Fetpype: An Open-Source Pipeline for Reproducible Fetal Brain MRI Analysis

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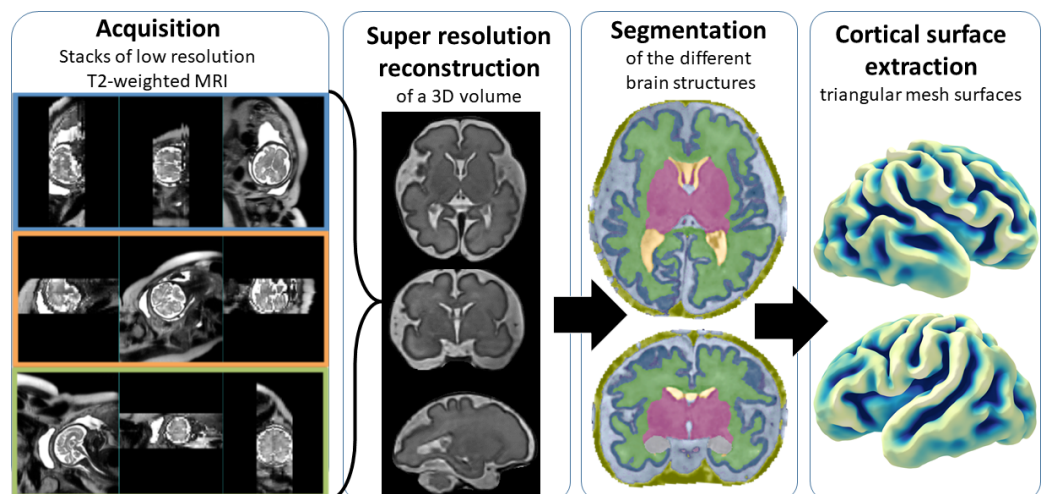
Summary

Fetal brain magnetic resonance imaging (MRI) is crucial for assessing neurodevelopment *in utero*. However, fetal MRI analysis remains technically challenging due to fetal motion, low signal-to-noise ratio, and the need for complex multi-step processing pipelines. These pipelines typically include motion correction, super-resolution reconstruction, tissue segmentation, and cortical surface extraction. While specialized tools exist for each individual processing step, integrating them into a robust, reproducible, and user-friendly end-to-end workflow remains difficult. This fragmentation limits reproducibility across studies and hinders the adoption of advanced fetal neuroimaging methods in both research and clinical contexts.

Fetpype addresses this gap by providing a standardized, modular, and reproducible framework for fetal brain MRI preprocessing and analysis, enabling researchers to process raw T2-weighted acquisitions through to derived volumetric and surface-based outputs within a unified workflow.

Statement of need

Fetpype is an open-source Python package designed to streamline and standardize the preprocessing and analysis of T2-weighted fetal brain MRI data. The package targets the fetal neuroimaging community, where methodological heterogeneity and complex software dependencies have historically limited reproducibility and comparability across studies.

Existing fetal brain MRI tools typically focus on individual processing steps and require customized code for pre- and post-processing, as well as to connect different modules, making it difficult to reproduce processing results across studies. Fetpype addresses these challenges by providing a configurable, containerized, and Nipype-driven solution that integrates state-of-the-art fetal MRI processing tools into a cohesive pipeline. By emphasizing reproducibility, extensibility, and ease of use, Fetpype lowers the barrier to applying advanced fetal MRI analysis methods and facilitates consistent processing across sites, scanners, and studies. In doing so, Fetpype improves comparability across studies and supports community collaboration by facilitating the dissemination of new image processing methods for clinical applications. The pipeline is publicly available on GitHub (https://github.com/fetpype/fetpype).

Figure 1: The different steps covered by `Fetpype`. Starting from several T2-weighted stacks of thick slices of the fetal brain (*acquisition*), Fetpype pre-processes data before feeding them to a *super-resolution reconstruction* algorithm that fuses them in a single high-resolution volume. This volume then undergoes *segmentation*, before moving to cortical *surface extraction*.

State of the field

Fetal brain MRI analysis relies on a range of specialized tools that address individual processing steps, particularly motion correction and super-resolution reconstruction. Widely used reconstruction frameworks include SVRTK (C++) (Kuklisova-Murgasova et al., 2012; Alena U. Uus et al., 2022), NiftyMIC (Python) (Ebner et al., 2020), and NeSVoR (Python/PyTorch) (Xu et al., 2023). While increasingly distributed as containers, these tools rely on distinct data organization schemes as well as custom pre- and post-processing steps. Downstream processing tools for brain extraction, segmentation, and surface reconstruction show similar diversity, combining Python scripts, compiled binaries, and domain-specific imaging libraries (Bazin & Pham, 2005; Faghihpirayesh et al., 2024; Makropoulos et al., 2018; Alena U. Uus et al., 2023). As a result, constructing an end-to-end fetal MRI workflow typically requires custom scripting to orchestrate multiple containers, manage data formats, and handle intermediate outputs, limiting reproducibility and accessibility.

Fetpype was built to address these limitations by providing a unified, Python-based framework to integrate existing containerized tools for fetal brain MRI analysis. By enforcing data formatting following the widely-used Brain Imaging Data Structure (BIDS) standard (Gorgolewski et al., 2016), and leveraging containerized execution and `Nipype`-based workflow management (Gorgolewski et al., 2011) and Hydra-based configuration (Yadan, 2019), Fetpype Fetpype provides a standardized and scalable environment for reproducible end-to-end fetal brain MRI analysis on both local workstations and large-scale computing clusters.

Software design

Fetpype is built around four core design principles: data standardization, containerization, workflow orchestration, and flexible configuration:

1. **Data Standardization**: Fetpype expects input data organized according to the BIDS standard (Gorgolewski et al., 2016), promoting interoperability and simplifying data management.
2. **Containerization**: Individual processing tools are encapsulated within Docker or Singularity containers. This ensures reproducibility and reduces installation issues, providing a better

experience for the end user.

3. **Workflow Management**: The `Nipype` library ([Gorgolewski et al., 2011](#)) is used to construct processing workflows: it provides a robust interface for combining different steps from different containers or packages, facilitating data caching and parallelization, and allowing pipelines to be easily shareable.

4. **Configuration**: Pipeline configuration is managed using simple YAML files and the Hydra library ([Yadan, 2019](#)), allowing users to easily select between different modules or parameters without directly modifying the code. The current implementation of `Fetpype` integrates modules for:

   a. **Data preprocessing**: including brain extraction using `Fetal-BET` ([Faghihpirayesh et al., 2024](#)), non-local means denoising ([Manjón et al., 2010](#)) and N4 bias-field correction ([Tustison et al., 2010](#)), all wrapped into a single container built at https://github.com/fetpype/utils_container,

   b. **Super-resolution reconstruction**: implementing three widely used pipelines: NeSVoR ([Xu et al., 2023](#)), SVRTK ([Kuklisova-Murgasova et al., 2012](#); [Alena U. Uus et al., 2022](#)), and NiftyMIC ([Ebner et al., 2020](#)),

   c. **Segmentation**: implementing BOUNTI ([Alena U. Uus et al., 2023](#)) and the developing human connectome project pipeline ([Makropoulos et al., 2018](#)) and

   d. **Cortical surface extraction**: using a custom implementation available at https://github.com/fetpype/surface_processing based on ([Bazin & Pham, 2005](#), [2007](#); [Ma et al., 2022](#)).

The overall processing workflow is summarized in [Figure 1](#).

Research impact statement

`Fetpype` is the result of a longstanding collaboration within a European consortium of researchers specializing in fetal neuroimaging. Its default configurations and processing workflows have been the result of extensive testing to achieve robust processing on data acquired across multiple hospitals in France, Spain, and Switzerland, covering a range of scanners and acquisition protocols.

The framework has been used to process large-scale fetal MRI datasets within the consortium, has contributed to a first publication ([Sanchez, Mihailov, et al., 2026](#)), and is supporting ongoing research projects. Fetpype is used by multiple research groups and has begun to receive external contributions, including pull requests that integrate additional processing methods. This suggests that `Fetpype` addresses a clear methodological need and can serve as shared community infrastructure for fetal brain MRI research.

In the future, we plan to supplement `Fetpype` with an automated reporting library containing automated quality control ([Sanchez, Zalevskyi, et al., 2026](#); [Sanchez et al., 2024](#)), subject-wise and population-wise biometry and volumetry ([Esteban et al., 2017](#); [Neves Silva et al., 2025](#)), as well as spectral analysis of surfaces ([Germanaud et al., 2012](#)). We welcome community contributions, particularly implementations of new methods that can be integrated into the existing containerized workflow framework.

AI usage disclosure

GitHub Copilot, integrated within Visual Studio Code, was used during software development to assist with code completion and implementation. ChatGPT (GPT-5.2) was used for proofreading and language refinement of the manuscript. The authors take full responsibility for the written content.

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