Atrophy specific MRI brain template for Alzheimer's disease and Mild Cognitive Impairment

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Learning objectives:

1. To create a brain template specific to the different levels of atrophy in the brains of patients with Mild Cognitive Impairment and Alzheimer's disease .
2. To study the pattern of brain change correlated in the rapidly atrophying brain.

Topic area: image processing

Keywords: anatomical template, atrophy, magnetic resonance imaging, Alzheimer's

Background

Rapid brain loss is characteristic for the patients with mild cognitive impairment (MCI) and Alzheimer disease (AD) [1]. In particular, increase of the lateral ventricular volume is strongly correlated with the progression of the disease. Other parts of the brain (hippocampus, entorhinal cortex, etc.) are also subject to the rapid neuronal loss. Many automated image processing methods rely on usage of an anatomical template for registration into a common stereotaxic space for tissue classification, structure segmentation or voxel-based morphometry (VBM). Unfortunately, most commonly available anatomical templates are based on the scans of healthy individuals: for example the MNI-ICBM152 template used in the publicly available SPM and FSL image analysis tools is based on MRI scans of young healthy adults [2], and thus may be suboptimal for image registration techniques. The use of disease-specific templates have been proposed in the literature [3], however high variability in the degree of atrophy for subjects with AD and MCI makes use of a single disease-specific template challenging. Ideally, one would like to use an average MRI template that is matched to the level of atrophy for the subject in question.

In this paper we propose a novel approach to generate a continuous four-dimensional template, where the 4^{th} dimension is a surrogate measure of overall brain atrophy, thus making it possible to generate the appropriate representative anatomical template from the wide range of possible levels of atrophy such that it is closely matched to the progression of the disease of the subject, while maintaining continuous one-to-one mapping to the common stereotaxic space.

Methods

In this study we used MRI scans obtained from the ADNI database (www.loni.ucla.edu/ADNI). This database contains 1.5T and 3T T1-w MRI scans of different populations such as Cognitively Normal (CN) subjects (n=233), patients with MCI

(n=408) and patients with early AD (n=200) acquired at baseline. Automated methods to correct for image intensity non-uniformity [4], normalize the image intensity range for 0-100, linearly register all available subjects to the MNI-152 stereotaxic space [5] and estimate intracranial capacity (ICC) and lateral ventricles volume (LVV) [6] was applied to all available datasets. A human expert assessed quality of the resulting segmentations, and datasets failing any of the data processing steps were removed from processing. This QC process resulted in 173 NC, 150 AD and 332 MCI datasets that were available to participate in the 4D model creation.

The ratio between LVV and ICC (RLVV) was used as a surrogate measure of overall brain atrophy with mean (standard deviation) value of 2.46 (0.87)%. Subsets from all subjects (CN, MCI and AD) were selected with uniform distribution of RLVV from 1.0 to 6.0%, resulting in a total of 160 subjects.

Our algorithm for creating a Minimum Deformation Template [2] was modified to perform simultaneous 1) creation of the template and 2) linear regression of image intensity and shape versus RLVV. The output of the algorithm is a series of 3D volumes representing both linear model parameters of the intensity change and deformation at each voxel in the brain. These parameters can be used to generate an atlas for any value of RLVV.

Results

The ratio between LVV and ICC yielded values of mean(sd) 2.13(0.72)% for NC, 2.45(0.84)% for MCI and 2.84(0.91)% for AD.

The continuous, four dimensional anatomical template was created. For a given RLVV, an appropriate three dimensional anatomical template may be constructed, reflecting the average shape of the brain and the contrast between different tissue types for the given level of atrophy. Figure 1 shows transverse, sagittal and coronal images through 6 example values of increasing RLVV. As expected, CSF spaces in the lateral ventricles and sulcal spaces increase. Interestingly, the corpus callosum thins, and the superior and lateral surfaces of the brain appear to ‘sag’ down with increasing atrophy. The cerebellum atrophies as well.

Finally, it is worth noting that explicit, one-to-one mapping is calculated between templates corresponding to different RLVV values, making it possible to co-register MRI scans from subjects with very different levels of atrophy within same stereotaxic space, thus facilitating VBM studies.

Conclusions

The proposed method and resulting template will be useful tools for the development of robust automatic image processing methods targeted to the study of the populations with high degree of variability of atrophy. Furthermore, method presented is not limited to be used only with MCI and AD subjects, but can also be easily adopted for other neuro-degenerative studies.

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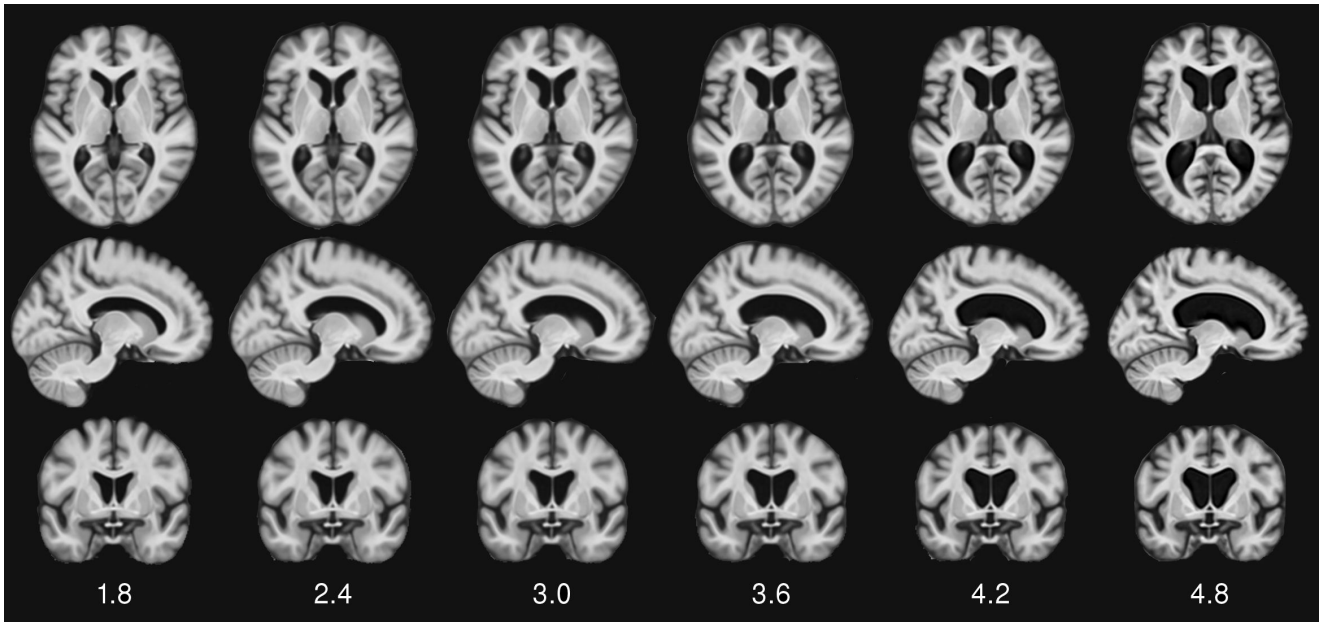

Figure 1: Atrophy specific MRI brain template sampled at various relative lateral ventricles volume sizes, in percent of the Intra Cranial Capacity.