SVRTK fetal brain reconstruction quality
   a) The output reconstructions will be set at resolutions of 0.50 mm, 0.75 mm, and 1.0 mm
   b) We expect the maximum executable image resolution to be 0.75 mm
2) Create a framework to establish a normative dataset comprised of high-resolution, motion-corrected fetal brain reconstructions
   a) Analyze retrospective data from a placenta imaging study conducted by Schabel et al.[2]

Conclusions

Preliminary findings demonstrate a correlation between higher-resolution inputs (≤ 0.75 mm) and heightened visual definition and contrast. However, certain reconstructions were unable to execute at 0.50 mm, suggesting a resolution threshold for brain volumes with increased slice counts. Additionally, these results highlight a key trade-off between processing speed and image quality. These early results emphasize the importance of balancing image quality with computational efficiency. Ongoing work will expand the dataset and explore additional parameters to refine SVRTK's performance as well as establish a standardized framework for normative fetal brain reconstructions.

Future Direction

We aim to implement these high-quality reconstructions within the Medical Open Network for AI (MONAI)-based automated processing pipeline for SVRTK dockers to perform deep learning segmentation, and potentially map growth across different brain regions. Additionally, we will examine the correlation between calculated brain volumes and other input quantities. Eventually, the resulting normative datasets may potentially serve as controls in studies with high-risk populations, (i.e. fetuses with prenatal alcohol exposure) to determine if abnormalities in brain development are statistically significant.

Acknowledgements

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