Automated Volumetric Measurements of Posterior Cranial Fossa by MRI: Applications to Chiari I Malformation

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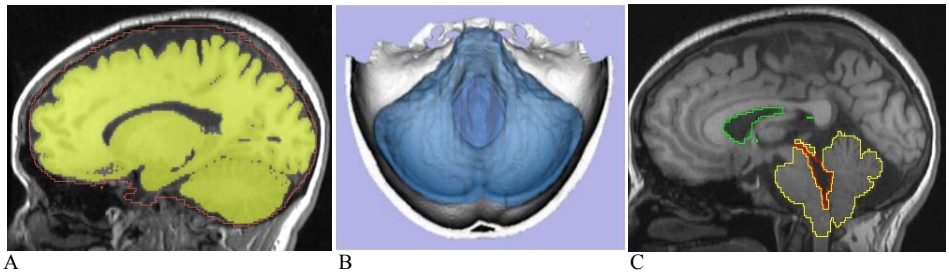
Introduction

Manual delineation of the posterior cranial fossa (PCF), either in CT [1] or MRI [2] revealed that Chiari I malformation (CMI) is often associated with a smaller PCF and that the fraction of the PCF relative to the supra tentorial volume may predict outcomes of decompression surgery [2]. Since no difference was found in posterior fossa brain tissue volume, it is suggested that CMI is associated with overcrowding of a normally developed hindbrain [3]. This "over-crowdedness" could lead to a decrease in cerebrospinal fluid (CSF) volume within the PCF. Therefore, reliable automated measurements of the cranial vault compartments, brain tissue volumes, and ventricular volumes potentially provide important markers for diagnosis and treatment decision in CMI. An automated protocol for segmentation of the PCF and the lateral and 4th ventricles using T1-weighted MR images was developed and applied to further characterize PCF morphology in CMI.

Methods

High resolution 3D sagittal T1-weighted MR images were obtained from 27 CMI patients (5M:22F, 33±11 years) and 27 healthy subjects (7M:20F, 34±13 years). Out of the 27 CMI patients, 13 had typical symptoms (e.g. valsalva-induced suboccipital headache) and 14 had atypical symptoms (e.g. non-valsalva- induced headache at regions other than suboccipital). MR data was acquired with 3T (Siemens) and 1.5T (GE healthcare) scanners. Scan parameters include field-of-view of 22cm, slice thickness of 0.9 or 1.0 mm, flip angle of 15 or 20 degrees, repetition time of 11ms, echo time of 5ms, inversion time of 450ms, and acquisition matrix of 256x192.



A B C

Fig. 1 The segmented brain tissue (shaded-yellow) and intracranial (orange) masks overlaid on T1-weighted image (A), the 3D rendered PCF mask from MNI 152 reference data displayed on the MRI rendered skull model (B), and the fourth (red) and lateral (green) ventricles and the hindbrain (yellow) delineated by FreeSurfer overlaid on a sagittal T1-weighted image (C).

A reference volume with pre segmented PCF was used to guide the automated classification of each subject's PCF. Brain and intracranial masks are obtained using BET and FAST software tools from FSL library (FMRIB, University of Oxford, Oxford, UK) [4,5] (Fig. 1A). The MNI 152 reference image was used to construct PCF mask (Fig. 1B), which was used to obtain PCF volume by projecting the mask onto the subject space using non-linear registration. The lateral and 4th ventricles and the hindbrain were delineated automatically using the subcortical segmentation routine from FreeSurfer (version 4.5.0) [6] (shown in Fig. 1C). It has been previously shown that scanner field strength does not bias ventricular segmentation by FreeSurfer [7]. Intracranial compartment volume, PCF volume, total brain tissue and hindbrain tissue volumes as well as lateral and 4th ventricle volumes were determined in the healthy and the CMI cohorts.

Results

Mean, SD, and %SD of the respective cranial compartments and brain tissue volumes, as well as lateral and 4th ventricle volumes are listed in Table 1. As expected, a statistically significant smaller PCF volume was found in the CMI group. The atypical symptomatic group had slightly larger PCF than the typical symptomatic group. Intracranial volume, brain tissue volumes, and lateral ventricular volume were similar among the CMI and the healthy cohorts. In contrast, the 4th ventricle volume was significantly smaller in CMI. Within the CMI cohorts, patients with atypical symptoms tend to have a larger 4th ventricle than patients with typical symptoms.

Table 1. Mean, SD, and %SD of cranial compartments, brain tissue volumes, ventricle volumes

		Controls n=27	Chiari I Malformation		
			All CMI n=27	Typical Symptoms n=13	Atypical n=14
Intracranial Volume (mL)	Mean	**1511**	**1501**	1489	1512
	SD	112	157	136	172
	%SD	7	10	9	11
	p-value*	-	0.80	0.64	0.98
Total Brain tissue (GM+WM) (mL)	Mean	**1170**	**1162**	1168	1157
	SD	154	115	105	124
	%SD	13	10	9	11
	p-value*	-	0.85	0.96	0.79
PCF Volume (mL)	Mean	**212**	**185**	**183**	**187**
	SD	15	20	19	20
	%SD	7	11	10	11
	p-value*	-	< 0.0001	0.0002	0.0006
Hindbrain Volume (mL)	Mean	**168**	**161**	159	163
	SD	15	17	15	18
	%SD	9	11	9	11
	p-value*	-	0.15	0.12	0.45
Lateral Ventricle Volume (mL)	Mean	**14.9**	**13.7**	12.1	15.3
	SD	6.6	6.4	5.6	6.8
	%SD	44	47	46	44
	p-value*	-	0.51	0.18	0.88
4th Ventricle Volume (mL)	Mean	**2.05**	**1.54**	**1.45**	**1.61**
	SD	0.49	0.49	0.37	0.56
	%SD	24	32	26	35
	p-value*	-	0.0004	0.0002	0.025

*p-values from T-Test versus Controls

Conclusion

An automated scheme for segmentation of the cranial compartment and the PCF sub-compartment, and their respective contents has been presented. The method successfully demonstrated a smaller PCF in CMI, as previously shown using CT or MR data with manual delineation [1, 2]. Application of this methodology demonstrated, for the first time, smaller 4th ventricles in CMI. Further, the volumes of the PCF and the 4th ventricles were associated with the type of symptoms presented by the CMI patients.

References

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