Improved slice to volume reconstruction of the fetal brain for automated cortex segmentation

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Introduction The analysis of the structure and geometry of human cortex is an area of increasing interest in neuroscience and several methods have been developed to automatically segment the cortex from magnetic resonance images of the adult brain (e.g. [1]). The source data for segmentation are generally high resolution T1 weighted volumetric images. Recent extensions to automated methods have allowed reliable segmentation of the cortex from neonates including premature babies using T2 weighted images [2]. For the study of cortical development, fetal subjects form the ideal control group for premature infants. The scope of such studies has, however, been limited as the acquisition of high resolution 3D brain images in utero has only recently become possible. The Snapshot to Volume Reconstruction (SVR) method allows single shot fast spin echo (ssFSE) acquired slices to be reassembled into a self consistent anatomical space so that full 3D fetal brain images can be obtained [3,4]. However, applying our automatic segmentation [2] to fetal brain volumes reconstructed using [4] did not result in useful cortex extraction. Although substantial brain detail is reconstructed by the existing SVR method, the cortex was not sufficiently robustly represented.

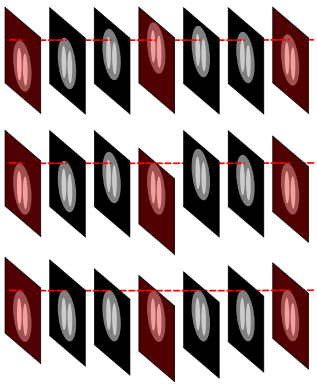

Figure 1 The chained slice method. A set of control slices – shaded in red- are defined in a slice time series (top) and moved (middle) affecting all surrounding slices (bottom)

The SVR method considers the fetal brain as a rigid body undergoing an unknown motion. The correct location in anatomical space for each acquired ssFSE slice is determined using slice-to-volume registration to an estimated target volume of the brain anatomy produced by compounding the slice data using the current transformation estimates. The final reconstruction of the anatomical volume is obtained using a scattered B-Spline approximation [4] or a 'Gaussian injection"' [3] of the registered slices into the target coordinate space. Both methods avoid local minima in the slice-to-volume registration by making successive approximations of the motion pattern. Slices are divided in packages which are registered and then subdivided into smaller groups, and the process repeated until slices are treated individually. However, these approaches do not consider the continuity of the motion pattern in time and can introduce inconsistencies, especially for slices close to the package borders. In this work, we improve the SVR method proposed in [4] to generate data suitable for automated cortical extraction by replacing the simple slice package division scheme with one that models continuous motion over time.

Chained slices Acquired slices are considered as a 4 dimensional temporally ordered dataset with a number of *control slices* defined at regular time intervals. These *control slices* can be moved freely in space –with six degrees of freedom. The intervening slices are then moved proportionately, with their positional changes determined by a interpolation of the transformation parameters of the nearest control slices, as shown in Figure 1. The spatial transformations of the *control slices* are adjusted to minimise the cross correlation (cost function) between all the spatio-temporal data and a current estimate of the target anatomy. The optimisation employs a gradient-descent method, with an analytical expression for the gradient of the cost function to increase its speed and accuracy. Once the optimal transformations have been found, extra control slices are inserted mid-way between the existing ones and the process repeated until slices are registered individually. The algorithm was implemented using Matlab (http://www.mathworks.com) and the registration utilities in ITK (http://www.doc.ic.ac.uk/~dr/software).

Methods A ssFSE sequence (TR=1046ms, TE=120 ms) was implemented on a 1.5T Achieva scanner (Philips Healthcare, The Netherlands) and was used to make continuous scans of 20 fetuses (GA between 22 and 31 weeks). Acquired slices had an in-plane resolution of 1.18 x 1.18 mm and a thickness of 2.5 mm with 50% overlap. Typically, 2-4 complete sets of images were acquired, in the transverse orientation and 2 sets in each of, coronal and sagittal orientations, with each orientation scanned as a single time series. Total scanning time was ~5-8 minutes. No breath hold or sedation of either mother or fetus was used.

The data was exported from the scanner using the DICOM standard and converted to Nifti images that preserve absolute scanner coordinates. A single complete stack of slices was then manually segmented to roughly extract the fetal brain from surrounding maternal tissues. All other processing is automatic. Registration target volumes are constructed for each time series from the other two, and new targets are reconstructed as the slice positions of each time series are updated. Scattered data interpolation based on B-splines [5] is used to reconstruct the targets and the final image volumes that combine all the registered data. The new SVR method was tested on a synthetic dataset, which consisted of slices sampled from a 3D neonatal scan using a simulated motion pattern with added noise, and was also applied to the fetal datasets. The latter were visually assessed for cortical visibility using a scale from 1 (cortex clearly seen with no breaks) to 3 (cortex not seen, or badly disrupted at numerous locations). Automated cortical extraction as described in [2] was tested on 3 data sets for fetuses aged 24, 27 and 30 weeks gestational age that had been graded 1.

Results In simulated data the slices were correctly positioned with accuracies of 0.11±0.2 mm and 0.24±0.48 degrees. There were no failures in reconstruction of the fetal datasets, and of these 10 were graded 1 (see figure 2) and 10 were graded 2 with none graded 3. The extracted cortices were almost complete (Figure 3, an error is indicated by the arrow) and surface reconstructions were made (Figure 4).

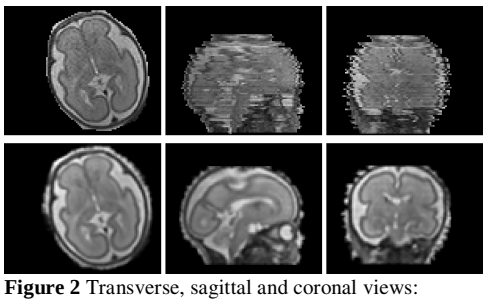

Figure 2 Transverse, sagittal and coronal views: original image (top) and the motion corrected result

Conclusions The control slice approach allied with data acquired in 3 orthogonal views and a scattered B-spline interpolation has produced fetal brain reconstructions that allowed automated cortical extraction. The extracted cortices are not quite complete, but results so far are promising.

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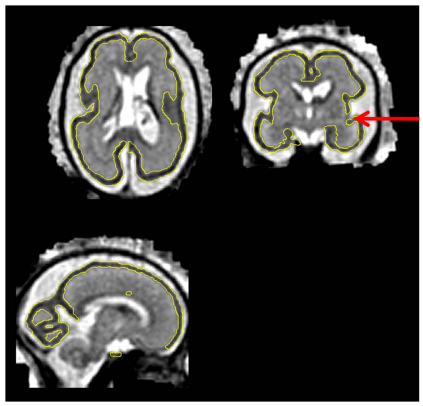

Figure 3 Orthogonal views of extracted inner and outer cortical surfaces. Arrow indicates a break in the extracted cortex

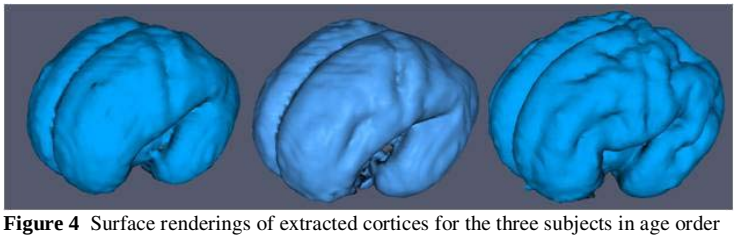

Figure 4 Surface renderings of extracted cortices for the three subjects in age order

References [1] Brain Voyager, www.brainvoyager.com [2] Xue *et al*, NeuroImage 38 pp 461-477, 2007 [3] Rousseau et al., Academic Radiology, 13 pp 1072-1081, 2006 [4] Jiang *et al*, IEEE Trans Med Imaging, 26 pp 967-980, 2007 [5] Lee, et. al., IEEE Trans VCG 3, pp. 228-244, 1997.