The application of integrated MRI CSF flowmetry in the diagnosis and treatment of CSF dynamic changes in hydrocephalus patients: a systematic review

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Abstract

Background: CSF has contributed to the growth of brain development during the time of evolution and later protects against external trauma. Idiopathic normal pressure hydrocephalus (iNPH) is known as an aberration of intracranial hydrodynamics resulting in the accumulation of CSF endo-ventricular. The use of phase-contrast (PC) MRI is proven effective in assessing the communication of arachnoid cyst and subarachnoid CSF spaces. The CSF flow MRI has been found to show efficacy in differentiation between the communicating and non-communicating hydrocephalus for localizing obstruction levels in obstructive hydrocephalus and later providing important information concerning the preoperative evaluation of NPH, along with the differential diagnosis and the prediction of the related advantages from surgery and post-operative follow-up. Hence, the present study aimed for analyzing the role of MRI CSF flowmetry in the evaluation of patients with suspected hydrocephalus.

Method: The role of MRI CSF flowmetry in the evaluation of patients with suspected hydrocephalus was undertaken by conducting a systematic literature review. The current review was reported as required reporting features for systematic reviews and meta-analysis statements (PRISMA). The systematic literature review included a total of 22 studies that analyzed the various applications of MRI CSF flowmetry in the medical field, mainly focusing on the use of MRI CSF flowmetry in the evaluation of patients with suspected hydrocephalus.

Results: The result mainly included the identification of the CSF flow by integrating the PC MRI technique and the aqueduct-CSF flow rate was detected accurately showing as statistically significant in diagnosis of NPH. Evaluating the peak velocities and aqueductal stroke volume (ASV) showed a significant increase among hydrocephalus patients.

Conclusion: The condition of hydrocephalus makes the ventricular size increase and eventually puts pressure on the brain due to excess accumulation of fluid while blocking the CSF flow after it exits ventricles. Currently, many imaging techniques are available for the detection of hydrocephalus that study the CSF flow dynamics and its related parameters. Among them, the MRI technique is the most reliable, rapid, and most importantly, a non-invasive method for the quantitative measurement of CSF flow rate and intracranial pulsations.

Keywords: Intracranial pressure, Magnetic resonance imaging (MRI), MRI CSF Flowmetry, Neurological disorder, CSF dynamics

Introduction

The cerebrospinal fluid is formed initially within choroid plexus in ventricles with 500 mL flow rate every day. The CSF flows at downward direction around the spinal cord and above cerebral convexities when it enters into the SAS. The resorption method for CSF was dependent upon the tracer studies conducted during previous decades through the use of large molecules. The microscopic flow of CSF is explained in terms of the functioning of the lymphatic system in different body parts (Iliff et al., 2012). CSF has contributed to the growth of brain development during the time of evolution and later provides protection against external trauma (Fan et al., 2012). The flow of CSF is observed into and from motion through aqueduct of Sylvius and the foramen magnum. During the condition of systole, the flow of CSF continues from the aqueduct and foramen magnum within the caudal direction and later back in diastole. Hence, this flow is considered to be pulsative which can be measured phase-contrast MRI (Raybaud, 2004).

Normal-pressure hydrocephalus (NPH) is still considered to possess no appropriate cause of occurrence to date. Different theories of normal-pressure hydrocephalus (NPH) are available in which one theory implicates the reduction in CSF absorption and the other one is dependent upon the changes within periventricular ischemic resulting in slowing down the discharge of CSF from extracellular spaces while in turn resulting into evolving ventricular enlargement due to effect of back pressure. The infants suffer from progressive macrocephaly and the childhood phase presents the patient having symptoms of increased intracranial tension in case of normal-pressure hydrocephalus (NPH); NPH being categorized as communicating and non-communicating/obstructive hydrocephalus.

Idiopathic normal pressure hydrocephalus (iNPH) has been known as an aberration of intracranial hydrodynamics resulting in the accumulation of CSF endo-ventricular (Jacobsson et al., 2018). In this condition, the brain shows compression against the calvaria while boosting arterial pulsation with progressive vascular damage atrophy along with reducing the ventricular squeezing, known to be the force-moving CSF (Bradley, 2015). iNPH is managed by CSF stroke volume (SV) known to be the predictor of CSF shunting outcome (Abbey et al., 2009; Marmarou et al., 2005).

Most of the cases of normal pressure hydrocephalus (NPH) have been known as idiopathic. Rising cases of NPH have been found to be increasing mostly among the elderly population. Different types of MRI features such as ventriculometry, periventricular hyperintensity, crowding of gyri at the vertex and several other symptoms have represented the occurrence of NPH. The evaluation of CSF dynamics among the patients suffering from hydrocephalus was considered an important aspect. Phase-contrast MRI (PC-MRI) is considered as the common MRI technique for the evaluation of CSF flow dynamics in real-time. The utilization of these MRI techniques of CSF flow is combined with cardiac cycle and CSF flow dynamics which is later evaluated by integrating different parameters. The evaluation of CSF flow dynamics using cine magnitude imaging has been found in the initial phase of discovery (Post et al., 1986). Hence, the phase-contrast MRI has been found effective in determining the CSF flow velocity which is considered to be quantitative along with its combination to qualitative assessment.

Void of CSF flow is representative of hyperdynamic CSF flow showing similarity with flow voids observed within the arteries after conducting MR imaging. Correlation of CSF flow void after obtaining conventional spin-echo images was observed with the response towards ventriculoperitoneal shunting. The modern techniques of MR imaging involving the fast/turbo spin-echo have been known to be intrinsically flow-compensated that does not consist of the same flow void as observed during the initial phases of MR imaging. The above characteristics have resulted in developing advanced phase-contrast (PC) MR imaging techniques for the estimation of CSF flow for selecting appropriate symptomatic patients for undergoing ventriculoperitoneal shunting for NPH.

Different types of tests were undertaken for the diagnosis of NPH involving the invasive methods, that resulted in serious complications. Hence, the application of flow-sensitive cardiac gated phase-contrast MR imaging techniques are integrated which is capable of providing significant care for the non-invasive study of CSF flow dynamics (Siraj, 2011). The CSF flow MRI has been found to show efficacy in differentiation between the communicating and noncommunicating hydrocephalus for localizing the level of obstruction in obstructive hydrocephalus and later providing important information concerning the preoperative evaluation of NPH, along with the differential diagnosis and the prediction of the related advantages from surgery and post-operative follow-up (Ng et al., 2009). Therefore, the utilization of different imaging techniques has been integrated for accessing the visualization of physiological processes and structural details along with diagnostic tests and prognostic tools utilized in assessing the patients suffering from NPH (Halperin et al., 2015).

The application of PC-MRI has been widely used with clinical perspectives that range from NPH evaluation along with follow up, surgical decision and post-surgery and post shunting status, Chairi malformation, syringomyelic cyst, posterior cystic malformation, etc. NPH was previously considered as an idiopathic entity which is now being increasingly identified as a chronic communicating hydrocephalus providing effectiveness to the patients belonging to the group from VP shunting. The incidence of NPH was estimated as 5.5 per 100,000 and prevalence is 21.9 per 100,000 (Brean and Eide, 2008).

Aims and Objectives

The present study aims for analyzing the role of MRI CSF flowmetry in the evaluation of patients with suspected hydrocephalus. The following objectives and research questions have been framed as per the major aim of the study:

1 Objectives of the study:
The following objectives have been obtained for conducting the systematic literature review within the study:
● To determine the role of MRI CSF flowmetry in diagnosis and treatment in intracranial CSF Dynamics of hydrocephalus
● To assess the integration of MRI CSF flowmetry for diagnosis and treatment in intracranial CSF Dynamics of hydrocephalus
● To determine the changes in intracranial CSF Dynamics of hydrocephalus patients in comparison to the mechanism of normal CSF circulation
● To evaluate the possible outcome for the comparative analysis of changes in intracranial CSF Dynamics of hydrocephalus patients with the mechanism of normal CSF circulation

Materials and Methods

The current review was integrated towards the preferable features for systematic reviews and meta-analysis statements (PRISMA).

1 PRISMA methodology:
The impact of changes in intracranial CSF Dynamics of hydrocephalus on the patients' health has been studied in the present study. The mechanism of normal CSF circulation has been analyzed. The diagnosis and related treatments for intracranial CSF Dynamics of hydrocephalus patients have been determined. The role of MRI CSF flowmetry in diagnosis and treatment in intracranial CSF Dynamics of hydrocephalus have been determined in the present study. The integration of MRI CSF flowmetry for diagnosis and treatment in intracranial CSF Dynamics of hydrocephalus has been assessed in the present study. The changes in intracranial CSF Dynamics of hydrocephalus patients compared with the mechanism of normal CSF circulation have been clearly represented. The relative outcome for the comparative analysis of changes in intracranial CSF Dynamics of hydrocephalus patients with the mechanism of normal CSF circulation has been determined. PRISMA analysis was carried out for identification, screening, and selection of studies for supporting systematic literature review.

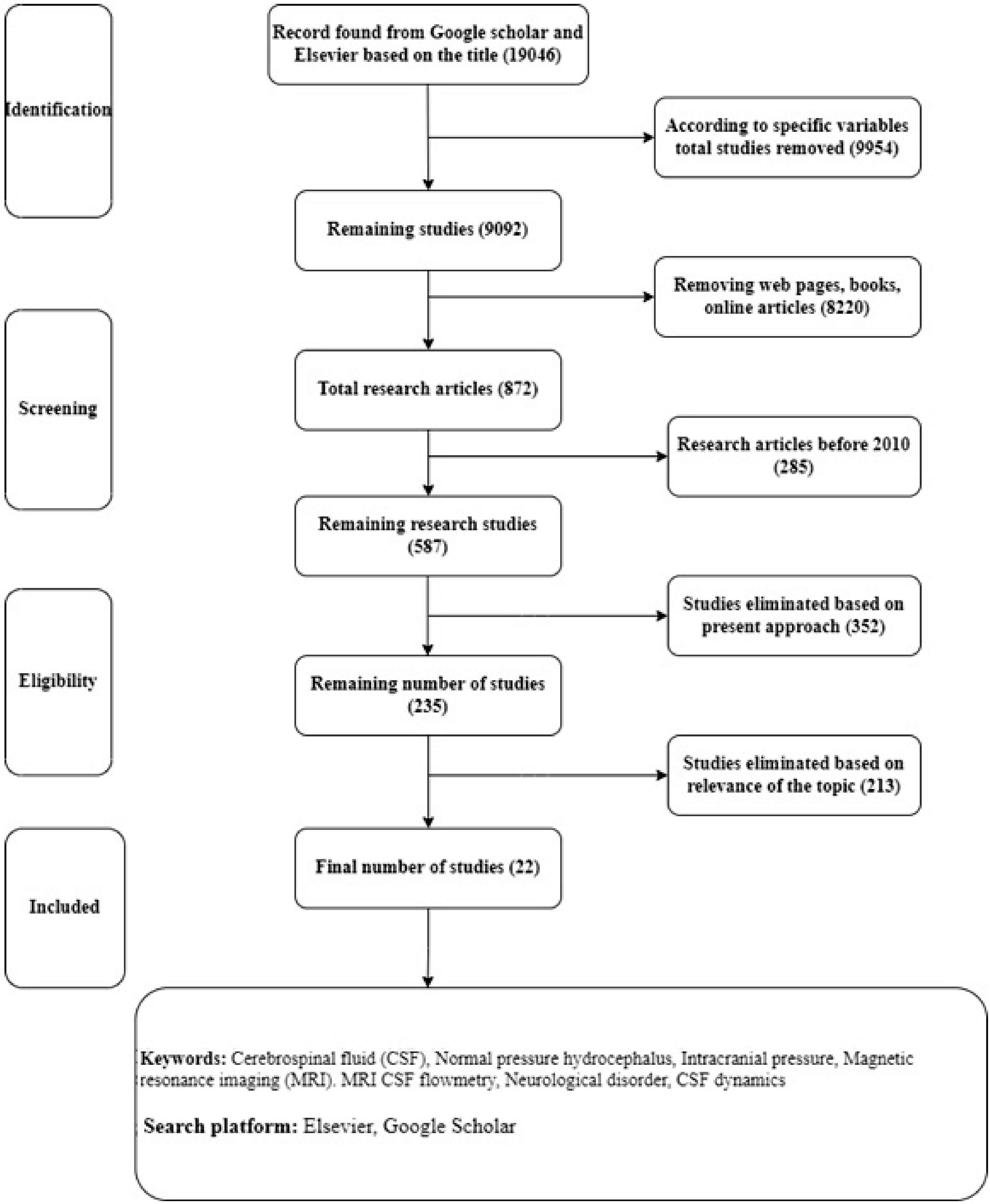
2 Search Strategy
Utilization of electronic databases was checked for research papers using the keywords "Cerebrospinal fluid (CSF)", "Normal-pressure hydrocephalus (NPH)", "Intracranial pressure", "Magnetic resonance imaging (MRI)", "MRI CSF Flowmetry", "Neurological disorder", "CSF dynamics", etc. Various databases involving Google Scholar, Pub Med, Scopus and Elsevier were screened, and studies with the integration of framework and models were taken into consideration for this study. Also, the search in the databases was conducted in a period of 10 years, 2011-2021. A total 19,046 articles constituting the articles were screened.

3 Eligibility criteria:
Following is the criteria for study inclusion and exclusion:
● Criteria for study inclusion: The study represents the information regarding the applications of MRI CSF flowmetry in the medical field. The application of MRI CSF flowmetry in the evaluation of patients with suspected hydrocephalus has been taken into consideration. The studies showing the extent of successful integration of CSF circulation in suspected hydrocephalus patients were included in this study. The inclusion of the obtained differences observed in normal individuals from the studies has been included. The detection of CSF changes were accurately compared to other existing techniques for hydrocephalus.
● Criteria for study exclusion: Studies with the absence of any application of MRI CSF flowmetry were excluded from this study. The patients with no suspicion of hydrocephalus have been excluded from the study. The studies showing no efficacy rate of integrating the use of CSF circulation for suspected hydrocephalus patients were excluded from the study. The studies not representing any changes related to CSF flowmetry have been excluded from the study.

4 Study selection:
Studies showing relevancy were selected by adopting the search strategy in two steps. Firstly, the articles with appropriate topics were independently involved with the process of screening using important keywords concerned with the study, and important information regarding the same was utilised. The available titles and abstracts were recognized and examined in terms revealing the justification of the included studies present in the paper. The second step involved the investigation of the full-text articles appropriately by reviewing them in an independent manner. The utilization of Google Scholar (https://scholar.google.com/), and Elsevier (https://www.elsevier.com/en-in) was observed for citing the papers so that relevant articles with key findings could be included in the study in subsequent primary research. After study selection, if there were any disagreements it was mutually discussed, and a consensus was made before the inclusion of the study in this review. The review included a final total of 22 studies

5 Data extraction:
Studies justifying the inclusion criteria were used for processing the related articles for data extraction. The primary focus of the review was determining the role of MRI CSF flowmetry in diagnosis and treatment in intracranial CSF Dynamics of hydrocephalus. The secondary outcome included the integration of MRI CSF flowmetry for diagnosis and treatment in intracranial CSF Dynamics of hydrocephalus. It included the data on the following study characteristics - the name of the first

Figure 1: PRISMA model



author, year of publication, the population, and the sample size used in the study, the study analyzed the role of MRI CSF flowmetry in diagnosis and treatment in intracranial CSF Dynamics of hydrocephalus, MRI CSF flowmetry was used for diagnosis and treatment in intracranial CSF Dynamics of hydrocephalus, changes in intracranial CSF Dynamics of hydrocephalus patients in comparison to the mechanism of normal CSF circulation, possible outcome for the comparative analysis of changes in intracranial CSF Dynamics of hydrocephalus patients with the mechanism of normal CSF circulation, a summary of the analyzed result, and the significance involved.

8 Data analysis:
The present study analyzed the data along with the interpretation of the results of the selected studies. The data analysis includes is difficult due to the availability of a sheer volume of information. The synthesis of findings from multiple qualitative studies was undertaken and a collection of major findings were included for analyzing the major outcome of the systematic literature review. The quantitative studies of similar quality and methodology were analyzed, compared, and aggregated.

Results and Discussion

The present systematic literature review included a total of 22 studies and analyzed the various applications of MRI CSF flowmetry in the medical field. In the present review, we explored the use of MRI CSF flowmetry in the evaluation of patients with suspected hydrocephalus. The extent to which MRI CSF is advantageous in the detection of CSF circulation in suspected hydrocephalus patients and the differences observed in normal individuals have been explored in the review. In order to justify the role of MRI CSF flowmetry in the evaluation of patients with suspected hydrocephalus, various studies have been screened out showing the application of MRI flowmetry in detecting CSF changes accurately as compared to other existing techniques.

Normal-pressure hydrocephalus (NPH) is considered a nebulous entity having no definite cause. Many tests have been conducted till now for the diagnosis of idiopathic NPH (iNPH) such as invasive methods that have resulted in serious complications and this is the reason, non-invasive techniques are required for increasing the specificity and sensitivity of imaging techniques used routinely. Youssef, Magdy, and Abdul-Rahman (2021) conducted a study to evaluate the role of MRI-CSF flowmetry, a noninvasive method in the diagnosis of iNPH in patients with clinically suspected hydrocephalus. The results of the study showed that 76% of the patients were diagnosed with NPH with phase-contrast (PC) MRI and 26% with hypo dynamic flow of CSF across the aqueduct in the study. The results suggest that PC MRI CSF flowmetry is a technique having high specificity and sensitivity in the diagnosis of NPH and differentiates from atrophic dilatation being a non-invasive method. Additionally, this method adds more accuracy to conventional MRI techniques by providing valuable information and reducing rates of complications as well as predicting responsiveness to shunt surgery. This result correlates with a study conducted by Al-Zain et al. (2008) wherein the results showed that the PC MRI technique helped in identifying the CSF flow and the patients were classified into iNPH and brain atrophy. An aqueduct-CSF flow rate was accurately detected by PC MRI technique which is statistically significant in the diagnosis of iNPH.

Pulsatile CSF flow rate diagrams are used for the inlet and outlet boundary conditions (BCs) in context to changes in CSF volume in the ventricular system. BC evaluation is suggested to investigate intracranial compliance in hydrocephalus patients. It is quite challenging in biomechanical simulations to evaluate BCs in terms of natural BCs such as load or pressure and essential BCs in non-slip-boundary conditions in hydrocephalus modelling. CINE-PC MRI technique helps in BCs investigation in improving the computer simulation of CSF dynamics in patients with hydrocephalus and was investigated by Gholampour and Fatouraee, (2021). The results showed that the CINE-PC MRI technique assessed the differences between the inlet/outlet BCs quite accurately in normal individuals and hydrocephalus patients. A similar study has been conducted by Akay et al. (2015) wherein the CINE-PC MR imaging technique was used to evaluate CSF flow dynamics across the aqueduct in patients with idiopathic intracranial hypertension (IIH) patients. The results of the study showed differences in the mean rate and flow of CSF across the aqueduct which is higher in patients with IIH as compared to controls suggesting that CSF flow analysis using the CINE-PC MR imaging technique is a marker for IIH patients. This result correlated with another study conducted by Yılmaz et al. (2019) to evaluate CSF flow dynamics in communicating hydrocephalus and IIH using the MRI technique. In hydrocephalus, the width of aqueductus sylvii (AS) or prepontine cistern (PPC) was found to be significantly higher along with other metrics in CSF flow dynamics having the standardized sum of diastolic and systolic flow durations which were found to be lower. Additionally, with the MRI technique, peak velocities and aqueductal stroke volume (ASV) were significantly increased in the case of hydrocephalus.

Owler et al. (2004) conducted a study wherein O-water positron emission tomography with MR and CSF infusion studies was applied for studying the changes in cerebral blood flow (CBF) with changes in pressure of CSF among patients with NPH. O-water PET with MRI imaging approach helps in studying the dynamic characteristics of NPH in terms of the cerebral vasculature. A computerized CSF infusion study and O-water PET scanning with MR co-registration are used for measuring cerebral pressure autoregulation in NPH patients.

Determination of pulsatile aqueductal CSF flow velocity and stroke volume using the CINE-PC MRI technique would aid in the assessment of intracranial pulsations in iNPH. Jaeger et al. 2016 conducted a study for the diagnosis of iNPH wherein Mean ICP pulse wave amplitude (MWA) and non-invasive cine PC-MRI was done for the quantitative aqueductal CSF flow rate as it is the gold standard for measuring intracranial pulsations. The results of the study showed the interplay of pulsations derived from MRI measurements and continuous ICP measurements to understand the CSF MRI flow dynamics.

In patients with NPH, the standard treatment is a ventriculoperitoneal (VP) shunt placement. However, not all patients are eligible and respond effectively to shunt surgery. Patients who are in the early stage of NPH seem to respond better to VP shunt as compared to patients who are in the later stage of NPH due to changes in the CSF flow dynamics. Over the years, many techniques have detected elevated CSF flow in aqueducts of clinical NPH patients and recently, CSF flow in NPH patients could be observed more accurately across the aqueduct by the CINE-PC MR imaging technique. Considering this fact, Witthiwej et al. (2012) conducted a study to evaluate patients with clinical NPH whether they are eligible and responsive towards shunt replacement. The results of the study suggested that cine-PC MRI could be a potential tool to study CSF flow dynamics for predicting the outcome of VP shunt placement in NPH patients. In the year 2015, Bradley also conducted a similar study to evaluate whether CSF flow dynamics need to be studied in patients presenting with clinical NPH. This is because hyperdynamic CSF flow has been observed across the aqueduct in patients with NPH having ventricular enlargement without cerebral atrophy. The study of CSF flow dynamics helps to predict the patients who would respond better to VP shunting as compared to individuals with decreased or normal CSF flow. NPH patients have been found to have larger intracranial volumes as compared to normal individuals and so, the study of CSF flow dynamics is important testing done by PC-MR imaging technique to evaluate a symptomatic NPH patient for VP shunting.

iNPH is a disorder of incontinence, gait impairment, and dementia and specific testing includes assessment of patients in terms of testing of CSF hydrodynamics. In iNPH patients, shunt surgery can improve the condition and this differential diagnosis is possible with imaging techniques like MRI technique. With PC-MRI, the evaluation of CSF flow dynamics provides relevant information about the diagnosis of iNPH superior to CT scan. High-resolution and high-speed MRI techniques could better identify the aqueductal stenosis and hyperdynamic aqueductal CSF flow which is associated with shunt-responsive iNPH (Williams and Relkin, 2013). This result correlates with a study conducted by Kartal and Algin (2014) wherein they highlighted the fact that MRI is not only beneficial in the diagnosis of CSF-related disorders like hydrocephalus, but also helps in the planning and management of the condition post-surgery and in the follow-up of the patients. In complex conditions, the PC-MRI technique helps to prevent false results in the case of the 3D-SPACE technique. In the case of non-communicating hydrocephalus, the MRI technique gives the most significant results as it helps to discriminate between chronic and acute forms of hydrocephalus such as periventricular hyperintensities which is consistent with the condition of acute interstitial oedema. The obstructed sites are detected accurately specific to the condition with the MRI technique.

Currently, PC-MRI is being used to measure the CSF volume that is flowing through the aqueduct in either direction over one cardiac cycle. When there is an elevation in the aqueductal CSF stroke volume (ACSV), there is an excellent chance for the patients with NPH towards shunt responsiveness. Bradley Jr (2016) shed light on the fact that MRI performed on an individual suspected with NPH shows ventricular dilation which is out of proportion to any sulcal enlargement which is a common pattern in hydrocephalus instead of atrophy. CSF flow void which indicates hyperdynamic CSF flow observed as flow voids could be visualized in arteries with MRI technique. Furthermore, the PC-MRI technique was developed that evaluated CSF flow for the selection of symptomatic patients who are responsive to VP shunt replacement in NPH. PC-MRI provides better resolution of the aqueduct as it is quite small in a few minutes. Lakhera et al. (2020) also conducted a study to evaluate the flow alterations of CSF in patients with meningitis using the PC-MRI technique. Quantitative CSF analysis was done at the cerebral aqueduct level by applying cardiac-gated PC-MRI. The results of the study showed wide variations in the CSF flow parameters noted in the case of meningitis patients irrespective of ventricular dilatation. Additionally, stroke volume and peak velocity also showed a significant difference in the case of patients with meningitis, and milder alterations were observed in the case of viral meningitis due to tuberculous and bacterial etiologies. This suggests that PC-MRI is highly sensitive to alterations in CSF flow dynamics which could improve the segregation of patients into non-viral and viral etiologies in meningitis supporting appropriate treatment.

Abdelhameed, Darweesh, and Bedair (2017) conducted a study to evaluate hydrocephalus in pediatric patients using MRI CSF flowmetry such as PC-MRI which is a non-invasive, rapid, and simple technique. Cine PC-MRI images detect the flow of CSF in a dynamic, more pleasing, and acceptable manner clearly depicting the obstruction that is present along the CSF pathway and in conditions where the obstruction is common such as AS and foramen of Monro. The results of the study showed that PC-MRI shows high sensitivity to even small flows of CSF and so it can be used in the evaluation of CSF both quantitatively and qualitatively and could also be applied in conjunction with the conventional technique of MRI in the assessment of hydrocephalus. This study correlates with another one conducted by Öztürk, Sığırcı, and Ünlü (2016) wherein cine-PC MRI technique was used to determine the differences in the parameters of aqueductal CSF flow in childhood as per gender and age groups divided into infants, children, and adolescents. For the quantitative evaluation of CSF flow, transverse plane images were taken at the level of cerebral aqueduct using the PC-MRI angiography technique. Although the results showed no differences in terms of gender and age in the area of the aqueduct, differences were observed in terms of cranial direction volume, peak velocity, and caudal direction among the three groups. This indicates that the PC-MRI technique could be used for determining the CSF flow parameters such as volume, velocity, and aqueduct area in a healthy pediatric population.

Abdalla and Zghair (2019) conducted a study using the PC-MRI technique that could be beneficial in the assessment of NPH differentiating it from involutional atrophy. PC-MRI flowmetry technique provided distinct differences in CSF parameters such as peak systolic velocity, mean systolic velocity, and systolic stroke volume between the patients and the control group. This indicates that PC-MRI is a useful tool for clinicians to differentiate between the two overlapping conditions, age-related brain atrophy and NPH in a non-invasive manner, especially among the elderly population. This non-invasive imaging technique has the potential to exclude patients with similar symptoms that may result in dementia. Another study conducted by Ringstad (2018) explored the characteristics of CSF flow dynamics in patients with iNPH condition whose cause is unknown but characterized typically by urinary incontinence, gait disorder, and dementia. MRI technique helps in the measurement of pulsatile intracranial CSF flow and compares it with intracranial pressure (ICP) pulsatility in patients with iNPH.

El Falaky, Metwally, and Abdelalim (2012) stated the fact that MRI CSF flowmetry, a noninvasive method is helpful in establishing the diagnosis of NPH and predicts that whether after the shunting procedure, the condition of the patient will improve or not. The results of the study showed that after the patients with NPH underwent MRI CSF flowmetry and lumbar tap for the confirmation followed by shunt insertion, immense improvement was noted in all the cases. There was improvement observed in terms of cognitive functioning and gait with improved bladder control. This indicates that MRI CSF flowmetry is a safe and reliable investigation for the diagnosis of NPH. Medica (2017) also conducted a similar study using cine-PC MRI to measure aqueductal stroke volume (ACSV) for the selection of patients with NPH who would be suitable candidates for the VP shunt surgery. ACSV measurements scanned by PC-MRI helped to select the patients suitable for shunt surgery more appropriately. The results of the study showed that the PC-MR imaging technique is beneficial in detecting the ACSV measurements which in turn is useful in stratifying patients with NPH after the shunt surgery which may be improved or not improved. In patients with high ACSV values, it is wise to apply a CSF diversion in the form of shunt surgery to prevent atrophy and ischemia. Similarly, a drop in the values of ACSV indicates that patients have benefitted from the shunt surgery detected by MRI CSF flowmetry, a non-invasive technique.

Metafratzi et al. (2020) conducted a study to evaluate that spontaneous intracranial hypotension (SIH) could be detected using MR CSF flow dynamics that present intense contrast enhancement in dura mater, diffuse smooth thickening, and increase in the size of pituitary gland along with downward brain displacement. Engorgement of the cavernous sinuses has also been reported in SIH detected by the MR imaging technique. Additionally, the PC-MRI technique which studied the CSF flow dynamics also revealed that there is a decrease in the diastolic and systolic CSF flow volume at the aqueduct level in SIH when it subsided. This indicates that CSF flow dynamics have an important role in SIH pathogenesis as revealed by PC-MRI and CSF dynamics normalized as SIH subsided. PC-MRI studies provide clinical information about VSF flow and help in the diagnosis of patients with suspected SIH conditions.

Yamada et al. (2020) conducted a study to evaluate the complex movements of CSF in patients with iNPH along with shear stress on a 4D flow MRI. The parameters in CSF movements such as shear stress, stroke volume, and reversed-flow rate were calculated along with relationships that were assessed between the morphological measurements and flow-related parameters. The results of the study showed that the flow-related parameters at the level of the cerebral aqueduct were found to be higher in patients with iNPH along with higher shear stress in context to ventral aspect at the level of the cerebral aqueduct. This indicates that 4D flow MRI is a useful imaging technique for detecting CSF flow-related parameters in the diagnosis of iNPH and could also elucidate the ventricular enlargement mechanism in iNPH. CSF stroke volume was found to be higher in iNPH patients with high shear stress at the cerebral aqueduct and was found to be associated significantly with the foramen of Magendie diameter.

Conclusion

From the above discussion, it is evident that hydrocephalus is a condition wherein there is abnormal fluid accumulation in the cavities or ventricles that are deep-seated in the brain. This condition makes the ventricular size increase and eventually puts pressure on the brain due to excess accumulation of fluid. In hydrocephalus, CSF flow is blocked after it exits ventricles. This is the reason, it is crucial to study the CSF flow dynamics to detect the condition in suspected individuals. Moreover, it is a serious condition with unknown cause and hydrocephalus also shares symptoms with other conditions such as aqueductal stenosis (AS), brain atrophy and other such disorders. Therefore, it is important to detect the hydrocephalus condition to have early diagnosis, treatment and proper management of the patients suspected with such conditions, especially among the paediatric population and also to differentiate it from other conditions with overlapping symptoms. Currently, many imaging techniques are available for the detection of hydrocephalus that studies the CSF flow dynamics and its related parameters. Among them, MRI technique is the most reliable, rapid and most importantly, a non-invasive method for the quantitative measurement of CSF flow rate and intracranial pulsations. MRI is not only beneficial in the diagnosis of CSF-related disorders like hydrocephalus, but also helps in the planning and management of the condition post-surgery as it predicts the condition of the patient and their responsiveness towards shunt surgery. Additionally, with the MRI technique, peak velocities and aqueductal stroke volume (ASV) could be detected significantly in case of patients with hydrocephalus. Apart from PC-MRI, cine-PC MRI and 4D MRI techniques evaluate the complex CSF movements such as shear stress, stroke volume, and reversed-flow rate in the case of iNPH. PC-MRI technique gives higher specificity and sensitivity towards CSF flow dynamics as it can detect even a small change in the CSF movement. Therefore, it can be said that MR imaging technique detects the CSF flow dynamics more accurately compared to other existing techniques not only in the diagnosis of hydrocephalus condition but also in differentiating it from other disorders sharing the same symptomatology and predicting responsiveness to shunt surgery in NPH.

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Conflict of interest
The authors have no conflicts of interest to disclose

References

1. Iliff, J.J., Wang, M., Liao, Y., Plogg, B.A., Peng, W., Gundersen, G.A., Benveniste, H., Vates, G.E., Deane, R., Goldman, S.A. and Nagelhus, E.A., 2012. A paravascular pathway facilitates CSF flow through the brain parenchyma and the clearance of interstitial solutes, including amyloid β. Science translational medicine, 4(147), pp.147ra111-147ra111.
2. Fan, H.C., Giiang, L.H., Huang, T.Y., Juan, C.J., Chen, C.Y. and Chen, S.J., 2012. 337 cerebrospinal fluid flow quantification of the cerebral aqueduct in children and adults with two-dimensional cine phase-contrast cine MR imaging. Archives of Disease in Childhood, 97(Suppl 2), pp.A99-A99.
3. Suman, A. and Pandya, S., 2018. Gross anatomy of cerebral ventricles and septum pellucidum of brain of Surti Buffalo (Bubalus bubalis). THE INDIAN JOURNAL OF VETERINARY SCIENCES AND BIOTECHNOLOGY, 14(02), pp.14-17.
4. Raybaud, C., 2004. Radiological assessment of hydrocephalus: new theories and implications for therapy. Neurosurgical Review, 27(3), pp.167-167.
5. Post, M.J., Quencer, R.M., Green, B.A., Montalvo, B.M. and Eismont, F.J., 1986. Radiologic evaluation of spinal cord fissures. American journal of neuroradiology, 7(2), pp.329-335.
6. Puy, V., Zmudka-Attier, J., Capel, C., Bouzerar, R., Serot, J.M., Bourgeois, A.M., Ausseil, J. and Balédent, O., 2016. Interactions between flow oscillations and biochemical parameters in the cerebrospinal fluid. Frontiers in aging neuroscience, 8, p.154.
7. Yildiz, H., Erdogan, C., Yalcin, R., Yazici, Z., Hakyemez, B., Parlak, M. and Tuncel, E., 2005. Evaluation of communication between intracranial arachnoid cysts and cisterns with phase-contrast cine MR imaging. American journal of neuroradiology, 26(1), pp.145-151.
8. Unal, Ö., Kartum, A., Avcu, S., Etlik, O., Arslan, H. and Bora, A., 2009. Cine phase-contrast MRI evaluation of normal aqueductal cerebrospinal fluid flow according to sex and age. Diagnostic and Interventional Radiology, 15(4).
9. Korosec, F.R., 2012. Basic principles of MRI and MR angiography. In Magnetic resonance angiography (pp. 3-38). Springer, New York, NY.
10. Siraj, S., 2011. An overview of normal pressure hydrocephalus and its importance: how much do we really know?. Journal of the American Medical Directors Association, 12(1), pp.19-21.
11. Ng, S.E., Low, A.M., Tang, K.K., Lim, W.E. and Kwok, R.K., 2009. Idiopathic normal pressure hydrocephalus: correlating magnetic resonance imaging biomarkers with clinical response. Ann Acad Med Singapore, 38(9), pp.803-8.
12. Toma, A.K., Holl, E., Kitchen, N.D. and Watkins, L.D., 2011. Evans' index revisited: the need for an alternative in normal pressure hydrocephalus. Neurosurgery, 68(4), pp.939-944.
13. Halperin, J.J., Kurlan, R., Schwalb, J.M., Cusimano, M.D., Gronseth, G. and Gloss, D., 2015. Practice guideline: Idiopathic normal pressure hydrocephalus: Response to shunting and predictors of response: Report of the Guideline Development, Dissemination, and Implementation Subcommittee of the American Academy of Neurology. Neurology, 85(23), pp.2063-2071.
14. Senger, K.P.S., Singh, R.K., Singh, A.K., Singh, A., Dashottar, S., Sharma, V. and Mishra, A., 2017. CSF flowmetry: an innovative technique in diagnosing normal pressure hydrocephalus. Int J Adv Med, 4, pp.682-687.
15. Bradley, W.G., 2015. CSF flow in the brain in the context of normal pressure hydrocephalus. American Journal of Neuroradiology, 36(5), pp.831-838.
16. Keong, N.C., Pena, A., Price, S.J., Czosnyka, M., Czosnyka, Z. and Pickard, J.D., 2016. Imaging normal pressure hydrocephalus: theories, techniques, and challenges. Neurosurgical focus, 41(3), p.E11.
17. Brean, A. and Eide, P.K., 2008. Prevalence of probable idiopathic normal pressure hydrocephalus in a Norwegian population. Acta neurologica Scandinavica, 118(1), pp.48-53.
18. Jacobsson, J., Qvarlander, S., Eklund, A. and Malm, J., 2018. Comparison of the CSF dynamics between patients with idiopathic normal pressure hydrocephalus and healthy volunteers. Journal of neurosurgery, 131(4), pp.1018-1023.
19. Bradley, W.G., 2015. CSF flow in the brain in the context of normal pressure hydrocephalus. American Journal of Neuroradiology, 36(5), pp.831-838.
20. Abbey, P., Singh, P., Khandelwal, N. and Mukherjee, K.K., 2009. Shunt surgery effects on cerebrospinal fluid flow across the aqueduct of Sylvius in patients with communicating hydrocephalus. Journal of Clinical Neuroscience, 16(4), pp.514-518.
21. Marmarou, A., Bergsneider, M., Klinge, P., Relkin, N. and Black, P.M., 2005. The value of supplemental prognostic tests for the preoperative assessment of idiopathic normal-pressure hydrocephalus. Neurosurgery, 57(suppl_3), pp.S2-17.
22. Youssef, A., Magdy, A.M. and Abdul-Rahman, A.A.A., 2021. The role of MRI-CSF flowmetry in the diagnosis of idiopathic normal pressure hydrocephalus. Fayoum University Medical Journal, 8(1), pp.19-30.

23. Al-Zain, F.T., Rademacher, G., Meier, U., Mutze, S. and Lemcke, J., 2008. The role of cerebrospinal fluid flow study using phase contrast MR imaging in diagnosing idiopathic normal pressure hydrocephalus. In Acta Neurochirurgica Supplements (pp. 119-123). Springer, Vienna.
24. Gholampour, S., & Fatouraee, N. (2021). Boundary conditions investigation to improve computer simulation of cerebrospinal fluid dynamics in hydrocephalus patients. Communications biology, 4(1), 1-15.
25. Owler, B. K., Pena, A., Momjian, S., Czosnyka, Z., Czosnyka, M., Harris, N. G., ... & Pickard, J. D. (2004). Changes in cerebral blood flow during cerebrospinal fluid pressure manipulation in patients with normal pressure hydrocephalus: a methodological study. Journal of Cerebral Blood Flow & Metabolism, 24(5), 579-587.
26. Akay, R., Kamisli, O., Kahraman, A., Oner, S., & Tecellioglu, M. (2015). Evaluation of aqueductal CSF flow dynamics with phase contrast cine MR imaging in idiopathic intracranial hypertension patients: preliminary results. Eur Rev Med Pharmacol Sci, 19(18), 3475-3479.
27. Jaeger, M., Khoo, A. K., Conforti, D. A., & Cuganesan, R. (2016). Relationship between intracranial pressure and phase contrast cine MRI derived measures of intracranial pulsations in idiopathic normal pressure hydrocephalus. Journal of Clinical Neuroscience, 33, 169-172.
28. Yılmaz, T. F., Aralasmak, A., Toprak, H., Mehdi, E., Kocaman, G., Kurtcan, S., ... & Alkan, A. (2019). Evaluation of CSF flow metrics in patients with communicating hydrocephalus and idiopathic intracranial hypertension. La radiologia medica, 124(5), 382-391.
29. Witthiwej, T., Sathira-ankul, P., Chawalparit, O., Chotinaiwattarakul, W., Tisavipat, N., & Charnchaowanish, P. (2012). MRI study of intracranial hydrodynamics and ventriculoperitoneal shunt responsiveness in patient with normal pressure hydrocephalus. J Med Assoc Thai, 95(12), 1556-62.
30. Williams, M. A., & Relkin, N. R. (2013). Diagnosis and management of idiopathic normal-pressure hydrocephalus. Neurology: Clinical Practice, 3(5), 375-385.
31. Kartal, M. G., & Algin, O. (2014). Evaluation of hydrocephalus and other cerebrospinal fluid disorders with MRI: an update. Insights into imaging, 5(4), 531-541.
32. Bradley Jr, W. G. (2016, April). Magnetic resonance imaging of normal pressure hydrocephalus. In Seminars in Ultrasound, CT and MRI (Vol. 37, No. 2, pp. 120-128). WB Saunders.
33. Abdelhameed, A. M., Darweesh, E. A. F., & Bedair, M. H. (2017). Role of MRI CSF flowmetry in evaluation of hydrocephalus in pediatric patients. The Egyptian Journal of Hospital Medicine, 68(2), 1291-1296.
34. Lakhera, D., Azad, R. K., Azad, S., Singh, R., & Sharma, R. (2020). Magnetic Resonance Imaging Cerebrospinal Fluid Hydrodynamics in Patients with Meningitis. Journal of Clinical Imaging Science, 10.
35. Öztürk, M., Sığırcı, A., & Ünlü, S. (2016). Evaluation of aqueductal cerebrospinal fluid flow dynamics with phase-contrast cine magnetic resonance imaging in normal pediatric cases. Clinical imaging, 40(6), 1286-1290.
36. Youssef, A., Magdy, A. M., & Abdul-Rahman, A. A. A. (2021). The role of MRI-CSF flowmetry in the diagnosis of idiopathic normal pressure hydrocephalus. Fayoum University Medical Journal, 8(1), 19-30.
37. Abdalla, R. N., & Zghair, M. A. G. Research Articles The role of magnetic resonance imaging cerebrospinal fluid flowmetry in differentiation between normal flow hydrocephalus and involutional brain atrophy.
38. Ringstad, G. (2018). Imaging cerebrospinal fluid dynamics in idiopathic normal pressure hydrocephalus.
39. El Falaky, O. M., Metwally, L. I., & Abdelalim, A. M. (2012). Diagnostic Value of MRI CSF Flowmetry for the Diagnosis of Normal Pressure Hydrocephalus. Egyptian Journal of Neurology, Psychiatry & Neurosurgery, 49(3).
40. MEDICA, E. M. (2017). Quantitative analysis of cerebrospinal fluid dynamics at phase contrast cine-MRI: predictivity of neurosurgical" Shunt" responsiveness in patients with idiopathic normal pressure hydrocephalus. Journal of neurosurgical sciences.
41. Metafratzi, Z., Argyropoulou, M. I., Mokou-Kanta, C., Konitsiotis, S., Zikou, A., & Efremidis, S. C. (2004). Spontaneous intracranial hypotension: morphological findings and CSF flow dynamics studied by MRI. European radiology, 14(6), 1013-1016.
42. Yamada, S., Ishikawa, M., Ito, H., Yamamoto, K., Yamaguchi, M., Oshima, M., & Nozaki, K. (2020). Cerebrospinal fluid dynamics in idiopathic normal pressure hydrocephalus on four-dimensional flow imaging. European radiology, 30(8), 4454-4465.
43. Bradley, W. G. (2015). CSF flow in the brain in the context of normal pressure hydrocephalus. American Journal of Neuroradiology, 36(5), 831-838.