ORIGINAL ARTICLE

Good Correlation between CT-Measured Z-Evans' Index and CT Volumetric of Ventricular System in Patients with iNPH Treated by Cerebrospinal Fluid Shunting

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Background: Patients with idiopathic normal pressure hydrocephalus (iNPH) demonstrated an increase in the volume of lateral ventricles oriented along the Z-axial axis, as opposed to the X-axial axis.

Objective: To determine which computed tomography (CT)-measured X-Evans' index and Z-Evans' index, exhibit a stronger correlation with CT-derived ventricular volume both before and after shunting procedures. Additionally, a comparative examination between those with iNPH characterized by disproportionate enlargement of subarachnoid space hydrocephalus (DESH) and those without DESH features.

Materials and Methods: The present study enrolled forty-three iNPH patients who underwent shunting between April 2013 and April 2016. The initial screening involved a thorough review of pre-shunting CT images, leading to the categorization of patients into two distinct groups, those with DESH and without DESH features.

Results: Both the X-Evans' index and Z-Evans' index exhibited a noteworthy correlation with ventricular volume, substantiated by correlation coefficients (r) of 0.777 ($p<0.001$) and 0.876 ($p<0.001$), respectively. Notably, the correlation between the change in CT ventricular volume and the change in Z-Evans' index was more conspicuous in the overall patient cohort ($r=0.730$, $p<0.001$) than X-Evans' index change ($r=0.599$, $p<0.001$). This tendency was particularly discernible within the DESH group, where the correlation with Z-Evans' index ($r=0.826$, $p<0.001$).

Conclusion: The Z-Evans' index emerged as a more effective representation of ventricular volume compared to the X-Evans' index in the entirety of the iNPH patient cohort. In contrast, during the subsequent CT follow-up, the change in X-Evans' index exhibited superior efficacy in capturing the corresponding alterations in ventricular volume.

Keywords: CT brain; iNPH; Evans' index; CT volumetric; DESH

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The prevalence of idiopathic normal pressure hydrocephalus (iNPH) among individuals aged 65 years and older ranges from 0.3% to 3%, with a notable uptrend attributed to advancements in diagnostic tools and heightened educational levels in the population[1-3]. iNPH is characterized by symptoms including dementia, gait disturbance, and urinary incontinence. Diagnostic tools such as computed tomography (CT) and/or magnetic resonance imaging (MRI) scans are instrumental in identifying non-obstructive hydrocephalus, whether it presents with or without disproportionately enlarged subarachnoid space hydrocephalus (DESH) features. These features encompass ventriculomegaly, a dilated Sylvian fissure, and high convexity tightness. Maintaining lumbar cerebrospinal fluid (CSF) pressure within the normal range, below 20 cmH2O, is imperative. The established treatment for iNPH involves a CSF shunting operation, incorporating ventriculoperitoneal and lumboperitoneal shunts. Remarkably, a meta-analysis reports that approximately 59% of iNPH patients exhibit significant clinical improvement in symptoms post-shunting[4].

Among individuals diagnosed with iNPH, about 30% exhibit DESH features in their imaging, while the remaining 70% do not demonstrate these characteristics[5]. This dichotomy allows for the categorization of iNPH patients into two distinct subgroups: those with DESH features and those

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without. An inquiry, drawing upon AJNR 2015 literature[6], revealed that iNPH patients responding positively to the tap test exhibited volume expansion of bilateral ventricles along the Z-axial direction, as opposed to the X-axial direction. Expansion in the X-axial direction is typically assessed through Evans' Index or X-Evans' Index, whereas expansion along the Z-axial direction, as delineated in Yamada et al.'s work[6], is denoted as Z-Evans' Index. The present study's primary aim was to discern which parameter, X-Evans' Index or Z-Evans' Index, manifested a more robust correlation with ventricular volume in both pre- and post-shunting procedures. This comparison was executed between two discernible patient cohorts, those diagnosed with iNPH featuring DESH features and those without.

In Thailand, CT scans emerge as the preferred modality for diagnosing and monitoring patients with ventriculomegaly, including those with iNPH. This preference is attributed to their cost-effectiveness and broader accessibility relative to MRI scans. The advent of multiple detectors computed tomography (MDCT) has facilitated the transformation of axial images into coronal and sagittal views. Additionally, post-processing techniques, notably volume measurement, are applicable to these images. Consequently, MDCT stands out as a pragmatic alternative to MRI in surgical contexts where reconstructed images and volume measurement play pivotal roles in disease evaluation. Therefore, the current study employed CT images to gauge imaging parameters of iNPH, aiming to validate the utility of CT scans in monitoring iNPH patients both before and after shunting procedures.

Materials and Methods

Patients

The present study received approval from the Siriraj Institutional Review Board Certificate of Approval (Si 249/2018). It was structured as a retrospective cohort study investigation with the objective of scrutinizing CT images acquired before and after treatment in patients with iNPH who underwent shunting procedures. The investigation focused on individuals treated at the Division of Neurosurgery, Department of Surgery, Faculty of Medicine, Siriraj Hospital, during the period spanning between April 2013 and April 2016.

Inclusion criteria

Patients who underwent shunting procedures for hydrocephalus at the Division of Neurosurgery, Department of Surgery, Faculty of Medicine, Siriraj Hospital between April 2013 and April 2016.

Patients diagnosed with iNPH, criteria for definite iNPH were the patients whose symptoms improved after CSF shunt surgery.

Patients with both pre-shunting CT images and at least one post-shunting CT image.

Table 1. Demographic data of cohort patients with DESH and non-DESH conditions

	Male (patients)	Female (patients)	Mean age (years)	Total (patients)
Sex	28	15	78.9	43
DESH	14	5		19
Non-DESH	14	10		24

DESH=disproportionately enlarged subarachnoid space hydrocephalus

Exclusion criteria

Patients who experienced complications during the follow-up period, such as intracranial or extracranial hemorrhage, brain abscess, or death.

Patients who had other intracranial diseases during the follow-up period, such as stroke, brain tumor, or brain metastasis.

Patients with incomplete CT images.

Demographic data, encompassing gender and age, were meticulously collected, and are presented in Table 1. Pre-shunting CT images underwent thorough review, and patients were systematically categorized into two groups, DESH and non-DESH, based on the criteria outlined in the SINPHONI trial[7]. These criteria delineated DESH features as encompassing tight high-convexity and medial subarachnoid spaces, enlarged Sylvian fissures, and ventriculomegaly.

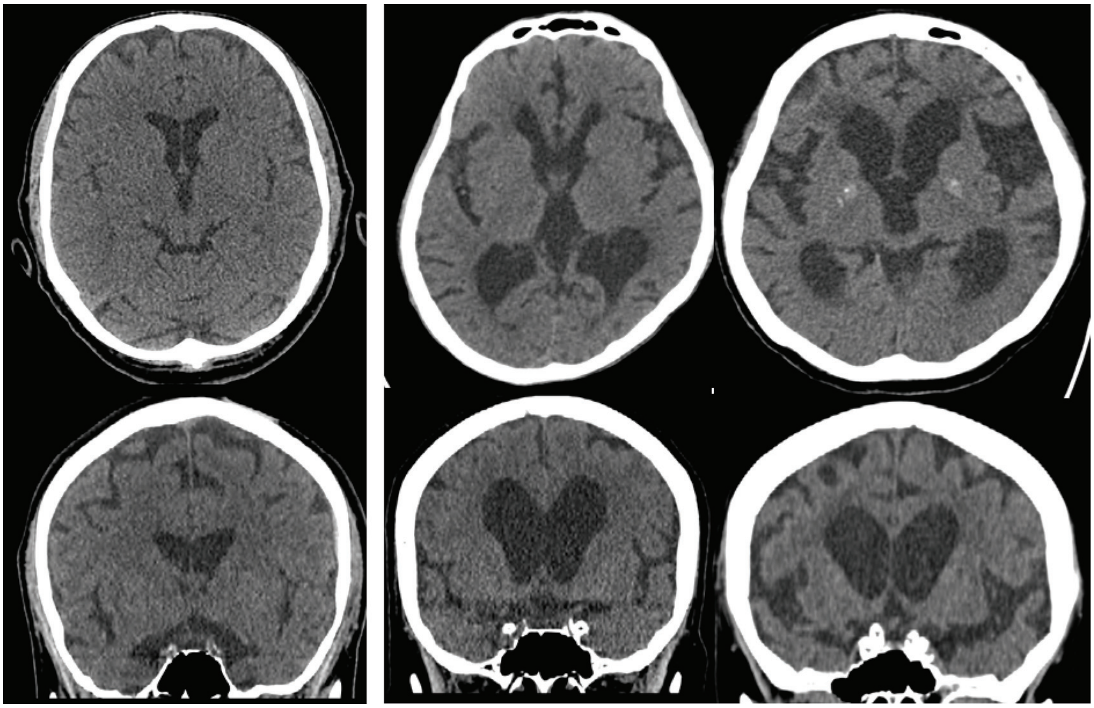
Imaging analysis

CT images, acquired with a slice thickness of 1.25 or 1.5 mm, underwent comprehensive evaluation by an experienced neuroradiologist. The standard CT plane was meticulously aligned with the orbitomeatal line. DESH features were identified utilizing the criteria from the SINPHONI trial, encompassing tight high-convexity and medial subarachnoid spaces, enlarged Sylvian fissures, and ventriculomegaly. The complete fulfillment of all three criteria was deemed indicative of positive DESH features, while their absence was unequivocally classified as negative[7].

1) Ventriculomegaly: X-Evans' index greater than 0.30.

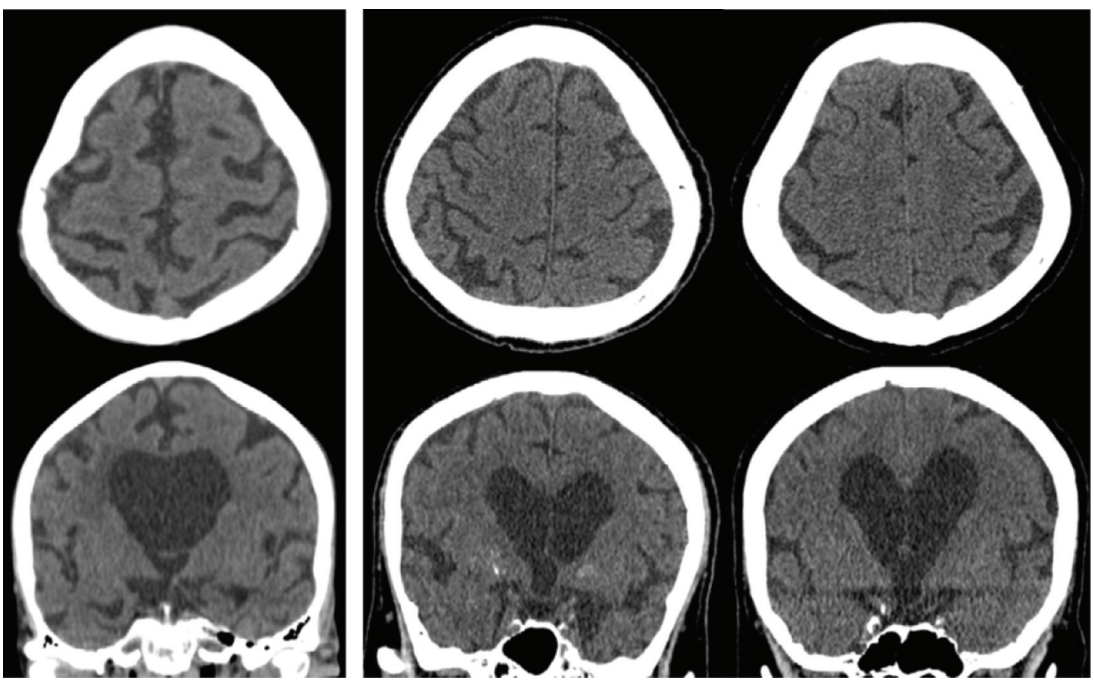
2) Sylvian fissure dilation: Assessed using visual rating scales[8] (Figure 1).

3) High-convexity tightness: Visual rating



Normal Mild Moderate

Figure 1. Present sylvian fissure dilation: assessed using visual rating scales.



Normal Mild Moderate

Figure 2. Present high-convexity tightness: visual rating scales.

scales[8] (Figure 2).

The X-Evans' index[6] represents the ratio between the maximal width of the frontal horns and the maximal width of the inner table of the cranium

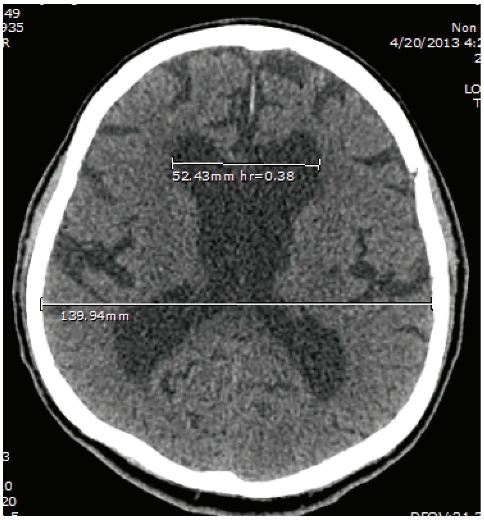


Figure 3. Present X-Evans' index, dividing the maximal width of the frontal horns by the maximal width of the inner table of the cranium at the level of the frontal horns on axial CT slice of the brain, 0.38.

at the level of the frontal horns on an axial CT slice of the brain, utilizing the orbitomeatal line as a reference (Figure 3).

The Z-Evans' index[6] is defined as the ratio between the maximal vertical length of the frontal horn of the lateral ventricle, as depicted in a coronal image showing the foramen of Monro and the maximal intracranial vertical length from the posterior clinoid to the inner table of the vertex, as measured using a mid-sagittal image (Figure 4).

The callosal angle is determined as the angle formed between the left and right corpus callosum, utilizing a coronal image at the posterior commissure (Figure 5).

Ventricular volume was quantified by manually delineating the volume using the GE reconstruction program (Figure 6).

Data analysis

The collected data were subjected to analysis using the IBM SPSS Statistics, version 22.0 (IBM Corp., Armonk, NY, USA). Pearson's correlation coefficient was employed to assess the relationship between ventricular volume and other CT-measured parameters, which encompassed the X-Evans' index, Z-Evans' index, and callosal angle. The magnitude of the correlation was interpreted according to the 'Rule of Thumb for Interpreting the Size of a Correlation Coefficient'[9], and the statistical significance of the correlation was evaluated at the 0.01 and 0.05 significance levels (Table 2).

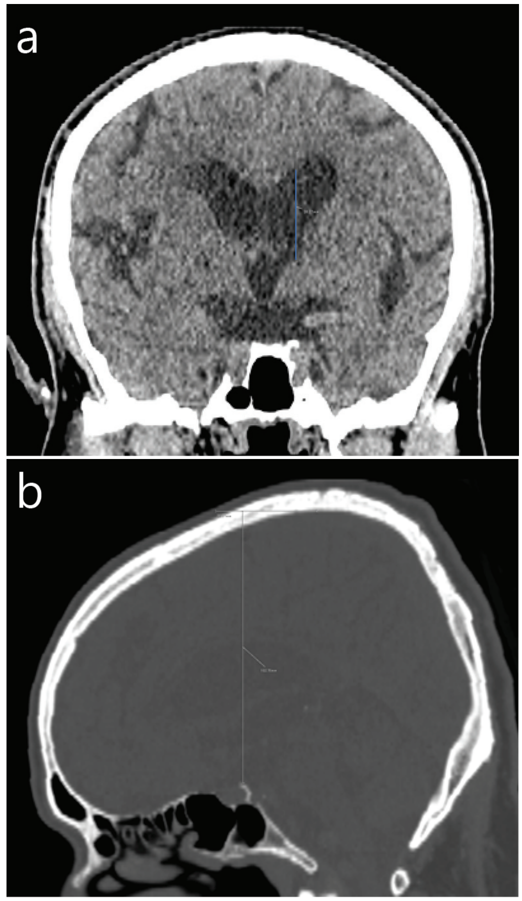


Figure 4. Z-Evans index measurement. By using coronal image that visible of foramen of Monro the maximal vertical length of the frontal horn of lateral ventricle, 38.27 mm (a) and using midsagittal image, maximal intracranial vertical length from posterior clinoid to inner table of the vertex, 102.75 mm (b), Z-Evans' index = 38.27/102.75 = 0.37.

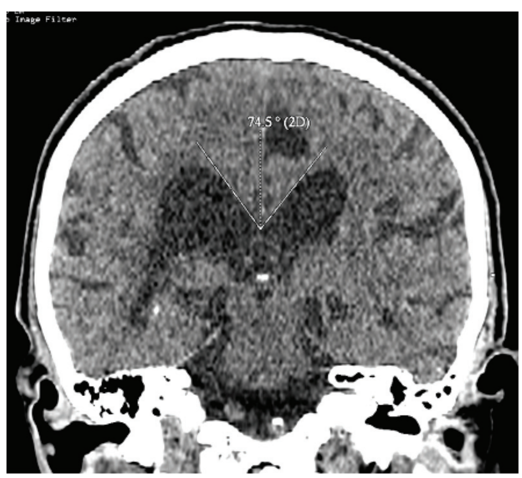


Figure 5. Present callosal angle. The angle between the left and right corpus callosum using coronal image at the posterior commissure, 74.5 degree.

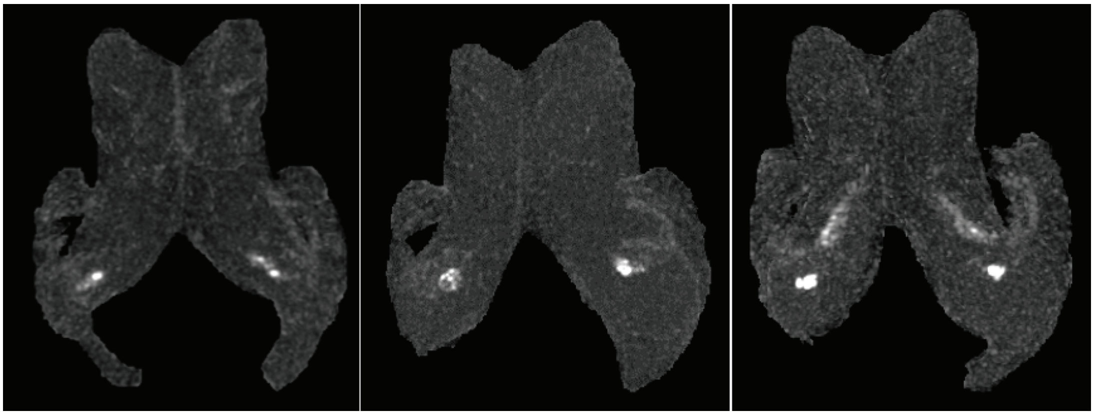


Figure 6. Ventricular volume was quantified by manually delineating the volume using the GE reconstruction program.

Table 2. present statistical significance of the correlation was evaluated at the 0.01 and 0.05 significant level

Size of correlation	Interpretation
0.90 to 1.00 (–0.90 to –1.00)	Very high positive (negative) correlation
0.70 to 0.90 (–0.70 to –0.90)	High positive (negative) correlation
0.50 to 0.70 (–0.50 to –0.70)	Moderate positive (negative) correlation
0.30 to 0.50 (–0.30 to –0.50)	Low positive (negative) correlation
0.00 to 0.30 (0.00 to –0.30)	Negligible correlation

Results

Three hundred fourteen patients diagnosed with hydrocephalus underwent shunting procedures between April 2013 and April 2016. Within this cohort, 94 patients were specifically identified as having iNPH without concurrent intracranial pathologies. Upon a meticulous examination of the CT images belonging to these 94 patients, it was observed that 35 individuals lacked pre-shunting CT images, 13 patients developed intracranial hemorrhage during the follow-up period, and two patients did not possess post-shunting CT images. Consequently, these 50 patients were deemed ineligible for inclusion in the present study. Additionally, another patient with incomplete CT images was also excluded, resulting in a final sample size of 43 patients for the present investigation (Figure 7).

The patients were subsequently classified into two distinct groups based on the presence or absence of DESH features, which included ventriculomegaly, Sylvian fissure dilatation, and high convexity tightness. Out of the 43 cases, 24 (56%) were designated as iNPH without DESH features due to their failure to meet all three specified criteria. In contrast, the remaining 19 cases (44%) were characterized as iNPH with DESH features, as they satisfied all three criteria (Figure 7).

In the present cohort of 43 patients, all individuals possessed both pre-shunting CT images and initial post-shunting CT images. However, only 38 patients had available second post-shunting CT images. The median time interval between the pre-shunting CT and the first post-shunting CT was 9.49 months, with a range of 0.69 to 34.92 months, for the non-DESH group, while the DESH group exhibited a median interval of 7.39 months, with a range of 1.35 to 44.29 months. Similarly, the median time interval between the pre-shunting CT and the second post-shunting CT was determined to be 19.75 months, with a range of 3.22 to 44.98 months, for the non-DESH group and 21.06 months, with a range of 10.78 to 50.86 months, for the DESH group.

The mean ventricular volume consistently showed higher values in the DESH group compared to the non-DESH group at the pre-shunting with 121.48±30.76 versus 98.48±49.63, at the first post-shunting with 114.94±33.40 versus 95.48±52.45, and at the second post-shunting with 113.69±89.97 (Figure 8).

Pearson's correlation coefficients (r) were computed to investigate the association between ventricular volume and both X-Evans' index and Z-Evans' index across the entirety of CT series incorporated in the present study, encompassing both pre-shunting and all post-shunting CT series, for a total number of CT series of 124. The outcomes revealed a robust positive correlation between ventricular volume and X-Evans' index ($r=0.777$, $p<0.001$), as well as a high positive correlation between ventricular volume and Z-Evans' index ($r=0.876$, $p<0.001$). These correlations demonstrated consistency across various time periods such

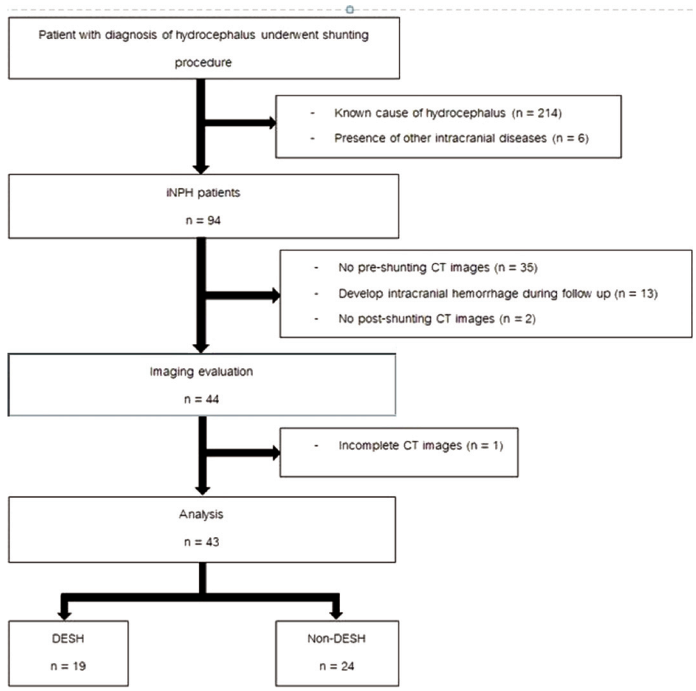


Figure 7. Diagram exclusion patient for the study.

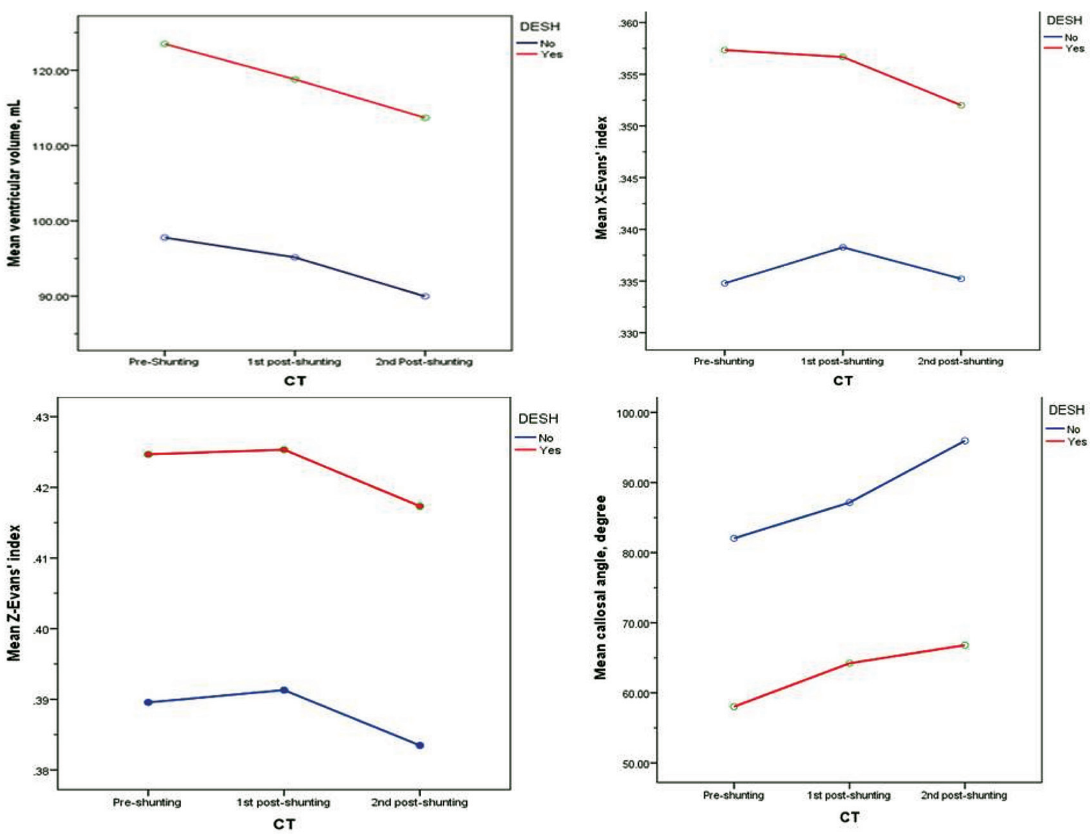


Figure 8. The mean ventricular volume, mean X-Evans' index, mean Z-Evans' index consistently demonstrated higher values in the DESH group when compared to the non-DESH group, and mean callosal angle exhibited a weak negative correlation.

Table 3. Correlation between ventricular volume and X-Evans' index, Z-Evans' index, callosal angle in patients with idiopathic normal pressure hydrocephalus, Pearson's correlation (r)

	Volume and X-Evans	Volume and Z-Evans	Volume and callosal angle
Pre-shunting (n=43)[a]	0.781 (p<0.001)	0.844 (p<0.001)	–0.509 (p<0.001)
1st post-shunting (n=43)[b]	0.761 (p<0.001)	0.877 (p<0.001)	–0.432 (p=0.004)
2nd post-shunting (n=38)[c]	0.800 (p<0.001)	0.915 (p<0.001)	–0.409 (p=0.011)
Non-DESH group (n=71)[d]	0.792 (p<0.001)	0.886 (p<0.001)	–0.325 (p=0.006)
DESH group (n=53)[e]	0.748 (p<0.001)	0.833 (p<0.001)	–0.573 (p<0.001)
All (n=124)[f]	0.777 (p<0.001)	0.876 (p<0.001)	–0.454 (p<0.001)

DESH=disproportionately enlarged subarachnoid space hydrocephalus

(a,b) All 43 patients had pre-shunting and 1st post-shunting CT scans, (c) Only 38 patients had 2nd post-shunting CT scans, (d) Number of CT scans in non-DESH group including pre-shunting, 1st and 2nd post-shunting was 71, (e) Number of CT scans in DESH group including pre-shunting, 1st and 2nd post-shunting was 53, (f) Overall number of All CT scans in this study was 124

as pre-shunting, first post-shunting, and second post-shunting, and patient groups for DESH and non-DESH groups, with no significant deviations in correlation coefficients. In contrast, the overall correlation between ventricular volume and callosal angle in all CT series exhibited a weak negative correlation (r= –0.454, p<0.001) (Table 3).

Upon scrutinizing modifications in ventricular volume, X-Evans' index, Z-Evans' index, and callosal angle, subtle changes were apparent from pre-shunting to the first post-shunting images, while more pronounced alterations occurred from pre-shunting to the second post-shunting images (refer to Table 5). The correlation between changes in ventricular volume and changes in Z-Evans' index across all patients exhibited a robust positive correlation (r=0.730, p<0.001), surpassing the correlation between changes in ventricular volume and changes in X-Evans' index, which showed a moderate correlation (r=0.599, p<0.001). Except for the correlation between changes in ventricular volume and changes in Z-Evans' index in the DESH group, manifesting a high positive correlation (r=0.826, p<0.001), the correlations between changes in ventricular volume and other parameter changes from pre-shunting to the first post-shunting images were largely deemed negligible to moderate (Table 4, Figure 9).

Concerning the correlation between alterations in ventricular volume and other parameter changes from pre-shunting to the second post-shunting images, both the non-DESH and DESH groups demonstrated a robust positive correlation between changes in ventricular volume and changes in X-Evans' index, with correlation coefficients of r=0.826 (p<0.001) and 0.829 (p<0.001), respectively. The correlation between changes in ventricular volume and changes in Z-Evans' index in the DESH group displayed an almost exceedingly high positive correlation (r=0.894, p<0.001), while in the non-DESH group, the correlation indicated a moderate positive correlation (r=0.613, p=0.002). Concerning changes in ventricular volume and changes in callosal angle, the non-DESH group exhibited a weak negative correlation (r= –0.389, p=0.066), whereas the DESH group demonstrated a moderate negative correlation (r= –0.704, p=0.003) (Table 5, Figure 10).

Discussion

iNPH represents a treatable condition, with a substantial majority, over 80% of patients, deriving benefits from CSF shunting procedures, markedly ameliorating symptoms, including cognitive impairment[10]. Timely diagnosis and intervention significantly augment the likelihood of a favorable prognosis[11]. However, lumbar drainage for iNPH diagnosis is not devoid of risks, evidenced by an 8.2% overall complication rate, encompassing serious complications such as subdural hemorrhage, infections, and retained catheters[12]. False results may arise due to severe spinal canal stenosis[13]. The quest for an ideal prognostic test has driven the exploration of noninvasive markers; however, widely used tools like the Evans' index exhibit potential reliability concerns[14].

The clinical preference for the Evans' index stems from its simplicity, speed, and independence from specialized software or anatomical expertise. However, it is crucial to note its limitations. Both X-Evans' index and Z-Evans' index, despite their utility, exhibit robust correlations with ventricular volume, irrespective of patient categorization into DESH or non-DESH groups. Intriguingly, the correlation between ventricular volume and Z-Evans' index consistently surpasses that with X-Evans' index for all patients.

Table 4. Correlation between ventricular volume change and ventricular indices including Evans' index (X axis and Z axis) and callosal angle changes from pre-shunting to first post-shunting CT images in iNPH patients with/without DESH features

Volume difference 1	Pearson's correlation (r)		
	Non-DESH (n=24)	DESH (n=19)	All (n=43)
X-Evans difference 1	0.567 (p=0.004)	0.642 (p=0.003)	0.599 (p<0.001)
Z-Evans difference 1	0.678 (p<0.001)	0.826 (p<0.001)	0.730 (p<0.001)
Callosal angle difference 1	0.036 (p=0.866)	−0.535 (p=0.018)	−0.201 (p=0.196)

DESH=disproportionately enlarged subarachnoid space hydrocephalus
Volume difference 1: Ventricular volume difference between pre-shunting and first post-shunting
X-Evans difference 1: X-Evans' index difference between pre-shunting and first post-shunting
Z-Evans difference 1: Z-Evans' index difference between pre-shunting and first post-shunting
Callosal angle difference 1: Callosal angle difference between pre-shunting and first post-shunting

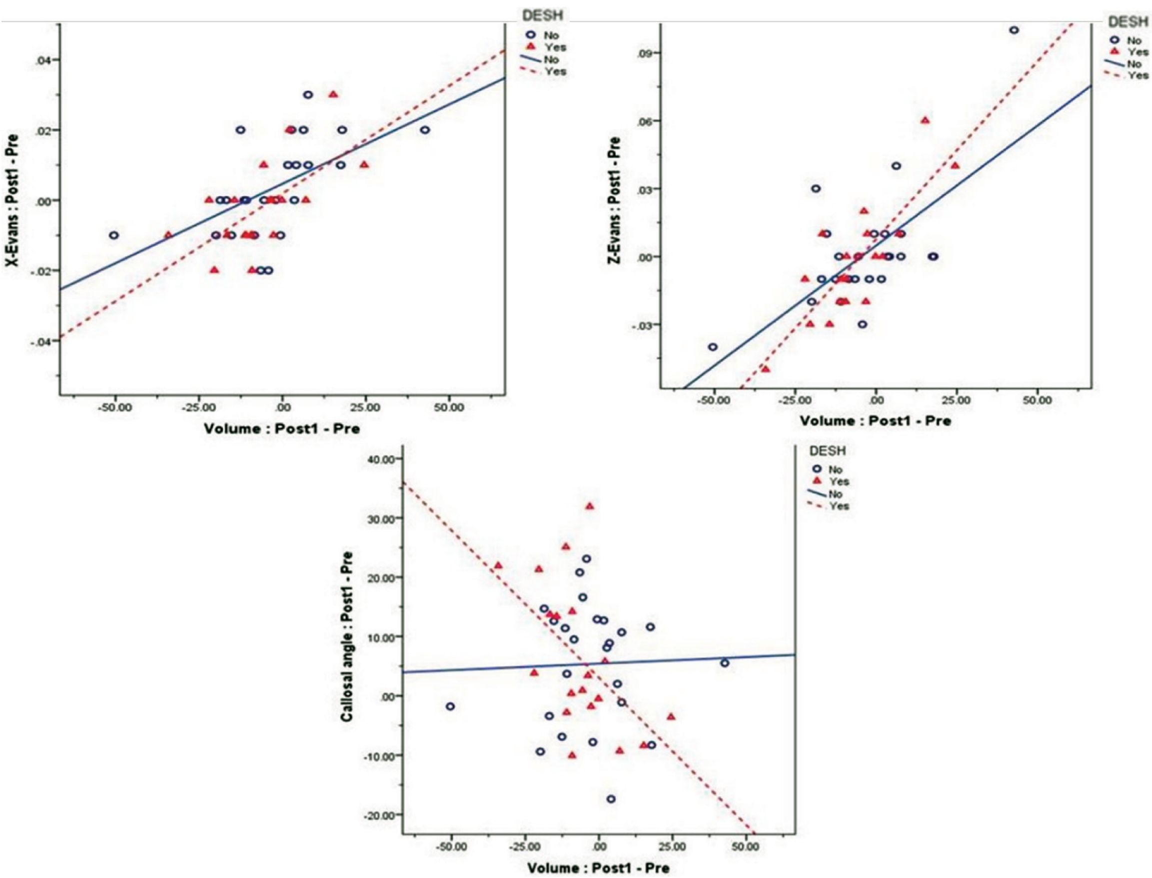


Figure 9. Correlation between ventricular volume change and ventricular indices including Evans' index (X axis and Z axis) and callosal angle changes from pre-shunting to first post-shunting CT images in iNPH patients with/without DESH features.

Examining changes in ventricular volume from pre-shunting to the second post-shunting images reveals a strong positive correlation between changes in ventricular volume and changes in X-Evans' index in both the DESH and non-DESH groups. Notably, the correlation between changes in ventricular volume and changes in Z-Evans' index, particularly in the DESH group, is notably higher, almost reaching a very high correlation. Conversely, the correlation between ventricular volume and callosal angle, and their respective changes, is weak, except for changes from pre-shunting to the second post-shunting CT.

The primary aim of the present study was to determine which axis of Evans' index exhibits a stronger association with ventricular volume. Confirming findings from Yamada et al.'s research

Table 5. Correlation between ventricular volume change and ventricular indices including Evans' index (X axis and Z axis) and callosal angle changes from pre-shunting and second post-shunting CT images in iNPH patients with/without DESH features

Volume difference 2	Pearson's correlation (r)		
	Non-DESH (n=23)	DESH (n=15)	All (n=38)
X-Evans difference 2	0.826 (p<0.001)	0.829 (p<0.001)	0.825 (p<0.001)
Z-Evans difference 2	0.613 (p=0.002)	0.894 (p<0.001)	0.762 (p<0.001)
Callosal angle difference 2	−0.389 (p=0.066)	−0.704 (p=0.003)	−0.504 (p=0.001)

DESH=disproportionately enlarged subarachnoid space hydrocephalus
Volume difference 2: Ventricular volume difference between pre-shunting and second post-shunting
X-Evans difference 2: X-Evans' index difference between pre-shunting and second post-shunting
Z-Evans difference 2: Z-Evans' index difference between pre-shunting and second post-shunting
Callosal angle difference 2: Callosal angle difference between pre-shunting and second post-shunting

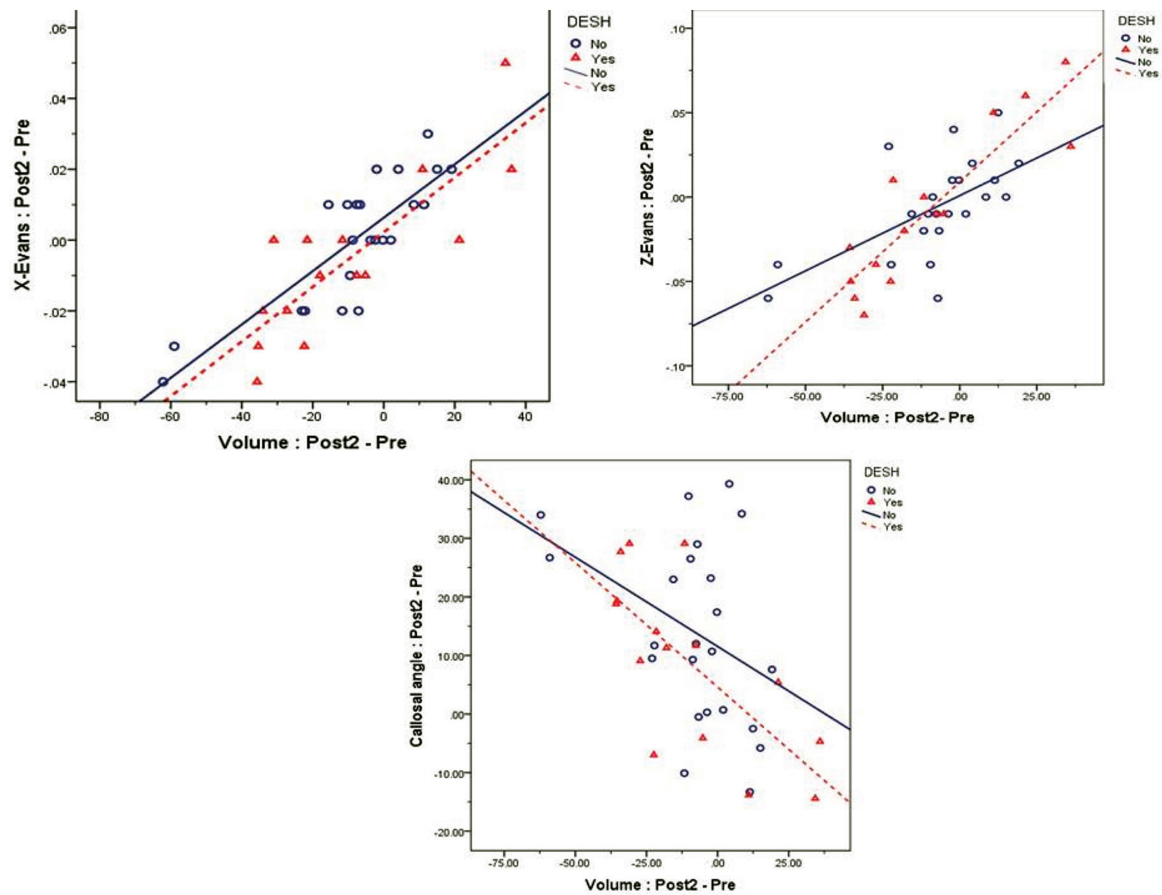


Figure 10. Correlation between ventricular volume change and ventricular indices including Evans' index (X axis and Z axis) and callosal angle changes from pre-shunting and second post-shunting CT images in iNPH patients with/without DESH feature.

in AJNR 2015(6), the Z-Evans' index emerges as a reliable indicator for predicting the response to the CSF tap test, showing high specificity (72% to 100%) in diagnosing shunt-responsive iNPH. The Z-Evans' index, therefore, stands out as a valuable tool for assessing shunt responsiveness in iNPH patients.

The present study results align with Yamada et al.'s findings, underscoring that the Z-Evans' index provides a more accurate representation of ventricular volume in iNPH patients, regardless of DESH features. The mechanism behind this could be the superoposterior displacement of the brain due to abnormal CSF distribution, leading to lateral ventricular stretching. Notably, Bao et al. reported moderate relationships between ventricular volume and Evans' index[15], while O'Hayon et al. found the frontal + occipital h-orn ratio to be more accurate than Evans' index in correlating with ventricular size[16].

Analyzing changes in ventricular volume, the change in Z-Evans' index notably precedes the change in X-Evans' index in the first post-shunting CT, particularly in iNPH patients with DESH features. In the second follow-up CT, the change in X-Evans' index effectively represents the change in ventricular volume for both DESH and non-DESH cases. However, the change in Z-Evans' index remains a viable option for assessing ventricular volume changes in iNPH cases with DESH features. This dynamic pattern can be attributed to the resolution of CSF over-accumulation following shunt placement, allowing the brain to return to its normal position.

In conclusion, the present study underscores the importance of nuanced considerations when employing Evans' index and its axes in evaluating ventricular volume and changes in iNPH patients post-shunting. The choice between X-Evans' and Z-Evans' index depends on the specific diagnostic or post-treatment context, with Z-Evans' index showing particular promise in predicting shunt responsiveness in iNPH patients.

Limitation

This retrospective cohort study is not without its specific constraints. Firstly, the non-uniform time intervals between follow-up CT scans in each patient have the potential to influence the observed changes in ventricular volume and other parameters. Secondly, the mean change in ventricular volume was small, introducing potential limitations in the statistical analysis. Addressing these limitations could involve augmenting the sample size and extending the duration of the follow-up period. This research involves analyzing only imaging parameters, specifically focusing on the relationship between Evans and Volume, without considering other patient-related factors.

Conclusion

Z-Evans' index had demonstrated a superior representation of ventricular volume compared to X-Evans' index in overall iNPH patients. In the first follow-up CT, the change in Z-Evans' index proved more suitable for accurately assessing the change in ventricular volume, particularly in iNPH cases with DESH features. Conversely, in the second follow-up CT, the change in X-Evans' index performed better in capturing the volume changes.

What is already known on this topic?

CT scan is popular imaging investigation and X-Evans' index is routinely used modality in diagnosis and follow up treatment of NPH.

What does this study add?

MDCT capabilities in reconstruction in coronal and sagittal planes give ability in measurement y- Evans' index and z- Evans' index as well as volumetric measurement are also available. The parameters are crucial factors impacting adjustment for NPH treatment.

Conflicts of interest

The authors declare no conflicts of interest.

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