

Automatic, Accurate Segmentation of the Brain and CSF in T1-weighted Volume Scans and its Application to Serial Volumetry

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Introduction

The segmentation of the brain and cerebrospinal fluid (CSF) is relevant to the quantitative analysis of morphological differences and changes due to neurological disorders. In particular, the total brain volume (TBV) is correlated to various independent measures of disease severity. The intracranial volume (ICV), on the other hand, is often used as a correcting, or normalization, factor in volumetric studies of brain sub-structures [1]. Segmentation of head scans into grey matter (GM), white matter (WM) and CSF can also be used to refine the quantitative analysis of magnetic resonance spectroscopy and positron emission tomography by correcting for partial volume effects due to the mixture of tissues in each voxel [2]. A further important application of segmentation of MRI scans of the head is for conduction modeling for the purpose of EEG and MEG source localization. Up to now, T1-weighted volume scans have been used for this purpose, although the problem of skull - CSF boundary segmentation has not been addressed properly, as it is often assumed that the CSF cannot be segmented from this kind of data. We present a new fully automatic algorithm for the segmentation of the brain and cerebrospinal fluid (CSF) from standard T1-weighted volume MRI scans of the head. The algorithm was specifically developed in the context of serial brain and intra-cranial volumetry with emphasis on reproducibility. The method is an extension of a previously published brain extraction algorithm, Exbrain [3].

Methods

The brain mask obtained using Exbrain is used as a basis for CSF segmentation using a method based on morphological operations, automatic histogram analysis and thresholding, incorporating a model of the partial volume effect. The first step is the identification of sulcal and ventricular CSF based on background connectivity. Following initial estimation of the CSF and background intensity means and variances, a conditional dilation of the initial CSF mask is performed based on the optimal background/CSF threshold level. Improved brain segmentation is then obtained by iterative tracking of the brain-CSF interface based on tri-Gaussian model of CSF/GM interface intensities. Finally, CSF, grey matter (GMV) and white matter (WMV) volumes are calculated based on automatic histogram fitting using a model of intensity probability distribution that includes pure CSF, GM and WM classes, and CSF/GM and GM/WM partial volume classes [4], allowing fuzzy voxel classification. The accuracy of the method was assessed using a digital phantom scan of the head [5]. The simulated scan had the following characteristics: axial, T1-weighted volume with 1x1x1mm³ voxels, 3% noise and 20% non-uniformity. Overlap between the given CSF, GM and WM compartments and the segmentation results was calculated, as well as the error in TBV and intra-cranial volume (ICV). Volume reproducibility was assessed by segmenting pairs of scans from 20 normal subjects (interval: 8 months) and 11 patients with epilepsy (interval: 3.5 years). The scan parameters were: TI/TR/TE: 450/17.4/4.2 msec, flip angle: 20°, matrix size: 256x192, 24x18 cm FOV, 124 1.5mm thick coronal slices on a Signa 1.5T MR imager (GE Medical Systems, Milwaukee, USA). The effect of registration and intensity matching [6] on the reproducibility was assessed.

Results

Segmentation accuracy as measured by overlap was 97.7% for the brain and 96.6% for the intra-cranial tissues (see figure 1). The errors on the TBV and ICV were -0.2% and +0.4%, respectively; for the GMV, WMV and CSF, the errors were +0.3%, -1% and +3.0%, respectively. For the repeated control scans (fig. 2), we found that registration resulted in a significant improvement in volume reproducibility (see Table 1). Reproducibility following intensity matching was not significantly improved. The coefficient of reliability (CR; equal to twice the standard deviation of the difference, expressed as a percentage of the mean baseline volume) was 1.6% for the TBV (3.2% for GM and 2.2% for WM) and 1.2% for the ICV after registration. In the patients, the mean TBV change was -0.24% and CR for the ICV was 1.3%.

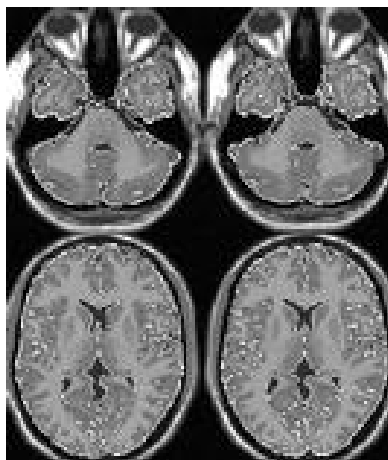


Figure 1. Result for MNI simulated scan. Left: segmentation result; right: reference

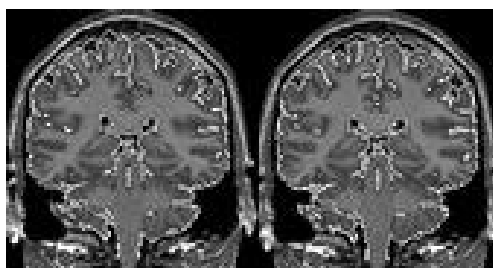


Figure 2. Typical result for repeated scans in a control subject. CSF border shown as white line. Left: baseline; right: repeat.

Discussion

This new fully automatic method allows accurate and reproducible intra-cranial tissue segmentation from T1-weighted volume scans and has been validated in simulated data, repeated scans from representative groups of control subjects and patients with epilepsy. The method should be useful in neurological MRI, MRS and functional imaging.

References

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Table 1. Result of repeat scan reproducibility study in 20 controls. Volume differences for GM, WM, CSF, TBV(=GMV+WMV) and ICV(=TBV+CSFV) as % of mean baseline value. B: baseline; R: repeat; RR: registered R; MRR: matched RR.

	dGMV	dWMV	dTBV	dCSF	dICV
	Mean (sd)	Mean (sd)	Mean (sd)	Mean (sd)	Mean (sd)
R-B	0.81 (1.65)	0.74 (3.05)	0.78 (1.24)	-1.53 (3.64)	0.46 (1.16)
RR-B	0.31 (1.34)	-0.21 (2.23)	0.10 (0.74)	1.22 (4.43)	0.26 (0.44)
MRR-B	0.67 (1.62)	-0.56 (1.11)	0.17 (0.79)	-0.31 (3.59)	0.11 (0.58)