Automatic Neonatal Brain Segmentation for Nine Tissue Types Simultaneously

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Introduction

Premature born infants carry a high risk for impaired neurodevelopment. Early identification of patients at risk for neurodevelopmental disabilities may lead to intervention programs improving longterm outcome. Cognitive outcome can not be predicted from visible abnormalities on T1-weighted (T1) and T2-weighted (T2) MR imaging of the brain. It has been suggested that volumes of specific brain structures might be better predictors for neurodevelopmental outcome. A few methods already exist for neonatal volume measurement of (un)myelinated white matter (UWM), cortical gray matter (GM), basal ganglia and thalamus (BG), and cerebro-spinal fluid (CSF). However, other structures may better indicators for neurodevelopment, such as ventricles (VENT), brainstem (BS), cerebellum (CB), and myelinated white matter in the cerebral peduncle (MWM), and the posterior limb of the internal capsule (PLIC). In this paper we propose a new method for segmentation of all these nine types of neonatal brain tissue simultaneously. 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: 3D-T1 and T2. MR images acquired at term age of four newborn children were included in this study. All patients were manually segmented into the nine tissue types: UWM, GM, BG, CSF, MWM, VENT, BS, CB and PLIC. These manual segmentations were used for training of the method and considered as gold standard. Three preprocessing steps were performed on the data: (1) rigid registration[1] (intra patient); (2) non-rigid coregistration[1] (inter patient); (3) generation of a brain mask by the BET-tool[2]. Voxels were classified by KNN-classification based on a probabilistic segmentation method[3]. The procedure generated nine probabilistic segmentations (probability maps), indicating per voxel the probability of being one of the tissue classes. Each patient was segmented using the training data composed from the manual segmentations of the three other segmentations (leave-one-out). Two types of features were applied: (1) voxel intensity values of the 3D-T1 and the T2 scans, (2) spatial features: coordinates x, y and z. After KNN-classification thresholds were applied to the probability maps, resulting in binary segmentations. Evaluation was performed by comparison of the binary segmentations with the manual segmentations. The sensitivity, specificity, and Dice similarity index (SI) over the binary segmentations were calculated. The SI is defined by:

$$\mathrm{SI} = \frac{2 \times (Ref \cap Seg)}{Ref + Seg}$$

with: Ref: the area of the reference (gold standard), Seg: the segmentation area.

Results

Figure 1 shows T2 images of one patient with the classification results. Examples were taken from different slices, such that all structures are shown. Table 1 presents the sensitivity, specificity and SI of the binary segmentations. Segmentations of CSF, GM, BS, UWM, VENT, CB and BG have high similarities with the gold standard. MWM and PLIC a lower similarity with the gold standard is observed.

Discussion

KNN-classification provides a powerful technique for probabilistic segmentation of brain tissue in neonatal MRI. The proposed method can be applied for segmentation of nine different tissue types simultaneously, resulting in high sensitivity, specificity, and SI for CSF, GM, BS, UWM, VENT, CB, and BG. The lower SI scores of MWM and PLIC segmentations are partially due to the small volumes of these structures. By visual inspection rather accurate segmentations were observed. However, the presented work is still preliminary, and further refinement of this method is necessary to improve the segmentation accuracy.

Having separate probability maps for each tissue type provides additional information, and a large flexibility in further processing 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.

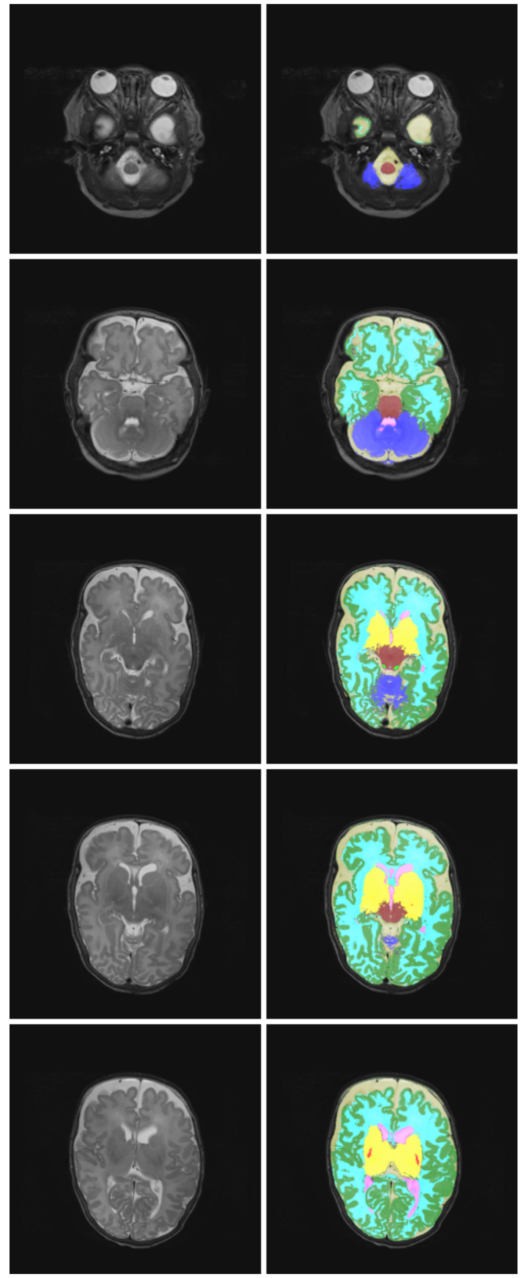

Figure 1: T2-weighted MRI and segmentation of nine tissue types in different regions of the neonatal brain.

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

Tissue type	Sensitivity	Specificity	Dice SI	Tissue type	Sensitivity	Specificity	Dice SI
CSF	0.685	0.964	0.738	CB	0.898	0.995	0.902
GM	0.848	0.905	0.805	BG	0.901	0.996	0.909
BS	0.861	0.999	0.883	MWM	0.518	1.000	0.527
UWM	0.851	0.926	0.843	PLIC	0.539	1.000	0.388
VENT	0.809	0.998	0.825				

REF: [1]M Staring et al. Phys Med Biol. 52: 6879-92 (2007); [2]SM Smith. Hum Brain Mapp. 17: 143-55 (2002); [3]P Anbeek et al. Pedriatr Res. 63: 158-63 (2008)