AJPMHS GLOBAL RESEARCH NETWORK

AMERICAN Journal of Pediatric Medicine and Health Sciences
Volume 3, Issue 10, 2025 ISSN (E): 2993-2149

Optimization of Diagnostics of CSF Cycle Disorders in Children Based on Comparative Clinical and Neuroimaging Analysis (MRI and Neurosonography)

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Abstract: Diagnosing cerebrospinal fluid flow disorders in children, such as hydrocephalus, requires a comprehensive approach using modern neuroimaging techniques. Currently, the primary tools for assessing the condition of the brain and cerebrospinal fluid (CSF) are magnetic resonance imaging (MRI) and neurosonography (NSG). Each of these methods has its own advantages and limitations, and their complementarity allows for increased diagnostic accuracy, improved prognosis, and optimized treatment.

Modern imaging techniques play an essential role for understanding the anatomy of the cerebrospinal fluid (CSF) spaces and ventricular system, as well as the hydrodynamics of CSF flow. These principles are important to the understanding of pathological processes affecting the ventricles and CSF spaces, and abnormalities induced by changes in the intracranial pressure.

The classical model of CSF hydrodynamics presumes that CSF is produced primarily in the choroid plexus epithelium (and to a lesser degree in the ependymal cells) at a rate of approximately 0.2–0.6 mL/min and 400–600/day. However, numerous evidences indicate that CSF is also produced throughout the entire CSF-interstitial fluid functional unit across the walls of the central nervous system (CNS) blood capillaries [1].

Since the total volume of CSF in the ventricles and subarachnoidal spaces (SAS) averages approximately 150 mL, a threefold turnover of CSF occurs daily, explaining the presence of a bulk flow of CSF from the sites of origin to the sites of absorption. This bulk flow of CSF starts in the lateral ventricles, passes through the third and fourth ventricles and, via the foramina of Luschka and the foramen of Magendie into the cerebellopontine angle and prepontine cisterns and the vallecula of the cisterna magna. From the basilar cisterns, the bulk flow of CSF continues cephalad along two major routes: a ventral route through the interpeduncular and pre-chiasmatic cisterns and a dorsomedial route through the ambient cisterns and the cisterna magna. The bulk flow also extends downward into the spinal canal dorsal to the cord to the lumbar thecal sac and upward in front of the cord to the basilar cistern.

CSF is absorbed not only via the arachnoid villi that are ideally positioned to drain CSF from the SAS into the major dural sinuses, but also through the lymphatic system, and through the

glymphatic system in the brain parenchyma, (extracellular fluid spaces that are in communication with the brain capillaries). In fact, it is widely accepted that the vast majority of CSF is absorbed through the capillary network of the CNS [1, 7,8].

Keywords: neurosonography, mri, pediatric neuroimaging, cerebrospinal fluid, hydrocephalus, ventriculomegaly, csf flow dynamics.

Purpose of the study— optimization of the diagnosis of cerebrospinal fluid flow disorders in children based on comparative clinical and neuroimaging analysis using neurosonography (NSG) and magnetic resonance imaging (MRI) in order to improve the accuracy of early detection, severity assessment and outcome prediction in central nervous system pathologies in newborns and older children.

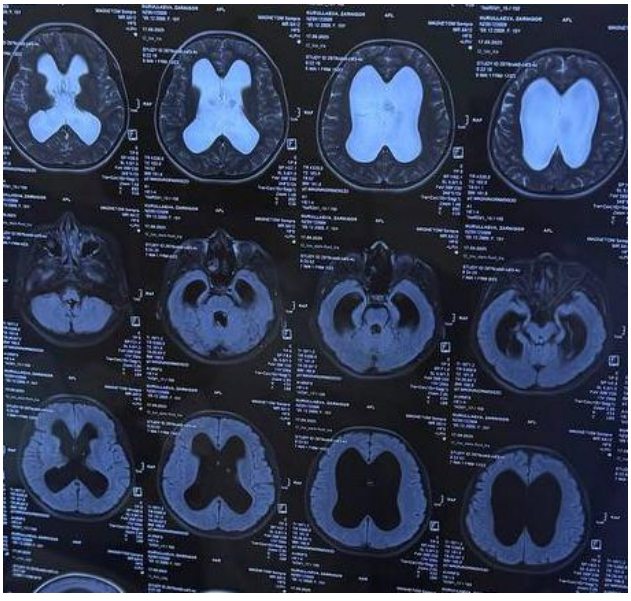
Materials and methods: The results of the study of outpatients and inpatients in the neurology and neurosurgery departments of the Multidisciplinary Clinic of the Samarkand State Medical University for the period 2024-2025 were analyzed.

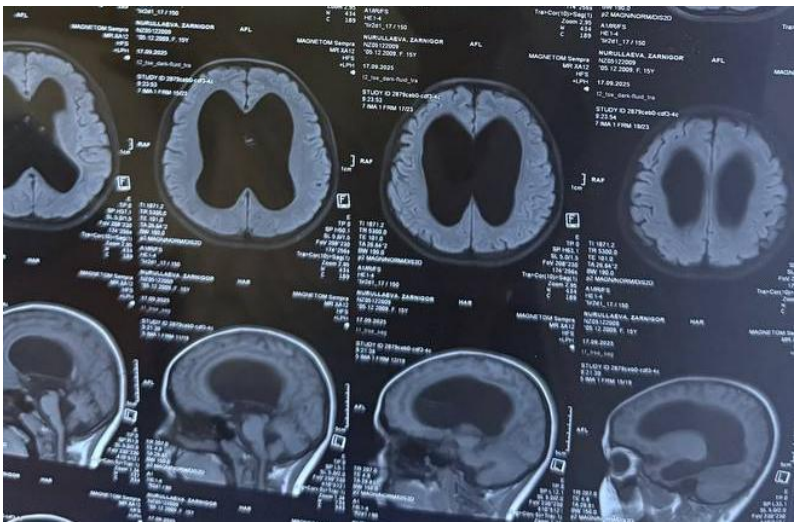
More than 25 years after the introduction of fetal MRI for diagnosing central nervous system (CNS) anomalies, it has become clear that this method provides important additional information to clarify diagnoses and improve counseling for patients with cerebrospinal fluid flow disorders. However, ultrasound, including neurosonography, remains the primary method for screening and primary diagnosis due to its availability, safety, and ability to be performed at the patient's bedside [1].

The Importance and Limitations of MRI and Neurosonography

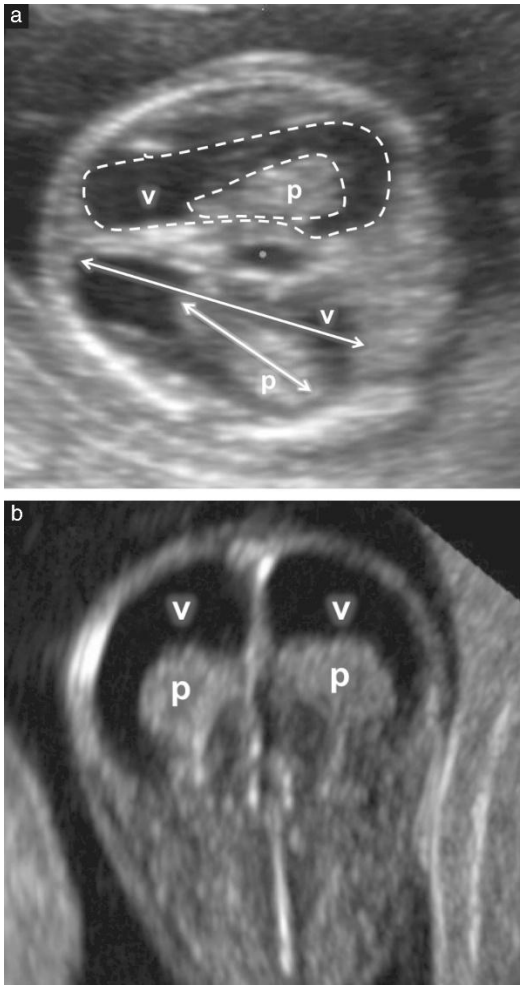
Fetal MRI is particularly valuable for identifying complex structural abnormalities and clarifying the diagnosis of suspected brain lesions, which cannot always be clearly visualized by ultrasound. Modern MRI protocols include T2-weighted spin-echo sequences, which provide high-contrast anatomical images, as well as more sophisticated techniques such as diffusion-weighted imaging, spectroscopy, and phase-contrast MRI (PC-MRI), which allow for the assessment of CSF microanatomy and dynamics (Pic1) [2].

A recent meta-analysis showed that in fetuses with isolated moderate ventriculomegaly, MRI reveals additional abnormalities not detected by ultrasound in approximately 10% of cases. However, when compared with targeted neurosonography, this percentage drops to 5%, and with a transvaginal approach, to 1.6%. This demonstrates the high diagnostic efficacy of specialized neurosonography, which, when performed correctly, can significantly reduce the need for additional MRI [3].





Pic 1. Imaging in MRI hydrocephalus



Pic 2. Imaging in neurosonography hydrocephalus

Functional MRI and assessment of cerebrospinal fluid dynamics. Phase-contrast magnetic resonance imaging (PC-MRI) has become an important tool for noninvasively assessing CSF flow parameters in patients with idiopathic normal-pressure hydrocephalus (iNH). Stroke volume and peak CSF flow velocity in the cerebral aqueduct are key parameters obtained using standardized methods that allow for real-time assessment of CSF flow dynamics.

Stroke volume is the total volume of CSF moved during one cardiac cycle (the sum of systolic and diastolic flows), providing a stable and reliable measure of CSF dynamics. In contrast, net

flow is highly variable and subject to potential error due to the subtraction of large flows in opposite directions, so most studies do not use this parameter for clinical decision-making.

Neurosonography is an accessible, safe, and rapid method for assessing newborns, especially in intensive care units. It enables the detection of cranial anomalies, ventricular dilation, vascular abnormalities, and hypoxic-ischemic encephalopathy (HIE) (Pic2). In the intensive care unit (ICU), neurosonography plays a key role in monitoring children at risk for stroke, complications after extracorporeal membrane oxygenation (ECMO), and in selecting patients for therapeutic hypothermia.

This method has the following advantages: no radiation exposure, the ability to conduct the examination at the patient's bedside, portability and accessibility of the equipment, real-time visualization and the possibility of dynamic monitoring.

Continuous improvements in ultrasound technology, increased resolution, and the development of a systematic approach to sonographic anatomy have significantly improved diagnostic accuracy, allowing the detection of even minor brain injuries and structural abnormalities.

Clinical aspects of diagnosis of cerebrospinal fluid dynamics disorders

Neurosonography allows for the early detection of hydrocephalus, assessment of ventricular dilation dynamics, and identification of associated changes—for example, signs of increased intracranial pressure, cerebrovascular accidents, or focal lesions [4]. For example, hydrocephalus is characterized by pathological dilation of the cerebral ventricles, which can be obstructive (impairing cerebrospinal fluid (CSF) outflow), non-obstructive, or secondary (ex vacuo) due to loss of brain parenchyma. In later stages, fenestration of the septum pellucidum may occur. The most sensitive ultrasound indicator of ventriculomegaly is the width of the anterior horn of the lateral ventricle.

Comparative analysis of neurosonography and MRI

Studies show that when performed professionally, neurosonography approaches the diagnostic value of MRI, especially when used transvaginally. However, MRI remains indispensable in cases of diagnostic uncertainty, the need for detailed analysis of complex structural anomalies, suspected brain damage, vascular pathologies, or white matter abnormalities requiring additional imaging sequences. Furthermore, MRI can identify conditions that may be missed by ultrasound, such as intracranial hemorrhages, polymicrogyria, listcephaly, and other congenital brain malformations.

Multidisciplinary approach to diagnosis and treatment

To improve diagnostic accuracy and patient care, specialists performing neurosonography and interpreting MRIs must be experts with regular practice. Diagnosis and consultation should be carried out in multidisciplinary teams, including pediatric neurologists, geneticists, perinatologists, neonatologists, and perinatal pathologists.

This approach minimizes the risk of diagnostic and prognostic errors, improves the quality of clinical decisions, and promotes better long-term neurological outcomes in children with cerebrospinal fluid flow disorders.

Conclusion. Optimization of the diagnosis of cerebrospinal fluid flow disorders in children is achieved through the integration of neurosonography and MRI. Provided that a high-quality, specialized neurosonographic examination is performed, the additional diagnostic value of MRI is small—approximately 1–2%. MRI is recommended in cases of diagnostic uncertainty, the need for extended sequences, and to confirm ultrasound findings in clinical decision-making.

The use of phase-contrast MRI allows for the acquisition of important CSF flow parameters, such as stroke volume and peak CSF flow velocity, which is particularly important when assessing patients with normal-pressure hydrocephalus. However, neurosonography remains the primary method for the initial assessment of newborns due to its availability and safety.

To improve the quality of diagnostics, regular training and professional development for specialists, the use of standardized examination protocols, and a multidisciplinary approach to diagnosis and consultation are necessary. Only a comprehensive approach will improve the early diagnosis, monitoring, and treatment of cerebrospinal fluid flow disorders in children, ultimately enhancing their quality of life and neurological outcomes.

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