Quantification of Fetal Motion Tracked with Volumetric Navigator MRI Acquisitions

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Intro: Motion of the fetus routinely limits fetal brain MR image acquisitions to rapid low-resolution, single-slice sequences, which in turn limits the types of image contrast achievable. Even with these rapid sequences, image quality is often compromised due to motion, with multiple repetitions commonly required for diagnostic studies. Prospective motion correction using fast 3D navigators has significantly improved pediatric brain imaging, and therefore fast 3D navigators that can accurately track fetal head motion are projected to be crucial for the development of higher resolution and high-fidelity contrast for diagnostic imaging of the fetal brain by MRI. Measurement and characterization of fetal motion by itself are also potentially clinically useful, as motion relates to well-being of the fetus. Here, we quantitatively measure time-series of fetal head motion using low-resolution volumetric navigator acquisitions (vNavs[1]). We show for the first time that vNavs can provide a high-frequency (0.7 Hz) time series of fetal brain volume motion. The fact that we can characterize fetal motion retrospectively indicates the potential for vNavs to be embedded in diagnostic sequences [1] to enable prospective motion correction in fetal imaging.

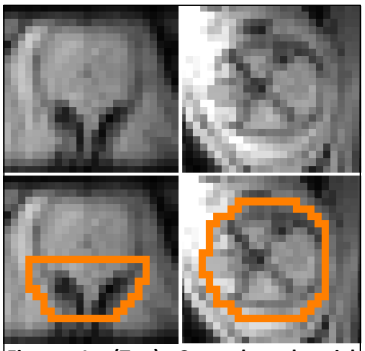


Figure 1: (Top) Coronal and axial sections showing brain/skull base contrast. (Bottom) Outline highlighting ROI used for motion tracking.

Methods: Five pregnant subjects were scanned using a 3T Siemens Skyra system. 3D gradient echo EPI images (TR=41ms, TE=13ms, 5x5x5mm^3, FOV=300x300x120mm^3, acquisition time= 738ms/volume) were acquired at 50 consecutive time points (TA=39s) over a 3D FOV including the fetal head. The acquisition that showed the most motion of the fetus was selected for further analysis. Each 3D volume was divided by a smoothed version of itself to remove inhomogeneities due to coil sensitivities. From the first 3D image, "Frame 1", a 3D ROI containing the high-contrast areas of the skull base and cervical vertebral bodies compared to temporal lobe, posterior fossa and cervical cord, was segmented (Figure 1). This ROI was then registered to each subsequent 3D image using an iterative method (Figure 2). Assuming Frame 1 had been registered to each of the first N-1 time points, we were able to register Frame 1 to the Nth time point, "Frame N". The ROI mask for Frame 1 was multiplied by the transformation matrix from the Frame 1 to Frame N-1 registration (Fig. 2B-C). This mask was dilated and multiplied by Frame N to produce a "Frame N ROI" image (Fig. 2D-F). The Frame 1 ROI image (Fig. 2A) was registered to the Frame N ROI image (Fig. 2F) with the FSL FLIRT registration tool (cost function=correlation ratio, DOF=6) [2]. Weighting masks were used in the registration to emphasize particularly clear areas of image contrast. Frames that were misaligned after registration were excluded from further analysis. The rigid-body transformation matrices obtained from the registrations were multiplied by points within the fetal head to produce time series of position along 3 translational and 3 rotation coordinates. To obtain time-series for 3 independent rotational position coordinates, the 3D rotation matrices were separated into 3 extrinsic rotations, applied in the order Y-X-Z. That is: $\boldsymbol{R_{3D}\bar{v} = R_z R_x R_y \bar{v}}$, for a 3D rotation $\boldsymbol{R_{3D}}$ and a rotation $\boldsymbol{R_i}$ about axis $\hat{\boldsymbol{\imath}}$. Each matrix $\boldsymbol{R_i}$ is determined by a single parameter, which was plotted as a function of time.

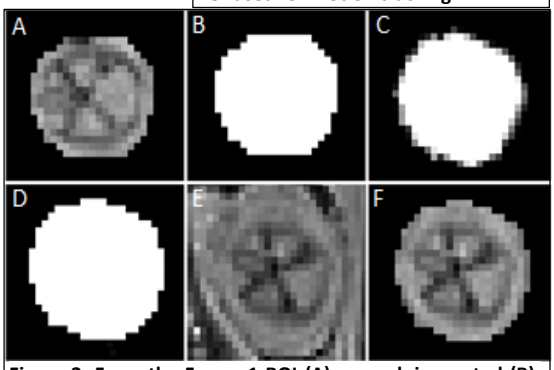
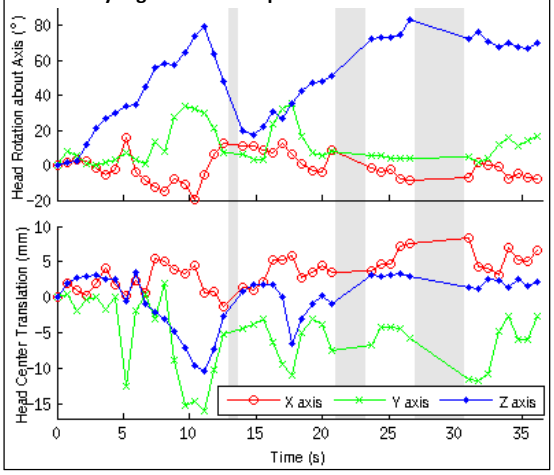


Figure 2: From the Frame 1 ROI (A), a mask is created (B). Using the Frame 1 to Frame N-1 transformation matrix, this is transformed (C) to get a "last estimate" of head position. The mask is then dilated (D) and multiplied by Frame N (E) to get an ROI for Frame N (F). To obtain the Frame 1 to Frame N transformation matrix, (A) is registered to (F).

Figure 3: Time-series of the 3 rotational and 3 translational position coordinates of the fetus' head, relative to position at t=0. Gray regions are time points that lack data.



Results: Measuring position at 50 time points required 49 registrations, and of these, 40 (82%) produced an accurate image alignment. By applying these 40 valid transformations to points located within the fetal head, we were able to measure its translational and rotational position over time (Figure 3). Using this method, we measured z-axis rotation from 0° to 84° and head center translation of 19mm over 11s, with a time resolution of 738ms.

Discussion: This study demonstrates the feasibility of utilizing low-resolution, fast 3D acquisitions to make quantitative in vivo measurements of fetal motion. We have demonstrated that these low-resolution images contain sufficient contrast for frame-to-frame registration. However, due to inherently poor contrast, the current registration pipeline is not robust enough to track all frames. Additionally, we did not require pre-segmentation of the ROI at each time point, demonstrating the potential of volumetric navigators to be used for live prospective, in addition to retrospective, motion tracking. The use a single ROI obtained from the first time point as a template for all registrations suggests that pattern matching may be a more general approach applicable to this problem.

References: [1] **Tisdall *et al.*** (2012) MRM, 68(2):389-399. [2] **Jenkinson *et al.*** (2002) NeuroImage, 17(2):825-841.

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