Project title: Towards a digital twin of the fetal heart: Predicting coarctation of aorta

Project reference: DT4H_08_2024

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Aim of the Project

We propose to develop a novel deep learning shape prediction and analysis technique to generate topologically correct model of challenging fetal cardiac anatomy from fetal MRI. We aim to accurately predict development of coarctation of aorta after birth, by expanding shape analysis to complex non-linear spaces, characterising fetal heart function from recently developed 3D+T fetal MRI, and performing causal analysis. We hypothesise, that these advanced techniques will improve the risk prediction and reach the threshold for successful clinical translation. The new technique will be evaluated through our unique fetal cardiac MRI service in Evelina Children's hospital, making immediate impact on diagnostic accuracy and management of unborn babies with congenital heart disease.

Project Description

Congenital heart disease (CHD) affects up to 1% of live births, with up to 25% of babies needing life-saving intervention soon after birth. Accurate diagnosis during fetal life is therefore essential for planning of neonatal care. Coarctation of aorta (CoA), narrowing of the aortic arch, is one of the most difficult forms of CHD to diagnose, while being life-threatening if surgery is not performed soon after birth, as the fetal circulation through placenta transitions to neonatal.

We have recently shown that statistical shape models, extracted from manually segmented motion corrected 3D fetal MRI, can capture differences between fetal hearts that go on to develop CoA and those that will not, with up to 90% accuracy (Hermida et al. Cardio. Trans. Res. 2023). However, the technique requires significant manual inputs, which can take several hours per case, and false positive rate is still too high for it to be translated to clinical practice. Our previous work also explored automating the fitting of the shape models to 3D fetal MRI through deep learning segmentation (Ramirez et al. MICCAI PIPPI 2023), however there were difficulties with accurate and topologically correct delineation of the fetal cardiac vessels, resulting in failure to correctly fit the shape model in up to 40% of the cases.

Recent work on deep learning shape analysis provides evidence that direct fitting of topologically correct surface models is feasible (Ma et al. MICCAI 2024) and advanced losses can improve delineation of tubular structures such as cardiac vessels (Shi et al. MICCAI 2024), potentially benefiting our application. Additionally, we only explored linear statistical shape models and extracted a simple one-dimensional score, so there is a scope for development of advanced nonlinear machine or deep learning techniques (Amrani et al. MICCAI 2024) to further improve accuracy of the predictions. Furthermore, so far we have only utilised stationary 3D cardiac MRI, but we now routinely acquire 3D+T MRI of moving fetal heart (van Ameron et al. MRM 2019), that potentially offer richer functional biomarkers for further improvement of the diagnosis.

Our unique fetal cardiac MRI service at St Thomas and Evelina Children's Hospitals provides UK-wide prenatal diagnosis of CHD based on our motion corrected 3D fetal MRI (Uus et al. MedIA 2022) and proof that 3D MRI improves confidence in diagnosis of CHD (Lloyd at al. Lancet 2019). Through this service we obtained over 500 motion corrected and segmented fetal cardiac MRI scans that will be available for this project. This service will also provide direct route for clinical translation of results of this PhD project.

Requirements:

This project would be suited for a candidate with strong technical background in computing, engineering or similar, with interest in medical image analysis, machine learning and deep learning.

Suggested reading:

Hermida *et al.* (2023). Learning the Hidden Signature of Fetal Arch Anatomy: a Three-Dimensional Shape Analysis in Suspected Coarctation of the Aorta. *J. of Cardiovasc. Trans. Res.* **16**, 738–747. https://doi.org/10.1007/s12265-022-10335-9

Ramirez *et al.* (2023). Towards Automatic Risk Prediction of Coarctation of the Aorta from Fetal CMR Using Atlas-Based Segmentation and Statistical Shape Modelling. Perinatal, Preterm and Paediatric Image Analysis. PIPPI 2023. Lecture Notes in Computer Science, vol 14246. Springer, Cham. https://doi.org/10.1007/978-3-031-45544-5_5

Ma *et al.* (2024). Weakly Supervised Learning of Cortical Surface Reconstruction from Segmentations. Medical Image Computing and Computer Assisted Intervention – MICCAI 2024. MICCAI 2024. Lecture Notes in Computer Science, vol 15011. Springer, Cham. https://doi.org/10.1007/978-3-031-72120-5_71

Shi *et al.* (2024). Centerline Boundary Dice Loss for Vascular Segmentation. MICCAI 2024. Lecture Notes in Computer Science, vol 15008. Springer, Cham. https://doi.org/10.1007/978-3-031-72111-3_5

El Amrani (2024). A Universal and Flexible Framework for Unsupervised Statistical Shape Model Learning. In: Medical Image Computing and Computer Assisted Intervention – MICCAI 2024. MICCAI 2024. Lecture Notes in Computer Science, vol 15011. Springer, Cham. https://doi.org/10.1007/978-3-031-72120-5_3

van Amerom (2019). Fetal whole-heart 4D imaging using motion-corrected multi-planar real-time MRI. Magn Reson Med. doi: 10.1002/mrm.27798. https://doi.org/10.1002/mrm.27798

Uus (2022). Automated 3D reconstruction of the fetal thorax in the standard atlas space from motion-corrupted MRI stacks for 21–36 weeks GA range, Medical Image Analysis. https://doi.org/10.1016/j.media.2022.102484.

Three-dimensional visualisation of the fetal heart using prenatal MRI with motion-corrected slice-volume registration: a prospective, single-centre cohort study

Lloyd, David F A et al. The Lancet, Volume 393, Issue 10181, 1619 – 1627
https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(18)32490-5/fulltext