Average probabilistic brain atlases for post-mortem newborn and fetal populations and application to tissue segmentation

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Introduction: Segmentation of the fetal and neonatal brain from magnetic resonance (MR) imaging is useful for understanding both normal and abnormal brain development. Although post-mortem MR imaging has the advantage of obtaining high-resolution 3D MR images, segmentation of this kind of data is challenging due to post-mortem artefacts and changes in T1 and T2 tissue values after death [1]. Atlas-based segmentation is one popular method adopted for the segmentation of the brain for which the choice of atlas is crucial. The atlas must be based on patients with similar morphologies in order to obtain an accurate segmentation. In this paper we create average probabilistic brain atlases for newborn and fetus populations and use them for automatic segmentation of the brain of further subjects with similar morphology from the same study.

Methods: We performed post-mortem cerebral MRI using a 1.5 Tesla Siemens Avanto MR scanner in 17 fetuses with ages greater than 24 gestational weeks (GW), 8 fetuses with ages lower than 24 GW and 17 newborns, all having normal brain appearance, as a part of the Magnetic Resonance Imaging Autopsy Study (MaRIAS) [2]. We automatically segmented the brain of the MaRIAS subjects from the 3D T2-weighted MR images (CISS) into cerebrum, cerebellum and brainstem. For this we used an atlas-based Expectation-Maximisation segmentation with prior relaxation (AdaPT [3]). To obtain more accurate segmentations, we introduced a cerebrospinal fluid (CSF) class that contained the CSF and any other abnormal fluid surrounding the cerebellum or brainstem. The newborn cohort was segmented using a publicly available neonate brain atlas [4] to create priors for AdaPT. The obtained segmentations underwent several registration steps and were averaged after each step to obtain an average probabilistic atlas of the MaRIAS newborn cohort. The MaRIAS newborn atlas was used for the initialisation of the AdaPT segmentation of the fetus (>24GW) cohort. Another atlas was created in the same way for later MaRIAS cohort to initialise the AdaPT segmentation of the fetus (<24 GW) cohort. This later cohort was more challenging to segment using the publicly available atlas. The segmentation process is best described in Figure 1. We manually segmented a subset of the MR images comprising of 8 newborns, 8 fetuses (>24 GW) and 4 fetuses (<24 GW) in order to validate the automatic segmentations. Dice scores were used to assess the agreement between the automatic and manual segmentations.

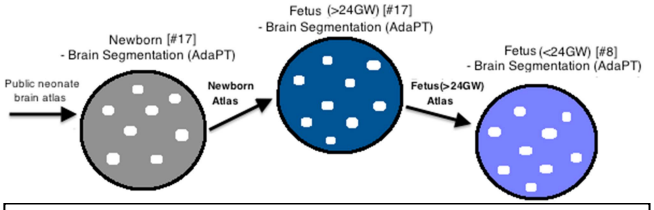

Figure 1) Segmentation propagation algorithm: creating a new atlas after each step (cohort) and using it as a prior for AdaPT

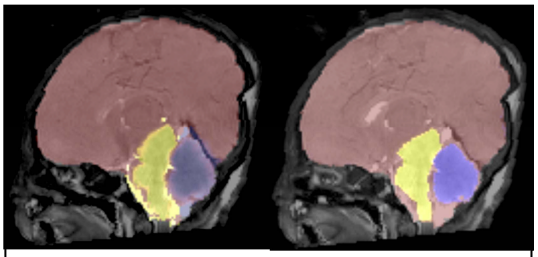

Figure 2) Segmentation of MaRIAS Fetus (>24GW) using the public atlas (A) and using the MaRIAS Newborn atlas (B)

Results: Figure 2 shows improvement in the brain segmentation of a MaRIAS fetal (>24GW) subject by using a cohort specific atlas. This can also be seen from the Dice score between the automatic segmentation of the fetuses (>24GW) obtained using the created newborn atlas and then the publicly available one with the manual segmentations (Table 1). Using an atlas based on subjects with similar morphologies gives a better segmentation. Table 1 presents the average Dice score overlap of the automatic segmentation with the manual ones for each cohort and each segmented region. It can be observed that the coefficient is influenced by the size of the segmented region. The cerebrum has a very high Dice score for all three cohorts. The cerebellum presents a high Dice score for the newborn and fetal (>24 GW) cohort, while a smaller value is obtained for the fetal (<24 GW) cohort, since the cerebellum is not as developed for these subjects. The brainstem presents the lower Dice score amongst all cohorts due to its small size.

	Cerebrum	Cerebellum	Brainstem
Newborn	0.991 ± 0.002	0.873 ± 0.028	0.819 ± 0.031
Fetus(>24GW)	0.992 ± 0.002	0.888 ± 0.016	0.853 ± 0.035
Fetus(>24GW) (public atlas)	0.984 ± 0.012	0.756 ±0.185	0.676 ± 0.262
Fetus(<24GW)	0.991 ± 0.001	0.836 ± 0.018	0.798 ± 0.023

Table 1) Average Dice score overlap of the automatic with manual segmentations

Discussion/Conclusion: We automatically segmented the cerebrum, cerebellum and brainstem of post-mortem newborns and fetuses of MaRIAS using atlas-based segmentation and the AdaPT algorithm. We used a publicly available neonate brain atlas to initialise the segmentation of the newborn cohort. We created new atlases for the newborn and fetal (>24GW) cohorts that we used to initialise the segmentation of the fetal cohorts with ages greater and lower than 24 GW, respectively. Improvements of the segmentations were obvious when using atlases based on patients with similar morphologies in the AdaPT algorithm (higher Dice scores when compared with the gold standard manual segmentation, clearer visual delimitations of the cerebellum). We validated the segmentation by comparing them with gold standard manual segmentations. Smaller values were obtained for the Dice score for the brainstem and cerebellum, since they represent a smaller percentage of the total brain volume. Nevertheless, the Dice scores show very good agreement for all cohorts and all segmented regions. This paper is the first to successfully generate post-mortem brain atlases from MR images of neonates and foetuses in a fully automatic way and these may be useful for exploring alterations of fetal brain development.

[1] Thayyil *et al* 2012 European Journal of Radiology 81(3) 232-238 [2] Thayyil *et al* 2013 Lancet 6736(13) 1-11 [3] Cardoso *et al* 2013 NeuroImage 65 97-108 [4] Kuklisova-Murgasova *et al* 2011 NeuroImage 54(4) 2750-2763