Automated Brain Tissue Segmentation in Neonatal MR Imaging

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Introduction

Preterm and fullterm neonates admitted to a neonatal intensive care unit carry a high risk for a delayed neurodevelopment. Early identification of patients at risk of neurodevelopmental disabilities may lead to intervention programs and an improved final outcome. Neuromotor development can hardly be predicted from abnormailities on T2-weighted (T2w) and T1-weighted inversion recovery (IR) MR imaging of the brain. It has been suggested that 'volumetric' MRI might be a better predictor of neurodevelopment than standard T2w and IR scans. In this study we propose a new method for segmentation of four types of neonatal brain tissue simultaneously: cerebro-spinal fluid (CSF), white matter (WM), basal ganglia (BG), and gray matter (GM). The method is fully automatic, and based on the K-Nearest Neighbor (KNN) classification technique using multi-spectral information.

Methods

The algorithm uses two types of regular MRI-scans: T2w and IR. Thirteen newborn children (age 5.4 ± 19.6 (mean ± st.dev.) weeks, gestational age of 36.2 ± 5.4 weeks.) were included in this study. Manual segmentations of the four tissue types were used for the learning of the system and considered as gold standard. Two preprocessing steps were performed on the data: (1) Rigid registration[1] (intra patient) and (2) the generation of a brain mask by 2-means clustering of the T2w image, and discarding small segments. Voxels were classified by the KNN-classification method (K=50), which generated four probabilistic segmentations (probability maps), which indicated per voxel the probability being one of the tissue classes, with two types of features: (1) Voxel intensity values of the two different scans, (2) spatial features: coordinates x, y and z. Binary segmentations were generated by applying thresholds to the probability maps. Evaluation was performed by comparison of the segmentations with the manual segmentations. The similarity index[2] (SI) over the binary segmentations was calculated, as well as the probabilistic similarity index (PSI) over the probability map. The SI and the PSI are defined by:

$$\mathrm{SI} = \frac{2 \times (Ref \cap Seg)}{Ref + Seg} \qquad \text{and:} \qquad \mathrm{PSI} = \frac{2 \times \sum \mathrm{P}_{\mathrm{x,\,gs\,=\,i}}}{\sum 1_{\mathrm{x,\,gs\,=\,i}} + \sum \mathrm{P_x}},$$

with: Ref: the area of the reference (gold standard), Seg: the segmentation area, $\sum \mathrm{P}_{\mathrm{x,\,gs\,=\,i}}$: Sum over all voxel probabilities, where in the gold standard (= manual segmentation) the voxel value = i (i = 1, 2, 3 or 4); $\sum 1_{\mathrm{x,\,gs\,=\,i}}$: Sum over all voxels with voxel value i in the gold standard; $\sum \mathrm{P_x}$: Sum over all probabilities in the probability map of tissue type i.

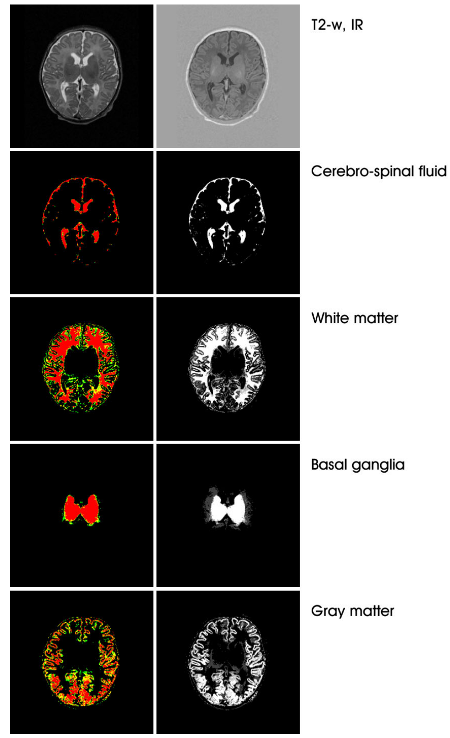

Figure 1: Classification of four tissue types; left image: black: probability (p) <= 0.3, green: 0.3 < p <= 0.5, yellow: 0.5 < p <= 0.8, red: 0.8 < p <= 1; right: gray levels indicate probability running from 0 (black) to 1 (white).

Results

Figure 1 shows an example image of the classification result. Figure 2 shows the ROC-curves for the segmentations of the four tissue types, with thresholds running from 0 to 1. Table 1 shows the sensitivity, specificity and SI of the binary segmentations, and the PSI of the probabilistic segegmentations.

Discussion

KNN-classification provides a powerful technique for probabilistic segmentation of brain tissue in neonatal MRI. A single method, which is fully automated, has been applied for segmentation of four different tissue types simultaneously: WM, GM, BG and CSF, resulting in high sensitivity and specificity for all tissue classes. The use of separate probability maps for each tissue type provides additional information, compared to one overall segmentation image, and a large flexibility in the classification and evaluation of the results. Finally, the method is based on the information from only two routine diagnostic MR scans, and is therefore suitable for large and longitudinal population studies for neonatal brain segmentation.

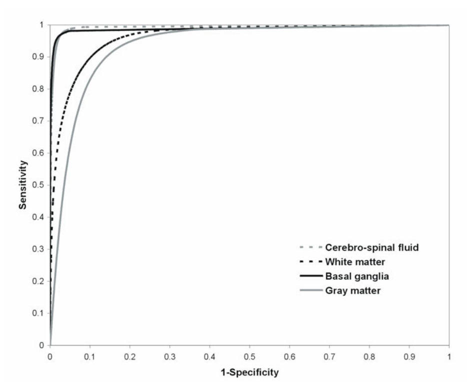

Figure 2: Similarity index of four tissue types for thresholds running from 0 to 1.

Table 1. Similarity measures of the segmentations of different tissue types

Tissue type	Sensitivity	Specificity	SI	PSI
CSF	0.923	0.985	0.899	0.856
WM	0.865	0.920	0.837	0.769
BG	0.881	0.994	0.871	0.805
GM	0.825	0.902	0.742	0.623

REFERENCES: *[1] F Maes, et al. IEEE Trans. Med. Imaging **16:** 187-198 (1997); [2] LR Dice. Ecology **26:** 297-302 (1945).*