# Automated Quantitation of CSF Volumes in Central Nervous System by MRI

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## Introduction

The amount of cerebrospinal fluid (CSF) and its distribution within the cranio-spinal system are central to our understanding of CSF related brain and spinal cord disorders. For example, impaired CSF absorption that is associated with increased CSF volume is believed to be the underlying cause for the idiopathic intracranial hypertension (IIH) and idiopathic normal pressure hydrocephalus (NPH) [1]. Limited data is available regarding the amount and distribution of CSF volumes in the cranio-spinal system as well as within the spinal column. While the CSF volume in the low thoracic and lumbar regions has been documented to study the effects of epidural anesthesia [2], the volume of CSF in the spinal column has only been reported in a limited number of cases [3]. The overall CSF volume within the central nervous system has not been reported to the best of our knowledge even though CSF moves uninterrupted between cranial and spinal canal compartments. This study presents a methodology to quantify the whole CNS CSF volume, including the cranial intra and extra ventricular and spinal canal compartments.

## Methods

The method was evaluated by measuring the whole CNS CSF volume in an IIH patient immediately pre and post lumbar puncture during which a know amount of CSF volume has been withdrawn. The study was performed on a 1.5T Siemens Symphony scanner. The protocol includes the following scan a 3D T1-weighted (MPRAGE) and 3D T2-weighted FSE (SPACE) covering the brain and two 3D T2 weighted FSE (SPACE) volumes covering the upper and the lower portion of the spine, respectively. Scanning parameters for the 3D T1-weighted MPRAGE were FOV of 25.6x25.6 cm; isotropic voxel size of 1.0 mm, Matrix/NEX of 256x256/1, FA of 8 degrees and TI/TR/TE of 100/2500/2.4 ms. Scanning parameters for the 3D T2-weighted (SPACE) were FOV: 25.6x25.6cm; isotropic voxel size of 1.0 mm, Matrix/NEX of 256x256/2, FA of 150 degrees, TR/TE of 1800/192 ms. The imaging parameters for the 3D T2 weighted (SPACE) of the spine were FOV of 32x32cm; isotropic voxel size of 1.0 mm Matrix/NEX of 320x320/2, FA of 120 degrees, TR/TE of 1500/250 ms. The quantification of the CSF volume within the whole cranio-spinal system were achieved in three steps: **Ventricular Volume:** The delineation of the ventricles is obtained automatically with Freesurfer software [4] using the high-resolution 3D T1-weighted volumetric MRI data. Freesurfer software uses an atlas based method as prior information to a Bayesian parameter estimation framework, to identify several brain regions including cerebral ventricles. **Intracranial CSF volume:** The classification of the intracranial CSF voxels are obtained using T1 and T2-weighted images that are co-registered and segmented into six tissue classes (CSF, GM, WM, bone, soft tissue, and air/background) based on image intensity distribution, using the "New Segmentation" toolbox in SPM8 software [5]. The SPM8 software uses an algorithm based on a mixture of Gaussians and tissue probability maps, accounting for intensity non-uniformity in the image; and provides the fraction of each of the six classes within every voxel in the image. The volume was calculated from partial volume estimates of CSF tissue class. **Extra-ventricular cranial CSF volume:** Extra-ventricular cranial CSF volume is obtained by excluding ventricular CSF from intra-cranial CSF. **Spinal Canal CSF Volume:** The CSF within the spine was segmented in two steps. First, MR images of the cervical-upper thoracic and lower thoracic-lumbar region were co-aligned with previously generated template of the spinal CSF space using rigid linear registration. The segmentation of the spinal column was guided by the spinal column mask defined on the template that was projected on the subject image and followed by tissue segmentation using FSL FAST software [6] into 3 classes (CSF, soft tissue and bone). The voxels containing more than 50% CSF on the partial volume maps were used to create a CSF mask and quantified as CSF volume. The accuracy of the segmentation was assessed by comparison with manual segmentation by an experienced operator. The agreement between automated CSF segmentation of spinal canal and the manual segmentation of the same region was assessed using Dice overlap coefficient.

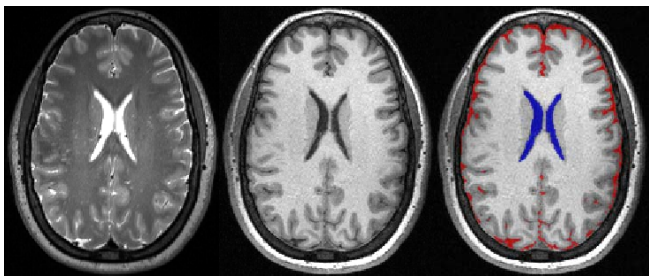

Fig. 1. An example demonstrating segmentation of the global intracranial volume and the extra (red) and intra (blue) ventricular CSF volumes using T1 and T2 weighted 3D MRI volumetric data.

## Results

An example demonstrating the automated segmentation of the intracranial CSF space is shown in Fig. 1. Reformatted T2 and T1 weighted images with the obtained ventricular (blue) and extra ventricular (red) CSF spaces are shown. An example segmentation of the spinal column CSF space is shown in Figure 2. Very good agreement between the automated and manual segmentation was achieved with mean Dice coefficients of 0.89 and 0.87 for cervical-upper thoracic and lower-thoracic lumbar regions, respectively. Regional cranial and spinal CSF volumes measured pre and post LP are summarized in Table 1. A decrease of 6.9 mL of CSF was measured after lumbar puncture. The amount withdrawn during LP was approximately 8 mL. The majority of this volume came from the extra ventricular cranial CSF space.

**Table 1: Regional CSF volumes before and after lumbar puncture**

| Scan | Ventricular CSF Vol. (mL) | Extra-ventricular cranial CSF Vol. (mL) | Cervical-upper thoracic CSF Vol. (mL) | Lower thoracic-lumbar CSF Vol. (mL) | Total |
|---|---|---|---|---|---|
| Pre-LP | 13.2 | 229.8 | 36.3 | 49.6 | 328.9 |
| Post-LP | 13.4 | 225.0 | 36.1 | 47.5 | 322.0 |
| **Difference** | **-0.2** | **4.8** | **0.2** | **2.1** | **6.9** |

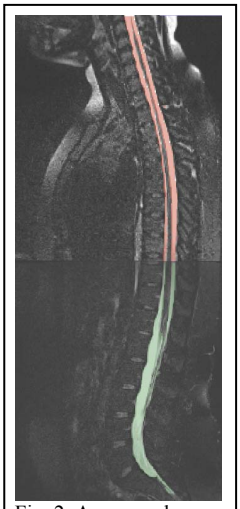

Fig. 2. An example demonstrating segmentation of the spinal CSF in cervical-upper thoracic (red) and lower thoracic-lumbar regions (green).

## Conclusion

Overall the CSF segmentation obtained with the automated whole CNS segmentation acquisition and post processing protocol is in good agreement with manual segmentation. It is likely that part of the difference of approximately 1 mL between the measured and the withdrawn amounts is due to CSF formation that occurred between the end of the LP and the MRI scanning which was approximately 30 minutes. The larger contribution from the cranial compartment is in agreement with recent report that IIH patients have larger extra-ventricular CSF space than healthy control. A reliable tool for automated quantitation of CNS CSF space would likely become clinically useful in differential diagnosis of CSF related disorders.

## References

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