Automatic Measurements of Brain Tissue Volumes and Volume Distributions

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INTRODUCTION: Accurate segmentation of cerebrospinal fluid (CSF), white matter (WM) and gray matter (GM) has many important applications in a wide array of neurological diseases, including Hydrocephalus (HC), Alzheimer's Disease (AD) [1], and infections [2]. For HC, the most common treatment method is the insertion of a shunt. HC Patients often encounter problems with shunts, including slit ventricle syndrome from over drainage of CSF. Quantification of the CSF distribution within the ventricles compared to the subarachnoid space before and after sudden shunt failure may provide insight into why these failures occur. However, even when excellent contrast between various tissue types is obtained, partial volume averaging often results in false classifications, subsequently affecting the calculated volumes. In order to minimize this problem, information from two three-dimensional (3D) image sets, one utilizing balanced-SSFP (bSSFP) for highlighting CSF, and the second using T1-SPGR for distinguishing GM and WM, will be segmented simultaneously to allow for the most accurate volumetrics.

IMAGE ACQUISITION: After obtaining written consent from five healthy volunteers and two pediatric HC patients, scanning was conducted on a 1.5T Philips Intera-Achieva scanner. 3D bSSFP images were obtained axially in three unique head positions so that accuracy and reproducibility of the volumetric measurements could be evaluated. Image acquisition parameters for the 3D SSFP sequence were: Field of View (FOV) = 21-24 cm, TE/TR = 2.5/5ms, flip angle = 50°, 1NEX, 336x336 matrix, 0.75 mm slice thickness (ST). Spoiled 3D T1-weighted gradient echo (3D SPGR) was only collected on two of the healthy control subjects, using identical geometry to the b-SSFP acquisition. In these experiments, the image acquisition parameters were: Field of View (FOV) = 21-24 cm, TE/TR = 5/30ms, flip angle = 25°, 1 NEX.

METHODS: Images were processed using custom software with Image J (Bethesda, Maryland), Matlab (Natick, MA) and MRIcro (Rorden, C. MRIcro.com). The Brain Extraction Tool (BET) was used to remove non-brain content from the images. The 3D images sets were segmented into CSF, WM, GM, and Background using fuzzy c-means clustering [3]. Clustering was completed for the 3D-SSFP and 3D-SPGR images. In addition, the clustering was performed on a volume made up of the two 3D SSFP and SPGR volumes. An automatic segmentation algorithm was implemented to separate the CSF in the ventricular system from the CSF in the SAS. This was accomplished by selecting four seed pixels within the center of the lateral ventricle and using a region growing approach to track connected components between the seed pixels and the most caudal and cranial slices containing ventricular CSF.

RESULTS: SAS and ventricular CSF segmentation were successfully accomplished for each subject exam with minimal user interference. The average ventricular/subarachnoid CSF distribution was 10.7±3.9% in the healthy volunteers and increased to 23.0±7.6% for the HC patients. The WM and GM volumes varied depending on the clustering approach. For the SPGR clusters, the WM and GM volumes were 617.1±60.8 and 672.6±21.5 cc, respectively. For the 4D SSFP/SPGR clusters, the WM and GM volumes were 852.8±99.6 and 506.3±135.1 cc, respectively. The CSF volumes were 154.2±7.1cc, 234.9±2.2cc, and 142.1±7.0cc for SSFP, SPGR, and the 4D SSFP/SPGR, respectively. The differences in cluster distributions for CSF in a single slice are shown in figure 1.

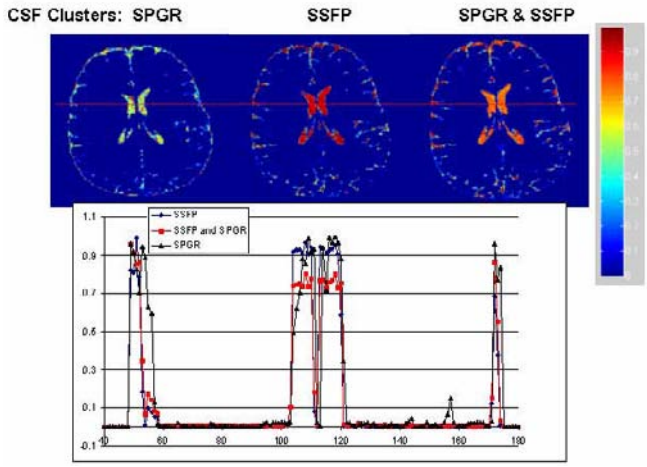

Figure 1 The CSF cluster from a single slice resulting from clustering the SPGR technique alone (top left), SSFP technique alone (top center) and both techniques together (top right). Bottom: the profile of a single row of CSF clusters, indicating a difference in CSF quantification. For this slice, the CSF volumes calculated from the SSFP and 4D SSFP/SPGR were similar, measuring 1.51cc and 1.37cc, respectively. The CSF volume for the SPGR slice was 2.18cc.

CONCLUSIONS: Quantification of changes in the ventricular cerebrospinal fluid (CSF) volume, as well as subarachnoid CSF volumes throughout the course of a Hydrocephalus (HC) patient's life is important. In order to quantify CSF volumes within the lateral ventricles separately from the CSF within the subarachnoid space (SAS), segmentation of the ventricular spaces is essential. However, in clinical applications, manual segmentation of the ventricles from the entire 3D volume can be very tedious and prone to errors. Many attempts to quantify CSF, WM, and/or GM have utilized several types of MRI techniques, including the T1-weighted SPGR, proton density, as well as spin-echo techniques. Because of the high contrast in the SSFP sequence, accurate estimates of CSF can be made in the ventricles. However, partial volume errors severely effect the measurements in the subarachnoid space due to the small CSF spaces. The purpose of this study was to introduce a novel method for quantifying CSF, WM, and GM from two 3D volumes simultaneously, each with different contrast weightings. Parameters that can be derived from these imaging and segmentation techniques may be useful for characterizing diseases, and may also allow for an objective measure of clinical improvement and/or decline in patients. In healthy adult controls, we calculated the normal distribution of ventricular to non-ventricular intracranial CSF as 10%. While enlargement of the ventricles in one very common indicator of hydrocephalus, the CSF distribution ratio may offer a second measure of the severity of the disease or possibly provide a measurable parameter for determining the success of shunting, or the likelihood of shunt failure. Within images sets of both subjects for which the 4D analysis was attempted, CSF volumes in excess of 200ml were measured using SPGR alone. This seems to be an overestimation, based on previous studies in which the total CSF volumes in healthy adults have been consistently less than 200ml using techniques appropriate for CSF imaging [4]. However, the results do indicate that the WM volumes increase with the 4D approach, while both WM and GM volumes are similar to previous reports using SPGR alone [5]. However, the 4D volumetric technique may be useful in the future for assessing diseases not only in terms of CSF volume distributions, but also white matter and gray matter distributions, which is important for measuring brain atrophy in many neurological diseases [5].

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