

Deep Learning-based Cerebrospinal Fluid Segmentation For Normal-pressure Hydrocephalus And Alzheimer's Disease



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Background

Disproportionately enlarged subarachnoid space hydrocephalus is characterized by ventriculomegaly, narrowing of the **high-convexity subarachnoid space**, and enlargement of the Sylvian fissures, and represents a **key imaging phenotype of idiopathic normal-pressure hydrocephalus**. Quantitative assessment of these cerebrospinal fluid compartments has traditionally relied on conventional volumetric neuroimaging approaches, which require substantial computational resources and processing time, thereby limiting applicability in large-scale cohorts. To address these limitations, we sought to establish an efficient **deep learning-based imaging framework** capable of **automated volumetric analysis** and disease differentiation. The objectives of this study were (1) to develop a **fully automated method for quantifying cerebrospinal fluid volumes in disease-relevant regions** and (2) to evaluate **its utility for distinguishing idiopathic normal-pressure hydrocephalus from Alzheimer's disease**.

Methods & Results

A total of **466 brain magnetic resonance imaging scans** were analyzed, including scans from patients with idiopathic normal-pressure hydrocephalus, Alzheimer's disease, and cognitively normal controls. Expert-annotated segmentations generated using conventional neuroimaging methods were used as reference standards. An **ensemble model combining nnU-Net and a three-dimensional vision transformer** was trained to segment the lateral ventricles, high-convexity subarachnoid space, and Sylvian fissure regions. Intracranial volume was calculated for volume normalization. Normalized cerebrospinal fluid measures were subsequently incorporated into a three-dimensional convolutional neural network classifier to differentiate idiopathic normal-pressure hydrocephalus from Alzheimer's disease.

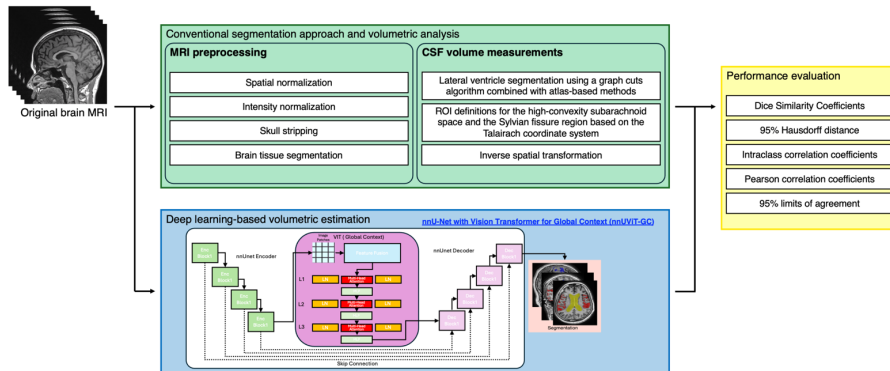


Figure 1 Flowchart depiction of the proposed analysis framework

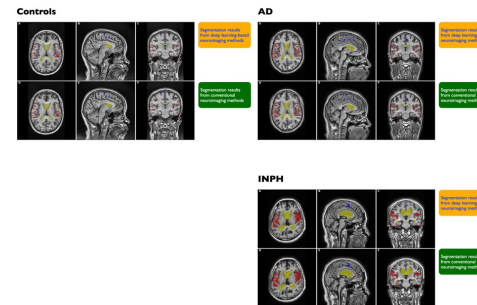
The proposed segmentation framework demonstrated strong agreement with reference annotations, achieving **Dice similarity coefficients** ranging from 0.81 to 0.97 and a **median Hausdorff distance** of approximately 1 mm across regions. The mean processing time per scan was under one minute.

Table 1 Performance metrics of deep learning-based volumetric estimation using conventional segmentation-based volumetric analysis as the reference standard

Abbreviations: CSF, cerebrospinal fluid; ICC, intraclass correlation coefficient; 95% LoA, 95% limits of agreement.

Region	Deep learning-based volumetric estimation (mean $\pm$ SD)	Conventional segmentation-based volumetric analysis (mean $\pm$ SD)	r	ICC	95% LoA	DICE score (mean $\pm$ SD)	Hausdorff distance 95 (mean $\pm$ SD)
Lateral ventricle	64.1 $\pm$ 47.0	63.2 $\pm$ 46.4	0.987	0.974	-1.2 to 3.1	0.963 $\pm$ 0.014	0.95 $\pm$ 0.21
High-convexity subarachnoid space	6.2 $\pm$ 2.9	6.1 $\pm$ 2.9	0.985	0.970	-0.9 to 1.1	0.809 $\pm$ 0.065	1.60 $\pm$ 0.97
CSF spaces of the Sylvian fissure region	40.4 $\pm$ 11.6	40.2 $\pm$ 12.0	0.957	0.915	-6.7 to 7.0	0.835 $\pm$ 0.042	1.37 $\pm$ 0.94
Intracranial volume	1351 $\pm$ 142	1352 $\pm$ 144	0.985	0.971	-49 to 47	0.968 $\pm$ 0.015	1.20 $\pm$ 0.25

Figure 2 Representative examples of individual cases across diagnostic groups



Using **volumetric features derived from automated segmentation**, the classification model achieved excellent discrimination between **idiopathic normal-pressure hydrocephalus** and **Alzheimer's disease**, with an area under the receiver operating characteristic curve of 0.99.

Table 2 Binary classification performance on the KNUCH dataset using volumes estimated by a deep learning-based volumetric approach (lateral ventricle, high-convexity subarachnoid space, Sylvian fissure region, and intracranial volume) Abbreviations: ROC-AUC, area under the receiver operating characteristic curve; INPH, idiopathic normal-pressure hydrocephalus; AD, Alzheimer's disease.

	ROC-AUC	Accuracy	Sensitivity	Specificity
INPH versus AD	0.990	0.924	0.890	0.955
INPH versus controls	0.998	0.989	0.987	0.991

Conclusions

This deep learning-based pipeline enables **rapid** and **reliable cerebrospinal fluid volumetry** with performance comparable to established techniques. Its accuracy, efficiency, and scalability suggest potential value for both research applications and future clinical implementation.