Optimal Diagnostic Indices for Idiopathic Normal Pressure Hydrocephalus Based on the 3D Quantitative Volumetric Analysis for the Cerebral Ventricle and Subarachnoid Space

S. Yamada, M. Ishikawa, and K. Yamamoto

ABSTRACT

BACKGROUND AND PURPOSE: Despite the remarkable progress of 3D graphics technology, the Evans index has been the most popular index for ventricular enlargement. We investigated a novel reliable index for the MR imaging features specified in idiopathic normal pressure hydrocephalus, rather than the Evans index.

MATERIALS AND METHODS: The patients with suspected idiopathic normal pressure hydrocephalus on the basis of the ventriculomegaly and a triad of symptoms underwent the CSF tap test. CSF volumes were extracted from a T2-weighted 3D spin-echo sequence named “sampling perfection with application-optimized contrasts by using different flip angle evolutions (SPACE)” on 3T MR imaging and were quantified semiautomatically. Subarachnoid spaces were divided as follows: upper and lower parts and 4 compartments of frontal convexity, parietal convexity, Sylvian fissure, and basal cistern, and posterior fossa. The maximum length of 3 axial directions in the bilateral ventricles and their frontal horns was measured. The “z-Evans Index” was defined as the maximum z-axial length of the frontal horns to the maximum cranial z-axial length. These parameters were evaluated for the predictive accuracy for the tap-positive groups compared with the tap-negative groups and age-adjusted odds ratios at the optimal thresholds.

RESULTS: In this study, 24 patients with tap-positive idiopathic normal pressure hydrocephalus, 25 patients without response to the tap test, and 23 age-matched controls were included. The frontal horns of the bilateral ventricles were expanded, with the most excessive expansion being toward the z-direction. The CSF volume of the parietal convexity had the highest area under the receiver operating characteristic curve (0.768), the z-Evans Index was the second (0.758), and the upper-to-lower subarachnoid space ratio index was the third (0.723), to discriminate the tap-test response.

CONCLUSIONS: The CSF volume of the parietal convexity of <38 mL, upper-to-lower subarachnoid space ratio of <0.33, and the z-Evans Index of >=0.42 were newly proposed useful indices for the idiopathic normal pressure hydrocephalus diagnosis, an alternative to the Evans Index.

ABBREVIATIONS: AUC = area under the receiver operating characteristic curve; DESH = disproportionately enlarged subarachnoid space; iNPH = idiopathic normal pressure hydrocephalus; SPACE = sampling perfection with application-optimized contrasts by using different flip angle evolutions.
sequence with sampling perfection with application-optimized contrasts by using different flip angle evolutions (SPACE sequence; Siemens, Erlangen, Germany) has been developed.\textsuperscript{11-14} This volumetric sequence enables the decrease of specific absorption rate limits and a scan of the whole brain in a single slab and a true isotropic 3D data record with high resolution (voxel size $\leq 1$ mm$^3$ without interpolation). Taking advantage of the high sensitivity to detect CSF on the T2-weighted 3D-SPACE sequence, a new automated segmentation technique by using a simple threshold algorithm has been developed.\textsuperscript{15} The aim of the present study was to investigate the association between several 1D and 3D parameters of the ventricles and subarachnoid space and the response to the CSF tap test in patients with suspected iNPH in a systematic manner.

**MATERIALS AND METHODS**

**Study Population**

The study design and protocol were approved by the ethics committee for human research at our hospital. We prospectively collected the patients for 3T MR imaging beginning in November 2013, when the best protocols of imaging acquisition and extraction of ventricular and subarachnoid CSF were determined. Patients 60 years of age or older who had ventriculomegaly and symptoms of short-stepped gait and/or cognitive impairment were referred to our iNPH center as having suspected iNPH by neurologists and neurosurgeons around Kyoto. The comorbidities, including Alzheimer disease and cerebrovascular diseases, were diagnosed by the neurologists before referral to our iNPH center and were confirmed on MR imaging and $^{123}$I-N-isopropyl-p-iodoamphetamine-SPECT in our center. Forty-nine consecutive patients with suspected iNPH underwent CSF removal of 30 mL via a lumbar tap (CSF tap test) concurrently with a T2-weighted 3D-SPACE sequence on 3T MR imaging and $^{123}$I-N-isopropyl-p-iodoamphetamine-SPECT. According to the Japanese iNPH guidelines,\textsuperscript{4} improvements of symptoms were assessed by the neurologists before referral to our iNPH center and were confirmed on MR imaging and $^{123}$I-N-isopropyl-p-iodoamphetamine-SPECT in our center. The labeling of the segmented volumes was measured by counting the number of voxels automatically. The volume ratios of the ventricles and subarachnoid spaces (%) were calculated as ratios of the ventricle volumes to the intracranial volume. To evaluate the validity of the measured volumes, we segmented and measured the ventricles and subarachnoid spaces in the first 11 consecutive patients by using the SYNAPSE 3D workstation and the open-source 3D Slicer software package (www.slicer.org).\textsuperscript{18} The Pearson correlation coefficients among the 2 software packages were 0.838 for a total intracranial CSF space and 0.989 for the total ventricular volumes.

**Image Acquisition**

All MR imaging examinations were performed with a 64-channel 3T MR imaging system (Magneton Skyra; Siemens). We preliminarily examined the most adequate TR and TE of the T2-weighted 3D-SPACE sequence for CSF discrimination. The parameters of the T2-weighted 3D-SPACE sequence were set at TR, 2800 ms; TE, 286 ms; section thickness, 0.9 mm with 192 sections in a single slab; FOV, 230 mm; bandwidth, 789 Hz/Px; matrix (pixel size), $192 \times 192$; voxel size, $0.6 \times 0.6 \times 0.9$ mm. Image acquisition time was 4 minutes 16 seconds.

**Segmentation and Quantification of the Ventricular and Subarachnoid Space**

The sagittal source images of T2-weighted 3D-SPACE were automatically processed to create 3D volume-rendering reconstruction and MPR images by using an independent 3D volume-analyzer workstation (SYNAPSE 3D; Japanese local name, SYNAPSE VINCENT; Fujifilm Medical Systems, Tokyo, Japan). The intracranial volume was segmented by the use of the combined techniques of the edge-guided nonlinear interpolation and user-steered live-wire segmentation.\textsuperscript{16,17} After that, the CSF spaces were automatically segmented from brain parenchyma by using a simple threshold algorithm (Fig 1).\textsuperscript{15} The threshold range for the signal intensity of CSF on the T2-weighted 3D-SPACE sequence of 3T MR imaging was extremely stable at 650–700 of the lower limit threshold and no upper limit threshold. The bilateral, third, and fourth ventricles were manually segmented, respectively, and they were subsequently combined as a total ventricle.

Subarachnoid spaces were automatically segmented as the total intracranial CSF space minus a total ventricle. Furthermore, subarachnoid spaces were divided into the upper and lower parts in a horizontal section on the anterior/posterior commissure plane at the level of the junction point of the vein of Galen and the straight sinus. The upper-to-lower subarachnoid space ratio was defined as the upper part to the lower part of the subarachnoid spaces (Fig 2). In addition, the subarachnoid space was divided into 4 parts, frontal convexity, parietal convexity, Sylvian fissure and basal cistern, and posterior fossa, by using the manual segmentation technique, as shown in Fig 3. The parietal convexity was defined as the posterior part from the central sulcus.

The labeling of the segmented volumes was measured by counting the number of voxels automatically. The volume ratios of the ventricles and subarachnoid spaces (%) were calculated as ratios of the ventricle volumes to the intracranial volume. To evaluate the validity of the measured volumes, we segmented and measured the ventricles and subarachnoid spaces in the first 11 consecutive patients by using the SYNAPSE 3D workstation and the open-source 3D Slicer software package (www.slicer.org).\textsuperscript{18} The Pearson correlation coefficients among the 2 software packages were 0.838 for a total intracranial CSF space and 0.989 for the total ventricular volumes.

**3D Coordinates of the Bilateral Ventricle**

Three axes for the spatial coordinates of the head position were used as follows: $x$ is the left/right dimension, $y$ is the posterior/anterior dimension, and $z$ is the ventral/dorsal or inferior/superior dimension. The $x$ and $z$ dimensions were perpendicular, and...
FIG 1. Automatic extraction of CSF space. The figures in the top row show the MIP images on the T2-weighted 3D-SPACE sequence in the representative iNPH case. Light green indicates the subarachnoid space segmented automatically at a threshold intensity of >700 on the SYNAPSE 3D workstation. The other figures show the 3D volume-rendering reconstruction images of the subarachnoid space on the second line, total CSF on the third line, and ventricles on the last line. The left, middle, and right column figures show axial, coronal, and sagittal dimensional views, respectively.
the y dimension was parallel to the anterior/posterior commissure line. The Evans Index was measured as the maximal width of the frontal horns of the bilateral ventricles to the maximal width of the internal diameter of the cranium on the basis of the x dimension. The z-Evans Index was defined as the maximum z-axial length of the frontal horn, which was between the roof and bottom of the larger lateral ventricle to the maximum cranial z-axial length at the base of the posterior end of the foramen of Monro (Fig 4). In the same procedure, the y-Evans Index was defined as the maximum y-axial length between the posterior end of the foramen of Monro and the anterior end of the frontal horns to the maximum cranial y-axial length. Additionally, x-, y-, and z-Maximum Indices were measured as the maximum width of the bilateral ventricles to the maximum internal cranium width on each of 3 dimensions, as shown in Fig 4.

**Statistical Analysis**

The prevalence ratios of high-convexity tightness, enlarged Sylvian fissure, and comorbidities such as Alzheimer disease or dementia with Lewy bodies, Parkinsonism, cerebrovascular diseases, narrow spinal canal, and disuse muscle atrophy were compared among the 3 groups by the $\chi^2$ test. Mean values and SDs for age and 3D and 1D indices among the tap-positive, tap-negative,
and control groups were calculated and compared in each group by the Mann-Whitney-Wilcoxon test. The volumes and volume ratios of the total ventricles, bilateral ventricles and total subarachnoid space, the 4 segmented parts of the subarachnoid spaces, upper-to-lower subarachnoid space ratio, 3-directional linear 1D indices of the bilateral ventricles, and the callosal angle were calculated as the area under the receiver operating characteristic curves (AUC) to evaluate the optimal thresholds to maximize the sum of sensitivities and specificities for differentiation between the tap-positive and the tap-negative groups. Using the optimal thresholds from AUC analyses, we calculated age-adjusted ORs and 95% CIs for comparing the tap-positive group with the tap-negative group in a multivariate logistic regression model. Additionally, 14 patients with shunt-effective iNPH were evaluated, and their 3D and 1D indices were compared to 25 patients without response to the tap test. The relationships between the 2 indices were compared by using the Pearson correlation coefficient ($r$). Age was treated as a continuous variable for all statistical analyses. All missing data were treated as deficit data that did not affect other variables. Statistical significance was assumed at $P < .05$. Statistical analysis was performed by using R software (Version 3.0.1; http://www.R-project.org).

RESULTS

Clinical Characteristics

An Evans Index of $>0.3$, callosal angle of $<90^\circ$, narrow sulci at the high convexity, and an enlarged Sylvian fissure, which were conventional morphologic indices for iNPH diagnosis, were significantly different between the tap-positive group and the controls, but there was not any statistical significance between the tap-positive and tap-negative groups (Table 1). The tap-negative group had a higher frequency of Alzheimer disease (48%) and cerebrovascular diseases (26%) compared with the tap-positive group.

Parameters Associated with CSF Tap-Test Responses

Table 2 shows the result of the mean values of the 3D and 1D indices. Among the 3D indices, volume ratios of the total ventricle or bilateral ventricles, CSF volume of the total subarachnoid space or parietal convexity, and upper-to-lower subarachnoid space ra-
CSF volume of parietal convexity was the highest index (AUC, 0.768; sensitivity, 91.7%; specificity, 52.0%), the z-Evans Index was the second (AUC, 0.758; sensitivity, 66.7%; specificity, 88.0%), and the upper-to-lower subarachnoid space ratio index was the third (AUC, 0.758; sensitivity, 66.7%; specificity, 88.0%), the z-Evans Index, z-Evans Index, and y-Maximum Index were statistically significant between the tap-positive and tap-negative groups. For discriminating the tap-test response, the CSF volume of the parietal convexity was the highest index (AUC, 0.768; sensitivity, 91.7%; specificity, 52.0%), the z-Evans Index was the second (AUC, 0.758; sensitivity, 66.7%; specificity, 88.0%), and the upper-to-lower subarachnoid space ratio index was the third (AUC, 0.758; sensitivity, 66.7%; specificity, 88.0%), as shown in Table 3 and Fig 5. These 3 indices remained statistically significant for discriminating the shunt-effective iNPH group from the tap-negative group (On-line Table). There was a statistically significant relationship between the upper-to-lower subarachnoid space ratio and CSF volume of the parietal convexity (r, 0.533 to 0.788; P < .001) or the CSF volume of the parietal convexity (r, 0.533 to 0.788; P < .001). Furthermore, the z-Evans Index was significantly associated with the upper-to-lower subarachnoid space ratio index (r, −0.527; 95% CI, −0.676 to −0.336; P < .001) or the CSF volume of the parietal convexity (r, −0.238; 95% CI, −0.445 to −0.007; P = .004). If the patients with Table 2: Parameters among the tap-positive, tap-negative, and control groups

| Parameter                                                                 | Tap-Positive | Tap-Negative | Control | P Valuea | Valueb | P Valuec |
|--------------------------------------------------------------------------|--------------|--------------|---------|----------|--------|----------|
| Total ventricle volume (mL)                                              | 123.7        | 156.7        | 226.1   | <.001d   | .060   | <.001d   |
| Total ventricle volume ratio (%)                                         | 8.1          | 10.5         | 7.2     | <.011d   | .017b  | <.011d   |
| Bilateral ventricle volume (mL)                                          | 114.2        | 147.7        | 125.9   | <.001d   | .060   | <.001d   |
| Bilateral ventricle volume ratio (%)                                     | 7.5          | 9.7          | 8.8     | <.011d   | .033b  | <.011d   |
| Total subarachnoid space volume (mL)                                     | 270.2        | 251.0        | 167.8   | <.001d   | .010d  | 294.8    |
| Total subarachnoid space volume ratio (%)                                | 18.0         | 16.8         | 19.3    | <.011d   | .001d  | 136.0    |
| CSF volume of frontal convexity (mL)                                     | 51.1         | 41.0         | 52.6    | 0.063d   | .016d  | 52.1     |
| CSF volume of parietal convexity (mL)                                    | 42.4         | 28.4         | 44.1    | <.011d   | .001d  | 42.4     |
| CSF volume of Sylvian fissure and basal cistern (mL)                     | 119.0        | 121.0        | 137.0   | <.001d   | .001d  | 119.0    |
| CSF volume of posterior fossa (mL)                                       | 57.1         | 59.1         | 58.9    | <.001d   | .026   | 57.1     |
| Upper-to-lower subarachnoid space ratio                                  | 0.55         | 0.37         | 0.49    | <.011d   | .079   |          |
| Evans Index                                                              | 0.31         | 0.34         | 0.32    | <.001d   | .29    |          |
| Y-Evans Index                                                            | 0.22         | 0.23         | 0.22    | 0.095    | 0.21   |          |
| Z-Evans Index                                                            | 0.38         | 0.43         | 0.39    | <.011d   | 0.31   |          |
| X-Max Index                                                              | 0.63         | 0.65         | 0.64    | <.011d   | 0.60   |          |
| Y-Max Index                                                              | 0.63         | 0.67         | 0.64    | <.011d   | 0.58   |          |
| Z-Max Index                                                              | 0.70         | 0.74         | 0.74    | <.011d   | 0.62   |          |
| Callosal angle (degree)                                                  | 80.9         | 66.2         | 73.4    | <.011d   | 0.104  |          |

Note: —Max indicates maximum.

aP value: probability value for the Mann-Whitney-Wilcoxon test between the tap-positive group and controls.
bP value: probability value for the Mann-Whitney-Wilcoxon test between the tap-positive and tap-negative groups.
cP value: probability value for the Mann-Whitney-Wilcoxon test between the tap-negative group and controls.
dSignificant.

Table 3: At the maximum AUC, thresholds, sensitivity, specificity, and age-adjusted OR (95% CI) for the tap-positive compared with the tap-negative group

| Parameter                                      | AUC | Optimal Threshold | Sensitivity | Specificity | OR (95% CI) | P Valuea |
|------------------------------------------------|-----|-------------------|-------------|-------------|-------------|----------|
| Total ventricle volume (mL)                    | 0.657| 155               | 58.3        | 80.0        | 1.49 (1.13–1.96) | .004    |
| Total ventricle volume ratio (%)               | 0.700| 8.6               | 79.2        | 56.0        | 1.49 (1.13–1.96) | .005    |
| Bilateral ventricle volume (mL)                | 0.657| 147               | 54.2        | 84.0        | 1.52 (1.15–2.07) | .003    |
| Bilateral ventricle volume ratio (%)           | 0.705| 7.9               | 83.3        | 56.0        | 1.40 (1.06–1.84) | .019    |
| Total subarachnoid space volume (mL)           | 0.714| 312               | 87.5        | 48.0        | 0.66 (0.49–0.89) | .006    |
| Total subarachnoid space volume ratio (%)      | 0.682| 17.9              | 75.0        | 72.0        | 0.63 (0.48–0.82) | <.001   |
| CSF volume of frontal convexity (mL)           | 0.701| 45.9              | 79.2        | 76.0        | 0.58 (0.45–0.74) | <.001   |
| CSF volume of parietal convexity (mL)          | 0.768| 37.9              | 91.7        | 52.0        | 0.60 (0.45–0.79) | <.001   |
| CSF volume of Sylvian fissure and basal cistern (mL) | 0.648| 137               | 75.0        | 56.0        | 0.71 (0.52–0.96) | .028    |
| CSF volume of posterior fossa (mL)             | 0.500| 78.7              | 16.7        | 96.0        | 1.41 (0.89–2.25) | .146    |
| Upper-to-lower subarachnoid space ratio (%)    | 0.723| 0.33              | 45.8        | 92.0        | 0.62 (0.46–0.83) | .002    |
| Evans Index                                    | 0.683| 0.33              | 58.3        | 80.0        | 1.37 (0.104–1.80) | .026    |
| Y-Evans Index                                  | 0.662| 0.24              | 41.7        | 92.0        | 1.42 (0.99–2.03) | .057    |
| Z-Evans Index                                  | 0.758| 0.42              | 66.7        | 88.0        | 1.74 (1.35–2.24) | <.001   |
| X-Max Index                                    | 0.640| 0.62              | 70.8        | 60.0        | 1.55 (1.12–2.16) | .009    |
| Y-Max Index                                    | 0.665| 0.69              | 45.8        | 92.0        | 1.69 (1.26–2.27) | <.001   |
| Z-Max Index                                    | 0.543| 0.74              | 58.3        | 60.0        | 1.13 (0.85–1.52) | .401    |
| Callosal angle (degree)                        | 0.632| 77.3              | 87.5        | 48.0        | 1.51 (1.13–2.02) | .005    |

aProbability value for the age-adjusted ORs in a logistic regression model.
bRows in which the AUC > 0.7 and P < .05 are at the optimal threshold.
suspected iNPH had any of the MR imaging findings—that is, the CSF volume of the parietal convexity of $<38$ mL, upper-to-lower subarachnoid space ratio of $<0.33$, and/or z-Evans Index of $>0.42$—they had the possibility of a 1.5-times higher effectiveness of the CSF tap test. No useful combination of parameters obviously increased the AUC compared with the single parameter.

**DISCUSSION**

Our quantitative volumetric analyses determined that volume expansion of the bilateral ventricles, especially at the frontal horns, was toward the z-axial direction, rather than the x-axial direction, in the patients with iNPH. Therefore, we newly proposed the z-Evans Index, which was a representative index for z-axial directional expansion of the frontal horns of the bilateral ventricles. We found that the z-Evans Index had the most significant relationship with the patients with iNPH responded to the tap test among the parameters of the ventricles. Because DESH or high-convexity tightness has been recognized as a highly sensitive radiologic finding for iNPH diagnosis, and/or z-Evans Index of $>0.42$—they had the possibility of a 1.5-times higher effectiveness of the CSF tap test. No useful combination of parameters obviously increased the AUC compared with the single parameter.

**CONCLUSIONS**

This study provides novel morphologic evidence that volume expansion of the bilateral ventricle is toward the z-axial direction, rather than the x-axial direction, in patients with iNPH responded to the tap test. In particular, the z-directional expansion of the frontal horn of the bilateral ventricles, named the z-Evans Index, was found to be a useful index for predicting the response to the CSF tap test. Cases of z-directional ventriculomegaly concurrent with decreased CSF volume at the parietal convexity subarachnoid space or a decreased upper-to-lower subarachnoid space ratio are thought to constitute a pivotal morphologic finding for iNPH diagnosis. These novel morphologic findings may contribute to future studies concerning the pathogenesis of iNPH underlying simultaneous enlargement of the ventricles, basal cistern, and Sylvian fissure and narrowing of the sulci at high convexity.

**ACKNOWLEDGMENTS**

We would like to thank Dr Yasutaka Fushimi, Department of Diagnostic Imaging and Nuclear Medicine, Kyoto University Graduate School of Medicine, for his advice concerning the MR imaging techniques; and also Professor Kazunari Ishii, Department of Radiology and Nuclear Medicine, Hyogo Brain and Heart Center, for the transfer of his original AVSIS 2013 software package by using the SPM8 software program. We would also like to thank the radiology staff of the Rakuwakai Otowa Hospital, par-

![FIG 5. Receiver operating characteristic curves for discriminating tap-positive from the tap-negative group. The ROC graphs show specificity on the x-axis and sensitivity on the y-axis. The left graph shows the ROC curve of the parietal convexity of the subarachnoid space, the middle one shows that of the z-Evans Index, and the right one shows that of the upper-to-lower subarachnoid space ratio. The black circle points indicate the optimal cutoff points of the maximum area under the ROC curve.](image-url)
particularly Masatoshi Katayama, Masaru Yamazaki, and Rikiya Kikumoto.

Disclosures: Masatsume Ishikawa—RELATED: Grant: Health and Labor Sciences Research Grant on Measures for Intractable Disease; studies on the epidemiology, pathophysiology, and treatment of normal pressure hydrocephalus; UNRELATED: Payment for Lectures (including service on Speakers Bureaus): lecture fees from Medtronic Japan (plus honoraria) and Codman Japan.

REFERENCES
1. Ishikawa M; Guideline Committee for Idiopathic Normal Pressure Hydrocephalus, Japanese Society of Normal Pressure Hydrocephalus. Clinical guidelines for idiopathic normal pressure hydrocephalus. Neurol Med Chir (Tokyo) 2004;44:222–23 CrossRef Medline
2. Ishikawa M, Hashimoto M, Kuwana N, et al. Guidelines for management of idiopathic normal pressure hydrocephalus. Neurol Med Chir (Tokyo) 2008;48(suppl):S1–23 CrossRef Medline
3. Marmarou A, Bergsneider M, Relkin N, et al. Development of guidelines for idiopathic normal-pressure hydrocephalus: introduction. Neurosurgery 2005;57:S1–3; discussion ii–v CrossRef Medline
4. Mori E, Ishikawa M, Kato T, et al; Japanese Society of Normal Pressure Hydrocephalus. Guidelines for management of idiopathic normal pressure hydrocephalus: second edition. Neurol Med Chir (Tokyo) 2012;52:775–809 CrossRef Medline
5. Relkin N, Marmarou A, Klinger P, et al; Study of INPH on neuro-instrumentation. Diagnosing idiopathic normal-pressure hydrocephalus. Neurosurgery 2005;57(3 suppl):S4–16; discussion ii–v CrossRef Medline
6. Hashimoto M, Ishikawa M, Mori E, et al; Study of INPH on neurological improvement (SINPHONI). Diagnosis of idiopathic normal pressure hydrocephalus is supported by MRI-based scheme: a prospective cohort study. Cerebrospinal Fluid Res 2010;7:18 CrossRef Medline
7. Ishikawa M, Hashimoto M, Mori E, et al. The value of the cerebrospinal fluid tap test for predicting shunt effectiveness in idiopathic normal pressure hydrocephalus. Fluids Barriers CNS 2012;9:1 CrossRef Medline
8. Evans WA. An encephalographic ratio for estimating ventricular enlargement and cerebral atrophy. Arch Neuropsych 1942;47:931–37 CrossRef
9. Ambarki K, Israelsson H, Wahlin A, et al. Brain ventricular size in healthy elderly: comparison between Evans index and volume measurement. Neurosurgery 2010;67:94–99; discussion 99 CrossRef Medline
10. Toma AK, Holl E, Kitchen ND, et al. Evans’ index revisited: the need for an alternative in normal pressure hydrocephalus. Neurosurgery 2011;68:939–44 CrossRef Medline
11. Algin O, Turkbey B. Evaluation of aqueductal stenosis by 3D sampling perfection with application-optimized contrasts using different flip angle evolutions sequence: preliminary results with 3T MR imaging. AJNR Am J Neuroradiol 2012;33:740–46 CrossRef Medline
12. Kartal MG, Algin O. Evaluation of hydrocephalus and other cerebrospinal fluid disorders with MRI: an update. Insights Imaging 2014;5:531–41 CrossRef Medline
13. Lichy MP, Wietek BM, Mugler JP 3rd, et al. Magnetic resonance imaging of the body trunk using a single-slab, 3-dimensional, T2-weighted turbo-spin-echo sequence with high sampling efficiency (SPACE) for high spatial resolution imaging: initial clinical experiences. Invest Radiol 2005;40:754–60 CrossRef Medline
14. Mugler JP 3rd. Optimized three-dimensional fast-spin-echo MRI. J Magn Reson Imaging 2014;39:745–67 CrossRef Medline
15. Gao KC, Nair G, Cortese IC, et al. Sub-millimeter imaging of brain-free water for rapid volume assessment in atrophic brains. Neuroimage 2014;100:370–78 CrossRef Medline
16. Falcão AX, Udupsa JK. A 3D generalization of user-steered live-wire segmentation. Med Image Anal 2000;4:389–402 CrossRef Medline
17. Zhang L, Wu X. An edge-guided image interpolation algorithm via directional filtering and data fusion. IEEE Trans Image Process 2006;15:2226–38 CrossRef Medline
18. Fedorov A, Beichel R, Kalpathy-Cramer J, et al. 3D Slicer as an image computing platform for the quantitative imaging network. Magn Reson Imaging 2012;30:1323–41 CrossRef Medline
19. Sasaki M, Honda S, Yuasa T, et al. Narrow CSF space at high convexity and high midline areas in idiopathic normal pressure hydrocephalus detected by axial and coronal MRI. Neuroradiology 2008;50:117–22 CrossRef Medline
20. Virhammar J, Laurell K, Cesarini KG, et al. Preoperative prognostic value of MRI findings in 108 patients with idiopathic normal pressure hydrocephalus. AJNR Am J Neuroradiol 2014;35:2311–18 CrossRef Medline
21. Kubo Y, Kazui H, Yoshida T, et al. Validation of grading scale for evaluating symptoms of idiopathic normal-pressure hydrocephalus. Dement Geriatr Cogn Disord 2008;25:37–45 CrossRef Medline
22. Wikkelso C, Hellstrom P, Klinger PM, et al; European iNPH Multicentre Study Group. The European iNPH Multicentre Study on the predictive values of resistance to CSF outflow and the CSF tap test in patients with idiopathic normal pressure hydrocephalus. J Neurol Neurosurg Psychiatry 2013;84:562–68 CrossRef Medline