

# HyKid: An Open MRI Dataset with Expert-Annotated Multi-Structure and Choroid Plexus in Pediatric Hydrocephalus

Yunzhi Xu <sup>1</sup>, Yushuang Ding <sup>2</sup> Hu Sun <sup>3</sup> Hongxi Zhang <sup>2</sup> Li Zhao <sup>1</sup>

<sup>1</sup> College of Biomedical Engineering and Instrument Science, Zhejiang University, Hangzhou, China.

<sup>2</sup> Department of Radiology, Children's Hospital, Zhejiang University School of Medicine, National Clinical Research Center for Child Health, Hangzhou, China

<sup>3</sup> Neurosurgery of Zhejiang Hospital, Hangzhou, China.

## Abstract

Evaluation of hydrocephalus in children is challenging, and the related research is limited by a lack of publicly available, expert-annotated datasets, particularly those with segmentation of the choroid plexus. To address this, we present HyKid, an open-source dataset from 48 pediatric patients with hydrocephalus. 3D MRIs were provided with 1mm isotropic resolution, which was reconstructed from routine low-resolution images using a slice-to-volume algorithm. Manually corrected segmentations of brain tissues, including white matter, grey matter, lateral ventricle, external CSF, and the choroid plexus, were provided by an experienced neurologist. Additionally, structured data was extracted from clinical radiology reports using a Retrieval-Augmented Generation framework. The strong correlation between choroid plexus volume and total CSF volume provided a potential biomarker for hydrocephalus evaluation, achieving excellent performance in a predictive model (AUC = 0.87). The proposed HyKid dataset provided a high-quality benchmark for neuroimaging algorithms development, and it revealed the choroid plexus related features in hydrocephalus assessments. Our datasets are publicly available at <https://www.synapse.org/Synapse:syn68544889>.

## Keywords

Pediatric, Hydrocephalus, Magnetic Resonance Imaging (MRI), Choroid Plexus, Medical Image Segmentation.

## Article informations

©YYYY Yunzhi Xu. License: CC-BY-NC 4.0

## 1. Introduction

### 1.1 Background

**H**ydrocephalus is a serious condition characterized by the abnormal accumulation of cerebrospinal fluid (CSF), which can be caused by congenital malformations, trauma, or tumors (Laurence and Coates, 1962). The CSF, mainly generated by the choroid plexus, flows through the interventricular foramen into the third ventricle, and then travels through the cerebral aqueduct to the fourth ventricle. From there, it passes through the median and lateral apertures into the subarachnoid space (Damkier et al., 2013). Besides congenital hydrocephalus, acquired hydrocephalus can be caused by tumors, infections, hemorrhage, post-traumatic events, and idiopathic factors. Disruption of the CSF circulation equilibrium causes excessive CSF accumulation within the cranium, leading to hydrocephalus (Kahle et al., 2016).

One common cause of hydrocephalus is the obstruction in the CSF pathway, which leads to CSF accumulation and elevated intracranial pressure. The incidence of pediatric

hydrocephalus is approximately 1 in 500 births (Flannery and Mitchell, 2014), which is the leading cause of brain surgery in children and which is often associated with severe postoperative sequelae (Kulkarni et al., 2013). Delayed or inadequate treatment of hydrocephalus can lead to brain damage, such as psychiatric and physical disabilities. For instance, Melot et al. found that 60.4% of hydrocephalus children presented with fine motor dysfunction, impacting accuracy and dexterity, while 41.9% had visual impairment (Melot et al., 2016). Furthermore, psychiatric and behavioral follow-ups have documented learning disabilities and autism (Lindquist et al., 2006).

Ventriculoperitoneal (VP) shunting is a standard treatment for pediatric hydrocephalus (Patwardhan and Nanda, 2005), which creates a new flow-out path for CSF to relieve its accumulation. The procedure implants a shunt system with a one-way valve to drain excess CSF from the ventricles to the peritoneal cavity (Garegnani et al., 2020). However, this procedure is associated with well-known complications, including high rates of shunt malfunction and brain infection (Kestle et al., 2011; Sedano

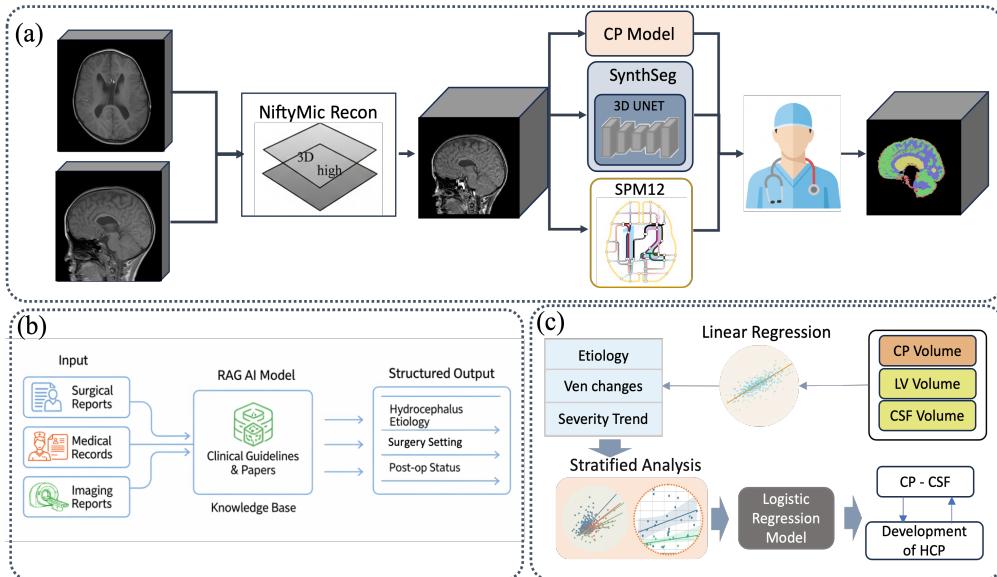


Figure 1: The methodological framework. (a) The pipeline for 3D high-resolution image reconstruction and semi-automated segmentation. (b) The Retrieval-Augmented Generation (RAG) framework for extracting structured clinical data from unstructured reports. (c) The statistical framework for analyzing the association between choroid plexus (CP) and lateral ventricles, and between CP and total CSF volume, incorporating stratified analysis, linear regression, ANCOVA, and logistic regression.

et al., 2023). Under- or over drainage of CSF can lead to a range of symptoms including headaches, nausea, vomiting, blurred vision, and dizziness (Ros et al., 2021). However, the proper amount of CSF drainage is determined in a TAP exam typically, which requires lumbar puncture and is evaluated in a few days. Therefore, it is highly demanded to evaluate the hydrocephalus based on image features to simplify the procedure and improve patient outcomes.

The ventricular volume is a conventional image biomarker used in hydrocephalus evaluation (Rekate, 2009), which can be quantified in the Evans index (Evans, 1942), temporal horns angle, and subarachnoid value. Meanwhile, other image-based features could be used to evaluate hydrocephalus, but have not been explored thoroughly. For example, the choroid plexus (CP), the primary site of CSF production within the ventricles, may have morphological and functional abnormalities that are closely linked to the pathophysiology of CSF circulatory disorders and hydrocephalus. Therefore, quantitative analysis of the choroid plexus can provide essential indicators for understanding hydrocephalus pathophysiology. In addition, hydrocephalus could damage adjacent brain tissue, leading to periventricular white matter atrophy (Del Bigio, 2010)(McAllister, 2012) and the abnormality of the gray matter which is correlated with the cognitive function (Fletcher et al., 1992). Therefore, its medical images may provide potential new features to evaluate the functional changes of hydrocephalus besides the conventional structural alterations.

## 1.2 Existing Datasets and Methodologies:

Although large-scale clinical data platforms like the UK Shunt Registry (Richards et al., 2009) and the Hydrocephalus Clinical Research Network (HCRN) (Kulkarni et al., 2013) exist, pediatric hydrocephalus datasets are seldom available to the public, especially well-annotated MRI datasets. On the other hand, pediatric brain MRIs were provided in open datasets (Akinci D'Antonoli et al., 2023), but hydrocephalus cases were very rare. The primary reasons for the shortage of pediatric hydrocephalus data are motion artifacts in pediatric MRI and low image resolution resulting from fast acquisition sequences used to reduce the motion (Ha et al., 2020). Consequently, datasets featuring expert-derived, voxel-level ground-truth segmentations were infrequently available (Taha et al., 2025). In addition, the structured clinical information, including the changing trend of ventricles and clinical conditions, is seldom provided to validate the performance of image biomarkers, which hinders the developments of novel models of clinical evaluations and outcomes.

## 1.3 Contributions

MRI can provide great soft tissue contrast and reveal potential changes caused by hydrocephalus. High-resolution MRI has been employed in research, enabling more precise anatomical diagnoses of hydrocephalus through morphometric analysis and volumetric measurements (Hunt et al., 2003)(Engelhardt et al., 2015). The present work

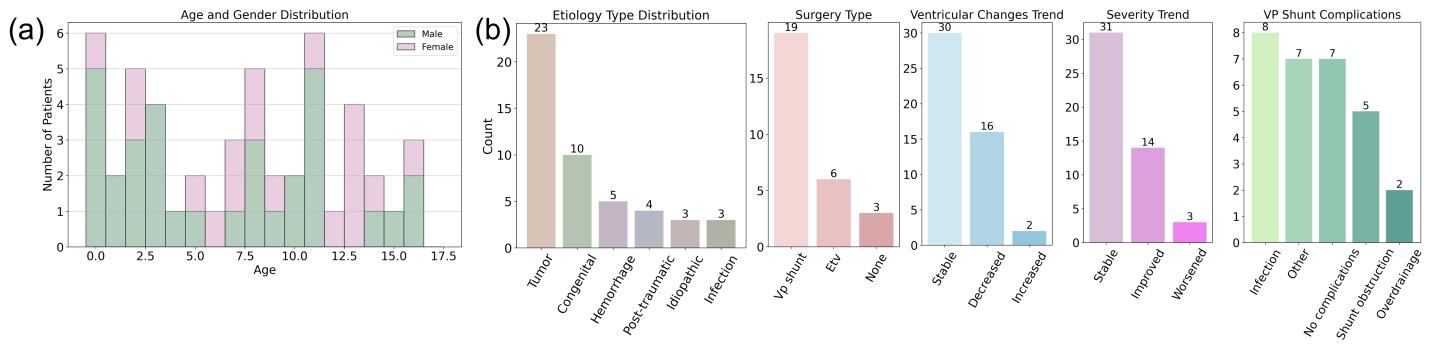


Figure 2: Demographic and clinical characteristics of the pediatric hydrocephalus dataset. (a) Patient distribution by age and gender. (b) Distribution of key clinical features.

Table 1: Demographic characteristics and MRI acquisition.

Statistics	
Cases	48
Male/Female, n [%]	31(64.6%)/17(35.4%)
Age, years, mean, std	$7.7364 \pm 5.0681$
median [IQR]	8.3435[2.8388 – 11.4938]
Number of axial slices, n	2054
Slice thickness, mm, mean [SD]	$7.1163 \pm 0.65615$
Slices per case, mean [SD]	19.0
In-plane resolution, mm, mean [SD]	$0.4202 \pm 0.0384$
In-plane matrix size	$512 \times 512$

attempted to establish the dataset and features from high-resolution images and precise structural segmentations to enable the quantification of more subtle brain structural characteristics in pediatric hydrocephalus.

The contributions of this work are three-fold: First, this study provided HyKid dataset from 48 pediatric hydrocephalus patients with 2,054 slices, which includes: 1) 3D high-resolution images reconstructed using a slice-to-volume technique; 2) manual segmentations of gray matter, white matter, external CSF, lateral ventricles, and the choroid plexus, performed by an experienced neurologist; and 3) structured clinical records parsed using a knowledge retrieval-augmented technique. The pipeline of HyKid dataset is illustrated in Figure 1. Second, through a stratified clinical analysis, significant correlations between CP volume and the volumes of the ventricles and total CSF were found, which could provide an indicator of clinical improvement. Third, the total global CSF volume, rather than ventricular volume, is a superior metric for predicting clinical symptoms, which may reveal the link between the choroid plexus and CSF and the patient’s clinical trajectory. This is evidenced by a 7% increase in explained variance ( $R^2$ , ANCOVA) and a 0.07 improvement in predictive accuracy (AUC, logistic regression).

## 2. Dataset Description

This dataset was collected retrospectively under the Institutional Review Board of Approval (No.20240520090500000 6293). Before data sharing, both imaging and clinical text data were anonymized to protect patient privacy. Specifically, imaging data were de-identified by removing personally identifiable information tags from the DICOM headers and converting all files to the NifTI format. For clinical reports, patient names were removed before processing with the Retrieval-Augmented Generation (RAG) technique (Lewis et al., 2020).

**Demographics and Acquisition Parameters:** Patients included in this study met the following criteria: 1) A clinical diagnosis of pediatric hydrocephalus; 2) An age range from neonate to adolescent (0–17 years); 3) Underwent a 3T MRI examination, with all scans performed on Philips MRI systems. Exclusion criteria were as follows: 1) Poor image quality that precluded effective super-resolution reconstruction; 2) Absence of an imaging report.

The dataset comprised 50 scans from 48 patients. Detailed demographic and MRI information is provided in Table 1. The age and sex distributions are shown in Figure 2.a. Patients younger than 5 years constituted 36% of the cohort. According to radiology reports, Figure 2.b, ventricular volume was stable in most cases (30 patients). In terms of overall condition assessment, 31 patients were stable, 14 showed improvement, and 3 showed deterioration. 28 patients were with available surgical records, 19 underwent VP shunting, 6 had an endoscopic third ventriculostomy, and the remaining 3 underwent tumor resection. Ward round reports (i.e., clinical progress notes) from 29 cases documented common complications, including infection, shunt obstruction, and overdrainage.

## 3. Method

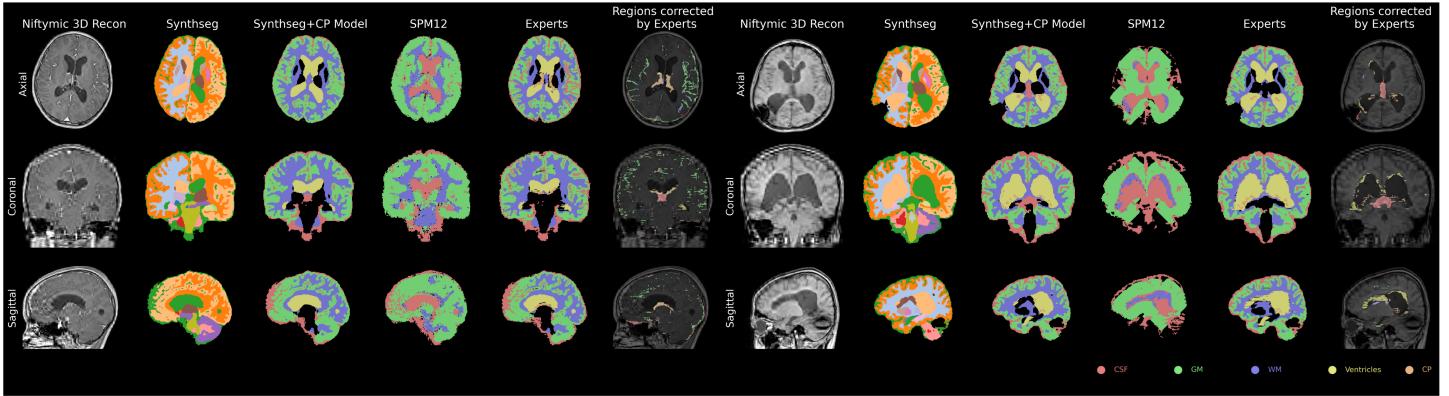


Figure 3: Comparison of segmentation methods. Results from three automated methods are compared against the physician-corrected gold standard in two pediatric hydrocephalus cases with differing severity: mild (left) versus severe (right) ventriculomegaly. The 'Regions corrected by Experts' panel displays the manual corrections based on the Synthseg+CP Model segmentation.

### 3.1 Slice-to-Volume Super-Resolution Reconstruction

To overcome the limitations of anisotropy and low resolution in the clinical data, a slice-to-volume reconstruction (SVR) technique, NiftyMIC (Ebner et al., 2020), was employed. Each case was acquired using fast-scan sequence at both axial and sagittal planes, which had a large slice thickness of about 7mm. The SVR began with converting the de-identified DICOM images to the NifTI format using SimpleITK version 2.4.1. Then, the initial manual orientation correction was performed on the axial and sagittal images to correct orientation by Y.X, a PhD candidate with four years of experience in medical image processing. Finally, the open-source NiftyMIC toolkit (Ebner et al., 2020) was used as the baseline for SVR to generate the 1mm isotropic 3D volumes. The SynthSR (Iglesias et al., 2023) was also evaluated; despite yielding fewer artifacts, its output suffered from structural distortion and blurring, Figure 4. Therefore, the experts selected the NiftyMIC reconstructions for manual annotation.

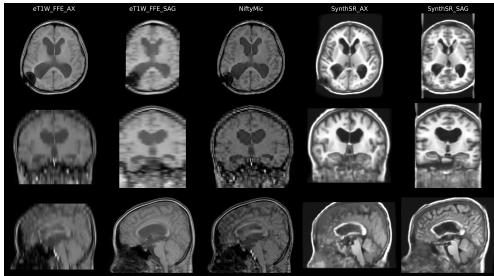


Figure 4: Visual comparison NiftyMIC versus SynthSR.

### 3.2 Tissue Segmentation

Accurate segmentation of brain tissues and ventricles is crucial for the quantitative assessment of hydrocephalus.

Based on the reconstructed high-resolution 3D images, three automated tools were used to obtain initial segmentations, including SynthSeg (Billot et al., 2023), SPM12 (Penny et al., 2011), and an in-house choroid plexus model (Li et al., 2024). Specifically, SynthSeg was used to generate segmentation labels for 61 brain regions. SPM12, which leverages Tissue Probability Maps and a unified segmentation model, was employed to generate probability maps for gray matter (GM), white matter (WM), and external CSF. The CP model utilized a two-stage 3D U-Net, which first localized the lateral ventricle to define a region of interest, and then segmented the CP within that cropped region. This model was subsequently refined through a human-in-the-loop active learning strategy, where an expert iteratively corrected the poorest segmentations to augment the training dataset.(Li et al., 2024) The labels of initial segmentations were combined into GM, WM, external CSF, lateral ventricle, and CP regions and provided to a neurologist for manual correction. This segmentations could be mapped back to the original low-resolution images.

### 3.3 RAG-based Structuring of Clinical Information

A RAG framework was employed to establish a structured clinical report. A knowledge base was constructed by compiling 10 clinical guidelines and cutting-edge surgical papers related to hydrocephalus. This knowledge base was then vectorized using zhipu-embedding-v3 (ZhipuAI) and stored in a FAISS index (Johnson et al., 2019). This knowledge base was then used to augment a large language model, qwen3-235b-A22b (Yang et al., 2025), to automatically extract key structured information from unstructured surgical notes, ward round reports, and imaging reports. It extracted structured clinical information for each patient,

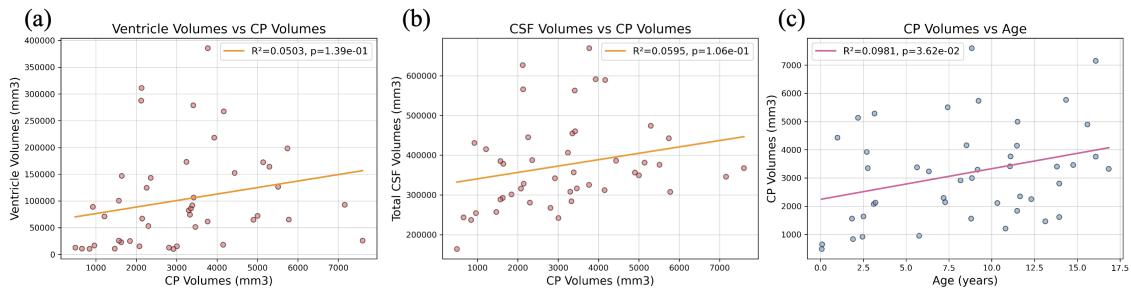


Figure 5: Linear Regression Analysis of Choroid Plexus Volume, Ventricles Volume, total CSF Volume, and Age. The CSF Volume refers to TCV in the Figure.

including hydrocephalus etiology, imaging features, surgical details, and postoperative status.

Among the extracted data, this study specifically focused on three structured variables to investigate the role of the choroid plexus: etiology, ventricular change trend, and condition severity trend. The hydrocephalus etiology was determined from the clinical course from imaging reports, the ventricular trend was derived from serial imaging reports, and the severity trend was synthesized from a holistic assessment of imaging, ward, and surgical notes.

Table 2: Comparison of Dice Coefficients (DSC) for brain tissue segmentation between automated methods and the expert gold standard.

Method	Tissue Type				
	External CSF	GM	WM	Ventricle	CP
Synthseg vs. Expert	0.9281 ± 0.0341	0.9740 ± 0.0260	0.9726 ± 0.0528	0.8663 ± 0.2021	0.4311 ± 0.2360
SPM12 vs. Expert	0.2790 ± 0.0726	0.5943 ± 0.0780	0.4557 ± 0.2964	—	—

## 4. Benchmarks

This dataset is intended to provide a comprehensive benchmark platform for research in pediatric hydrocephalus. We have established the primary data:

**Super-Resolution Reconstruction:** The dataset provides the original low-resolution orthogonal scans and the corresponding baseline reconstruction results from NiftyMIC. This allows researchers to develop novel super resolution algorithms and compare their performance against our established baseline.

**Brain Tissue Segmentation:** Qualitative segmentation results from the three automated methods are shown in Figure 3. The expert segmentations involved substantial manual corrections, particularly on the ventricles, CSF and the CP, Figure 3. The Dice coefficients between these results and the gold standard are shown in Table 2. The results clearly indicate that SPM12 performs poorly on this

task and that automated segmentation of the CP is particularly challenging. This highlights the need for specialized segmentation algorithms for hydrocephalus, a research direction this dataset aims to advance.

## 5. Association between Choroid Plexus and CSF Volume

To evaluate the association between choroid plexus volume and CSF volume, and its clinical heterogeneity in pediatric hydrocephalus, a multi-level statistical analysis was performed. Correlation analyses were performed using choroid plexus volume (CPV) as the independent variable, with both ventricular volume (VV) and total CSF volume (TCV, the sum of ventricular and extraventricular CSF volumes) as dependent variables. All these volumes were quantified based on the gold standard of manual segmentation by a neurologist, with the final measurement derived from voxel summation. This approach aims to more fully capture the role of the CP in the pathophysiology of hydrocephalus.

### 5.1 Baseline Correlation Analysis

In the baseline correlation analysis, we assessed the relationships between age and CPV, between CPV and VV, and between CPV and TCV, using both linear regression and Spearman's correlation.

### 5.2 Stratified Correlation

In addition, stratified correlation and covariance analysis was performed. Within each of the three clinical subgroups, including etiology (tumor, congenital, hemorrhage, post-traumatic and idiopathic), ventricular trend (stable and decreased), severity trend (stable and improved), the above correlation analyses were performed. Then ANCOVA (Kutner, 2005) was applied, using age as a covariate, to test for significant differences in these relationships among the subgroups.

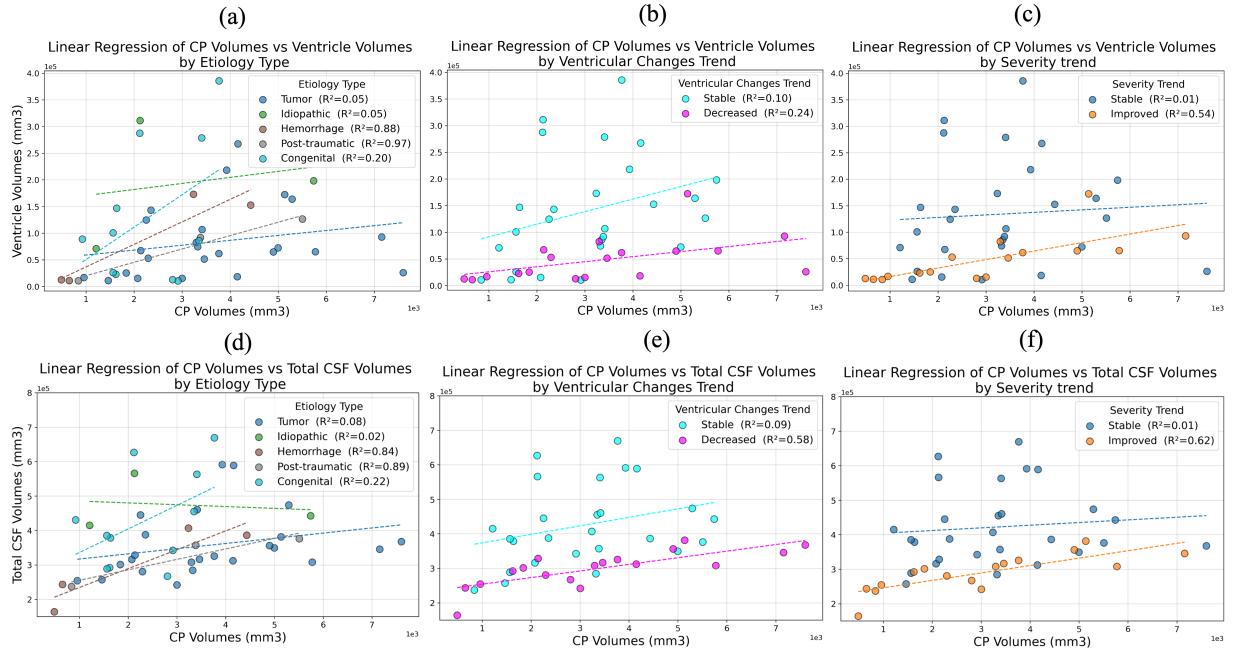


Figure 6: Linear regression plots for the stratified analysis of the association between CPV and VV/TCV. Subgroups stratified by etiology (left), ventricular trend (middle), and clinical severity trend (right) were presented, respectively. The relationship between CPV and VV was shown in the top row, and the relationship between CPV and TCV was shown in the bottom row.

### 5.3 Prediction Model

Prediction Models were developed, in which Logistic Regression (LR) models were constructed using age, CPV, and either VV or TCV as input features to predict ventricular trend and severity trend. The performance of the proposed models was evaluated using 5-fold cross-validation.

## 6. Results

### 6.1 Choroid Plexus Effects

As shown in Figure 5 and Table 3, Spearman's correlation analysis revealed a significant and positive correlation between CPV and VV ( $\rho=0.42$ ,  $p = 0.0045$ ), CPV and TCV( $\rho=0.37$ ,  $p = 0.013$ ), indicating a monotonic increase between the CPV and VV or TCV in hydrocephalus. However, the linear regression model did not show a significant linear relationship ( $R^2 = 0.05$ ,  $p = 0.139$ ). Concurrently, a significant and positive correlation was found between CPV and age (Spearman's  $\rho = 0.33$ ,  $p = 0.027$ ). Although the linear regression between the CPV and age was statistically significant ( $p = 0.036$ ), the low coefficient of determination ( $R^2 = 0.098$ ) indicated limited explanatory power given the sample size.

Table 3: Correlation and Regression Analysis of Choroid Plexus Volume, Ventricle Volume, total CSF Volume, and Age.

Variable Pair	Analysis Method	Coefficient	p-value
CPV vs. VV	Spearman's Correlation Linear Regression	$\rho = 0.420$ $R^2 = 0.050$	<b>0.005</b> 0.139
CPV vs. TCV	Spearman's Correlation Linear Regression	$\rho = 0.369$ $R^2 = 0.0595$	<b>0.013</b> 0.106
Age vs. CPV	Spearman's Correlation Linear Regression	$\rho = 0.330$ $R^2 = 0.098$	<b>0.027</b> <b>0.036</b>

### 6.2 Stratified Analysis of CP-CSF Association

As shown in Figure 6 and Table 4, the stratified analysis revealed association patterns that were highly dependent on the clinical subgroups. In both the "Decreased" ventricular (N=18) and the "Improved" severity trend group (N=16), CPV exhibited a significant positive correlation with VV ( $p = 0.0012$ ). In contrast, the "Stable" ventricular trend group (N=26) showed only a moderate positive correlation, while the correlation in the "Stable" severity trend group (N=28) was not significant.

The results in the "Decreased" ventricular volume group showed high linear correlation, with  $R^2$  increasing from 0.23 to 0.57, the Spearman coefficient rising from 0.63 to 0.77,

Table 4: Stratified Analysis of the Association between Choroid Plexus (CP) Volume and CSF Compartment Volumes. This table details the results of correlation (Spearman's  $\rho$ ) and linear regression ( $R^2$ ) analyses for the relationship between CPV VV/TCV. The analyses are stratified by clinical subgroups based on etiology, radiological ventricular trend, and clinical Severity trend. Key statistics, including sample size (N) and p-values, are presented for each subgroup.

Group	Clinical Outcome	Samples	Ventricle Volume				Total CSF Volume			
			Linear Regression			spearman		Linear Regression		
			$R^2$	F-statistic	p-value	Coefficient	p-value	$R^2$	F-statistic	p-value
Etiology	Tumor	24	0.0538	1.25	0.2756	0.4322	<b>0.0349</b>	0.0754	1.7951	0.194
	Idiopathic	3	0.0509	0.0536	0.8551	0.5	0.6667	0.025	0.0256	0.899
	Hemorrhage	4	0.8815	14.8809	0.0611	0.6	0.4	0.8438	10.8001	0.0814
	Post-traumatic	3	0.9694	31.629	0.112	1	0	0.8857	7.7516	0.2195
Ventricular Changes Trend	Congenital	11	0.1994	2.2421	0.1685	0.2364	0.4841	0.2204	2.5442	0.1452
	Stable	26	0.103	2.7562	0.1099	0.4619	<b>0.0175</b>	0.0838	2.2535	0.1464
	Decreased	18	0.2354	4.9256	<b>0.0413</b>	0.6367	<b>0.0045</b>	0.5778	21.8956	<b>0.0003</b>
Severity Trend	Stable	28	0.0054	0.1399	0.7114	0.2649	0.1731	0.0115	0.3029	0.5868
	Improved	16	0.5397	16.4127	<b>0.0012</b>	0.8647	<b>1e-5</b>	0.6183	22.6748	<b>0.0003</b>

Statistically significant p-values ( $p < 0.05$ ) are shown in bold.

and all p-values demonstrating greater statistical significance when the dependent variable was switched to TCV. This finding suggests that the correlation between CPV and VV/TCV may be a key indicator of improvement, signifying ventricular reduction and clinical betterment.

In the stratification by etiology, a significant and moderate positive correlation was observed between CPV and VV ( $\rho = 0.432$ ,  $p = 0.035$ ) in the tumor subgroup ( $N=24$ ). This correlation was enhanced when using TCV as the dependent variable, which had an increase in  $R^2$  by 0.21 and a reduction in the p-value from 0.0349 to 0.0154 in linear regression.

### 6.3 Multi-Group Comparision

As shown in Table 5, after controlling for age as a covariate, ANCOVA showed significant differences in volume (for both VV and TCV) among the clinical subgroups ( $p < 0.05$ ). Specifically, the "Stable" groups had significantly larger volumes than the "Improved"/"Decreased" groups, which is consistent with the scatter distribution in the regression plots, Figure 6. This may explain the weaker correlation in the "Stable" groups, as the exceptionally large volumes could attenuate the linear relationship with CPV. Importantly, the interaction effect between CPV and the clinical subgroups was not significant, indicating that the influence of CPV on ventricular/total CSF volume is consistent across these subgroups.

The model's explanatory power increased when TCV replaced VV as the dependent variable (from 0.327 to 0.403 in the ventricular trend group). More critically, after controlling for subgroup and age, the independent effect of CPV as a covariate on TCV was more significant ( $F=6.868$ ,  $p = 0.012$ ). This result reveals that TCV more robustly reflects the central role of CPV in the pathophysiology of hydrocephalus.

### 6.4 LR Model for Clinical Prediction

The clinical prediction models built on LR showed substantially improved performance when both CPV and TCV were included as features, Figure 7. In predicting the ventricular trend, the mean Area Under the Curve (AUC) from five-fold cross-validation increased from 0.75 (CPV and VV) to  $0.86 \pm 0.09$ . For predicting the severity trend, the mean AUC increased from 0.79 to  $0.87 \pm 0.09$ . These results indicate that the model integrating the CP-TCV association achieves excellent predictive performance.

Table 5: Analysis of Covariance (ANCOVA) for Ventricle and Total CSF Volumes Stratified by Ventricular Change and Severity Trend, with Choroid Plexus Volume as a Covariate.

Group	Source of Variation	Analysis	Degree of Freedom		F-value	p-value
			Between-group difference	1		
Ventricular Trend	Ventricle Volume	CPV (Covariate Effect)	1	15.5824	<b>0.0003</b>	
		Interaction Effect	1	4.346	<b>0.0434</b>	
		Residual	41	0.9139	0.345	
		Explanatory Power	0.327			
		Between-group difference	1	22.7225	<b>2e-4</b>	
	Total CSF Volume	CPV (Covariate Effect)	1	6.8683	<b>0.0123</b>	
		Interaction Effect	1	3.5494	0.067	
		Residual	41			
		Explanatory Power	0.403			
		Between-group difference	1	9.7356	<b>0.0033</b>	
Severity Trend	Ventricle Volume	CPV (Covariate Effect)	1	1.7934	0.1879	
		Interaction Effect	1	0.5417	0.466	
		Residual	41			
		Explanatory Power	0.243			
		Between-group difference	1	19.6529	<b>0.0001</b>	
	Total CSF Volume	CPV (Covariate Effect)	1	2.9421	0.0938	
		Interaction Effect	1	3.16	0.083	
		Residual	41			
		Explanatory Power	0.382			

### 6.5 Summary of Findings

The choroid plexus and CSF coupling may provide a novel biomarker of pediatric hydrocephalus. The strong linear relationship between the volumes of the CP and the CSF is

not constant among groups, and the correlation is associated to clinical improvement (ventricular reduction, symptomatic relief). This suggests that the CSF volume can be coupled with its production source, the choroid plexus.

Total CSF volume provided a superior explanatory variable in ANCOVA and LR result. Compared to ventricular volume alone, total CSF volume accurately and robustly reveals the intrinsic association between CP volume and the entire CSF space, making it a superior indicator.

The association between choroid plexus volume and total CSF volume may provide a novel indicator of clinical outcome. The LR model integrating CPV, TCV, and age demonstrated high predictive accuracy ( $AUC = 0.87$ ), confirming the significant potential of the CP-CSF association as a clinical biomarker for assessing hydrocephalus.

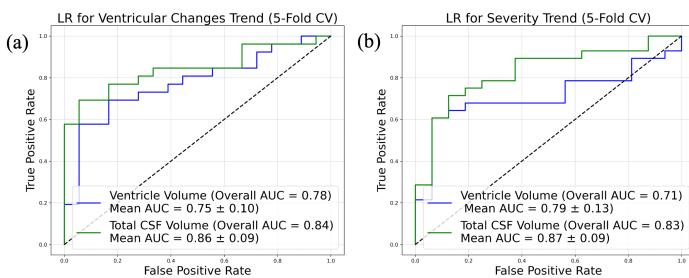


Figure 7: ROC curves for predicting (a) ventricular trend and (b) clinical severity trend. The curves compare models using either VV or TCV, adjusted for age and CPV.

## 7. Discussion

The present work shows that the association between choroid plexus (CP) volume and total CSF volume (TCV) is a potential biomarker of clinical status. A strong CP-CSF coupling was significantly correlated with clinical improvement.

In contrast, the monotonic, non-linear association observed in clinically stable patients suggests more complex pathophysiological mechanisms that warrant deeper exploration into their underlying causes. The inclusion of precise CP segmentations, a feature rarely available in public datasets, was critical to this analysis.

Furthermore, total CSF volume can provide a more robust metric than ventricular volume alone. This is physiologically plausible because TCV encapsulates the global state of intracranial fluid balance, not merely ventricular enlargement. The superior performance of total CSF volume in our predictive models underscores its value for assessing clinical status and its potential for tracking post-operative outcomes.

This study has several limitations. The single-center data and single expert manual correction may limit model

generalizability. Methodologically, limitations include artifacts in some super-resolution reconstructions and constraints on clinical data extraction due to incomplete records and potential LLM 'hallucinations'. The weaker volumetric correlations in "stable" patients likely reflect the clinical heterogeneity of this cohort.

## 8. Conclusion

In this work, a comprehensive dataset for pediatric hydrocephalus were provided, including high-resolution reconstructed MRI, manually labeled segmentations, and RAG-extracted clinical features. This resource may provide critical data and benchmarks for hydrocephalus model developments. Based on this dataset, choroid plexus-CSF coupling was presented as a novel biomarker of clinical evaluation, and total CSF volume was shown to be an effective indicator compared to the conventional ventricle volume. Besides age, the choroid plexus and total CSF volume demonstrated accurate prediction of clinical symptoms using LR model, which is readily to be used in hydrocephalus studies.

## Acknowledgments

This work is supported by the National Key R&D Program of China (2023YFE0118900) and the MOE Frontier Science Center for Brain Science & Brain-Machine Integration, Zhejiang University.

## Ethical Standards

The work follows appropriate ethical standards in conducting research and writing the manuscript, following all applicable laws and regulations regarding treatment of animals or human subjects.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Data availability

The HyKid dataset is publicly available on an open-source platform to support research in the field. The dataset is hosted at <https://www.synapse.org/Synapse:syn68544889>. To obtain the data, users are required to complete a short online application form and accept the terms of the Data Use Agreement.

## References

- Tugba Akinci D'Antonoli, Ramona-Alexandra Todea, Nora Leu, Alexandre N Datta, Bram Stieljes, Friederike Pruefer, and Jakob Wasserthal. Development and evaluation of deep learning models for automated estimation of myelin maturation using pediatric brain mri scans. *Radiology: Artificial Intelligence*, 5(5):e220292, 2023.
- Benjamin Billot, Douglas N. Greve, Oula Puonti, Axel Thielscher, Koen Van Leemput, Bruce Fischl, Adrian V. Dalca, and Juan Eugenio Iglesias. SynthSeg: Segmentation of brain MRI scans of any contrast and resolution without retraining. *Medical Image Analysis*, 86:102789, May 2023. ISSN 1361-8415. . URL <https://www.sciencedirect.com/science/article/pii/S1361841523000506>.
- Helle H Damkier, Peter D Brown, and Jeppe Praetorius. Cerebrospinal fluid secretion by the choroid plexus. *Physiological reviews*, 93(4):1847–1892, 2013.
- Marc R. Del Bigio. Neuropathology and structural changes in hydrocephalus. *Developmental Disabilities Research Reviews*, 16(1):16–22, 2010. ISSN 1940-5529. . URL <https://onlinelibrary.wiley.com/doi/abs/10.1002/ddrr.94>. \_eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1002/ddrr.94>.
- Michael Ebner, Guotai Wang, Wenqi Li, Michael Aertsen, Premal A Patel, Rosalind Aughwane, Andrew Melbourne, Tom Doel, Steven Dymarkowski, Paolo De Coppi, et al. An automated framework for localization, segmentation and super-resolution reconstruction of fetal brain mri. *NeuroImage*, 206:116324, 2020.
- Erin Engelhardt, Terrie E Inder, Dimitrios Alexopoulos, Donna L Dierker, Jason Hill, David Van Essen, and Jeffrey J Neil. Regional impairments of cortical folding in premature infants. *Annals of neurology*, 77(1):154–162, 2015.
- William A Evans. An encephalographic ratio for estimating ventricular enlargement and cerebral atrophy. *Archives of Neurology & Psychiatry*, 47(6):931–937, 1942.
- Ann Marie Flannery and Laura Mitchell. Pediatric hydrocephalus: systematic literature review and evidence-based guidelines. Part 1: Introduction and methodology. November 2014. . URL [https://thejns.org/pediatrics/view/journals/j-neurosurg-pediatr/14/Supplement\\_1/article-p3.xml](https://thejns.org/pediatrics/view/journals/j-neurosurg-pediatr/14/Supplement_1/article-p3.xml). Section: Journal of Neurosurgery: Pediatrics.
- Jack M Fletcher, Timothy P Bohan, Michael E Brandt, Bonnie L Brookshire, Stephen R Beaver, David J Francis, Kevin C Davidson, Nora M Thompson, and Michael E Miner. Cerebral white matter and cognition in hydrocephalic children. *Archives of neurology*, 49(8):818–824, 1992.
- Luis Garegnani, Juan VA Franco, Agustín Ciapponi, Virginia Garrote, Valeria Vietto, and Santiago Adalberto Portillo Medina. Ventriculo-peritoneal shunting devices for hydrocephalus. *Cochrane Database of Systematic Reviews*, (6), 2020. ISSN 1465-1858. . URL <https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD012726.pub2/full>. Publisher: John Wiley & Sons, Ltd.
- Ji Young Ha, Hye Jin Baek, Kyeong Hwa Ryu, Bo Hwa Choi, Jin Il Moon, Sung Eun Park, and Tae Byeong Kim. One-Minute Ultrafast Brain MRI With Full Basic Sequences: Can It Be a Promising Way Forward for Pediatric Neuroimaging? *American Journal of Roentgenology*, 215(1):198–205, July 2020. ISSN 0361-803X, 1546-3141. . URL <https://www.ajronline.org/doi/10.2214/AJR.19.22378>.
- RW Hunt, SK Warfield, H Wang, M Kean, JJ Volpe, and Terrie E Inder. Assessment of the impact of the removal of cerebrospinal fluid on cerebral tissue volumes by advanced volumetric 3d-mri in posthaemorrhagic hydrocephalus in a premature infant. *Journal of Neurology, Neurosurgery & Psychiatry*, 74(5):658–660, 2003.
- Juan E Iglesias, Benjamin Billot, Yaël Balbastre, Colin Magdamo, Steven E Arnold, Sudeshna Das, Brian L Edlow, Daniel C Alexander, Polina Golland, and Bruce Fischl. Synthsrs: A public ai tool to turn heterogeneous clinical brain scans into high-resolution t1-weighted images for 3d morphometry. *Science advances*, 9(5):eadd3607, 2023.
- Jeff Johnson, Matthijs Douze, and Hervé Jégou. Billion-scale similarity search with gpus. *IEEE Transactions on Big Data*, 7(3):535–547, 2019.
- Kristopher T Kahle, Abhaya V Kulkarni, David D Limbrick, and Benjamin C Warf. Hydrocephalus in children. *The Lancet*, 387(10020):788–799, February 2016. ISSN 0140-6736. . URL <https://www.sciencedirect.com/science/article/pii/S0140673615606948>.
- John R. W. Kestle, Jay Riva-Cambrin, John C. Wellons, Abhaya V. Kulkarni, William E. Whitehead, Marion L. Walker, W. Jerry Oakes, James M. Drake, Thomas G. Luerssen, Tamara D. Simon, and Richard Holubkov. A standardized protocol to reduce cerebrospinal fluid shunt infection: The Hydrocephalus Clinical Research Network Quality Improvement Initiative. *Journal of neuro-*

- surgery. *Pediatrics*, 8(1):22–29, July 2011. ISSN 1933-0707. . URL <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3153415/>.
- A.V. Kulkarni, J. Riva-Cambrin, J. Butler, S.R. Browd, J.M. Drake, R. Holubkov, J.R.W. Kestle, D.D. Limbrick, T.D. Simon, M.S. Tamber, J.C. Wellons III, and W.E. Whitehead. Outcomes of CSF shunting in children: Comparison of Hydrocephalus Clinical Research Network cohort with historical controls. *Journal of Neurosurgery: Pediatrics*, 12(4):334–338, 2013. .
- Michael H Kutner. Applied linear statistical models. 2005.
- K. M. Laurence and Stephen Coates. The Natural History of Hydrocephalus. *Archives of Disease in Childhood*, 37(194):345–362, August 1962. ISSN 0003-9888. . URL <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2012878/>.
- Patrick Lewis, Ethan Perez, Aleksandra Piktus, Fabio Petroni, Vladimir Karpukhin, Naman Goyal, Heinrich Küttler, Mike Lewis, Wen-tau Yih, Tim Rocktäschel, et al. Retrieval-augmented generation for knowledge-intensive nlp tasks. *Advances in neural information processing systems*, 33:9459–9474, 2020.
- Jiaxin Li, Yueqin Hu, Yunzhi Xu, Xue Feng, Craig H. Meyer, Weiying Dai, Li Zhao, and for the Alzheimer’s Disease Neuroimaging Initiative. Associations between the choroid plexus and tau in Alzheimer’s disease using an active learning segmentation pipeline. *Fluids and Barriers of the CNS*, 21(1):56, July 2024. ISSN 2045-8118. . URL <https://doi.org/10.1186/s12987-024-00554-4>.
- Barbro Lindquist, Göran Carlsson, Eva-Karin Persson, and Paul Uvebrant. Behavioural problems and autism in children with hydrocephalus: a population-based study. *European child & adolescent psychiatry*, 15:214–219, 2006.
- James P. McAllister. Pathophysiology of congenital and neonatal hydrocephalus. *Seminars in Fetal and Neonatal Medicine*, 17(5):285–294, October 2012. ISSN 1744-165X. . URL <https://www.sciencedirect.com/science/article/pii/S1744165X12000790>.
- A. Melot, A. Labarre, C. Vanhulle, S. Rondeau, M. Brasseur, V. Gilard, H. Castel, S. Marret, and F. Proust. Neurodevelopmental long-term outcome in children with hydrocephalus requiring neonatal surgical treatment. *Neurochirurgie*, 62(2):94–99, April 2016. ISSN 0028-3770. . URL <https://www.sciencedirect.com/science/article/pii/S0028377015003008>.
- Ravish V. Patwardhan and Anil Nanda. Implanted Ventricular Shunts in the United States: The Billion-dollar-a-year Cost of Hydrocephalus Treatment. *Neurosurgery*, 56(1):139–145, January 2005. ISSN 0148-396X, 1524-4040. . URL <http://journals.lww.com/10.1227/01.NEU.0000146206.40375.41>.
- William D Penny, Karl J Friston, John T Ashburner, Stefan J Kiebel, and Thomas E Nichols. *Statistical parametric mapping: the analysis of functional brain images*. Elsevier, 2011.
- Harold L. Rekate. A Contemporary Definition and Classification of Hydrocephalus. *Seminars in Pediatric Neurology*, 16(1):9–15, March 2009. ISSN 1071-9091. . URL <https://www.sciencedirect.com/science/article/pii/S1071909109000059>.
- Hugh K Richards, Helen M Seeley, and John D Pickard. Efficacy of antibiotic-impregnated shunt catheters in reducing shunt infection: data from the united kingdom shunt registry. *Journal of Neurosurgery: Pediatrics*, 4(4):389–393, 2009.
- Bienvenido Ros, Sara Iglesias, Jorge Linares, Laura Cerro, Julia Casado, and Miguel Angel Arráez. Shunt Overdrainage: Reappraisal of the Syndrome and Proposal for an Integrative Model. *Journal of Clinical Medicine*, 10(16):3620, January 2021. ISSN 2077-0383. . URL <https://www.mdpi.com/2077-0383/10/16/3620>. Number: 16 Publisher: Multidisciplinary Digital Publishing Institute.
- Sabrina Sedano, Matthew P Kronman, Kathryn B Whitlock, Chuan Zhou, Susan E Coffin, Jason S Hauptman, Evan Heller, Francesco T Mangano, Ian F Pollack, Joshua K Schaffzin, et al. Associations of standard care, intrathecal antibiotics, and antibiotic-impregnated catheters with cerebrospinal fluid shunt infection organisms and resistance. *Journal of the Pediatric Infectious Diseases Society*, 12(9):504–512, 2023.
- Birra R Taha, Gaoxiang Luo, Anant Naik, Luke Sabal, Ju Sun, Robert A McGovern, Carolina Sandoval-Garcia, and Daniel J Guillaume. Automated ventricular segmentation in pediatric hydrocephalus: how close are we? *Journal of Neurosurgery: Pediatrics*, 1(aop):1–8, 2025.
- An Yang, Anfeng Li, Baosong Yang, Beichen Zhang, Binyuan Hui, Bo Zheng, Bowen Yu, Chang Gao, Chengan Huang, Chenxu Lv, et al. Qwen3 technical report. *arXiv preprint arXiv:2505.09388*, 2025.
- ZhipuAI. zhipu-embedding-v3. [https://openbigmodel.cn/dev/api#text\\_embedding](https://openbigmodel.cn/dev/api#text_embedding). Accessed: 2025-06-29.