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ORIGINAL ARTICLE

Use of computed tomography and diffusion weighted imaging in children with ventricular shunt

Altan Gunes[1] · Ibrahim Halil Oncel[2] · Serra Ozbal Gunes[3] · Ahmet Ziya Birbilen[4] · Sahin Hanalioglu[5]

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Abstract

Purpose To evaluate the indications, number, and imaging results of brain computed tomography (CT) and diffusion weighted imaging (DWI) in children with ventriculoperitoneal shunt, to estimate the radiation dose, and to evaluate the effectiveness of DWI.

Methods This retrospectively study included 54 consecutive patients (boys/girls = 30/24, mean age, 3 ± 4.1 years) with shunt that were placed due to congenital abnormalities-hypoxic ischemic encephalopathy between January 2015 and March 2018. The presence of shunt-related complications (SRC) was assessed using clinical and neuroimaging findings, and the standard reference was accepted as the shunt revision. Size comparisons of ventricles were performed using Evans index and the frontal and occipital horn ratio, and each measurement made by the observers were compared using Bland-Altman analysis. A kappa coefficient and the intraclass correlation coefficient were calculated to assess the agreement between observers.

Results The mean number of hospital admission, number of CT scans, and DWI were 5.8, 4.8, and 1.1, respectively per patient. A significant linear correlation was observed between hospital admission and CT scans ($r = 0.288$, $p = 0.035$). The number of CT scans and the cumulative effective dose per patient were higher in patients with SRC than in those without ($p < 0.001$). The mortality rate due to radiation-induced neoplasia has increased by 0.33% in the study period. The inter-observer agreement was perfect or substantial for the catheter visualization, assessment of the ventricular system on DWI, and for the image quality of DWI between observers ($\kappa = 0.704$–1, $p \leq 0.001$). No significant difference was found between CT and DWI in the measurements of Evans index and the frontal and occipital horn ratio ($p > 0.05$). Inter-observer agreements between observers were almost perfect for the Evans index and the frontal and occipital horn ratio (ICC = 0.94–0.99, $p < 0.001$).

Conclusions An awareness of the use of CT in children is still inadequate and difficulties in the diagnosis of SRC probably cause the overuse of CT. DWI should be preferred in the diagnosis of SRC and the follow-up of patients. Otherwise, the increase in the prevalence of several diseases, particularly neoplasia, may be inevitable because of the over use of CT.

Keywords Ventriculoperitoneal shunt · Radiation dose · Diffusion weighted imaging

✉ Altan Gunes
draltangunes@gmail.com

Ibrahim Halil Oncel
ibrahimoncel63@hotmail.com

Serra Ozbal Gunes
sozbal@gmail.com

Ahmet Ziya Birbilen
abirbilen@hotmail.com

Sahin Hanalioglu
sahinhanalioglu@gmail.com

[1] Department of Radiology, Ankara Child Health and Diseases Hematology Oncology Training and Research Hospital, University of Health Sciences, Dıskapı, 06130 Ankara, Turkey

[2] Department of Pediatric Neurology, Ankara Child Health and Diseases Hematology Oncology Training and Research Hospital, University of Health Sciences, Dıskapı, 06130 Ankara, Turkey

[3] Department of Radiology, Dıskapı Yıldırım Beyazıt Training and Research Hospital, University of Health Sciences, Dıskapı, 06130 Ankara, Turkey

[4] Department of Pediatric Emergency, Ankara Child Health and Diseases Hematology Oncology Training and Research Hospital, University of Health Sciences, Dıskapı, 06130 Ankara, Turkey

[5] Department of Neurosurgery, Dıskapı Yıldırım Beyazıt Training and Research Hospital, University of Health Sciences, Dıskapı, 06130 Ankara, Turkey

Introduction

Hydrocephaly with various congenital and acquired causes is a non-rare disease in children and it is most often treated by surgically inserting a shunt system [1]. The main objective of using shunt systems is to re-ensure impaired cerebrospinal fluid (CSF) circulation and prevent intracranial pressure increase [1]. Shunt systems require monitoring and regular medical follow-up because abnormalities such as mechanical complications and infection can be observed in approximately 40% of the patients within the first year and reach as high as 60% within 10 years [2–4]. Imaging methods can help in follow-up of patients and the diagnosis of shunt-related complications, and computed tomography (CT) is frequently preferred in daily practice [5–7]. The most significant disadvantage of CT is radiation exposure and the probability of the same radiation dose to develop cancer in a 1-year-old child is 10–15 times more than that in a 50-year-old adult and repeated CT scans in children cause them to be exposed to high cumulative radiation doses [8]. This condition is associated with increased life-long risk of malignity in children who are vulnerable to long-term harmful effects of radiation [7, 9, 10].

MRI avoids ionizing radiation exposure, but lengthy imaging times and the frequent need for sedation have limited its use in children. Quick-brain MRI with fast imaging sequence (single-shot fast-spin echo, half-Fourier acquisition single-shot turbo spin echo) has been used as an alternative to CT in the evaluation of patients with ventriculoperitoneal shunt (VS) [11–13]. Prolonged examination duration and sedation requirement in MRI have been significantly decreased with quick-brain MRI and the resulting image sufficiently permits a reliable assessment of ventricle size, even in an uncooperative patient [11–13]. Unlike previous studies on quick-brain MRI with fast imaging sequence [11–13], we think that only axial diffusion weighted imaging (DWI) can also be used in shunt patients for the evaluation of the ventricular system and catheter visualization. DWI limits the scan time while providing images that are easily comparable with CT images.

The aims of this study were to evaluate the indications, number, and imaging findings of brain CTs in children with VS, to estimate the radiation dose, and to evaluate the effectiveness of DWI. We hypothesize that axial DWI is an appropriate substitute for CT scanning.

Material and methods

Study design and patients

The study was approved by the local ethics committee (ethics reference number: 2018–085). Patients under the age of 17 years who underwent brain CT and/or DWI for suspected shunt-related complications or follow-ups during a 3-year period from January 1, 2015, to March 1, 2018 were evaluated retrospectively. Medical records were reviewed to determine patients' clinical history, presentation, physical examination findings, and outcome by pediatric emergency doctor (A.Z.B.; with 5 years of experience in pediatric emergency), pediatric neurologist (I.H.O.; with 7 years of experience in pediatric neurology), and neurosurgeon (S.H.; with 6 years of experience in neurosurgery). Inclusion criteria for the patients in the study were (a) having a VS due to congenital abnormalities or hypoxic ischemic encephalopathy, (b) having medical documentation, and (c) having CT or DWI within diagnostic quality and were taken with a time interval of less and/or equal to 1 day. Exclusion criteria for the patients in the study included (a) having inadequate medical records ($n = 8$), (b) not having regular follow-up ($n = 6$), (c) having suboptimal/inadequate CT due to motion artifacts ($n = 9$), and (d) having a VS for reasons other than congenital abnormalities or hypoxic ischemic encephalopathy ($n = 32$). Consecutive 54 children (boys/girls = 30/24, mean age = 3 ± 4.1 years, range, 0.1–17 years) were included in this study.

The presence or absence of shunt-related complications was assessed using all available information including patients' symptoms, signs, and results of neuroimaging. For the diagnosis of shunt-related complications, the standard reference was accepted as the shunt revision performed within the first 7 days following the evaluation of patients. The following conditions were assessed on neuroimaging: (a) over-drainage of CSF (existence of subdural collection, slit-like ventricles), (b) under-drainage of CSF (expansion in ventricles), and (c) malposition of the shunt catheter. The image quality of DWIs is also assessed. The CT and DWI of patients were re-evaluated by the pediatric radiologist (A.G.; with 8 years of experience in neuroimaging) and by comparing the latest CT. All DWI studies were independently reviewed by another radiologist (S.O.G.; with 13 years of experience in neuroimaging) and inter-observer agreement was determined between radiologists, and between radiologist (A.G.) and neurosurgeon (S.H.). The DW image quality, the ventricular size, and the catheter visualization were graded as follows; poor (1), good (2), or excellent (3), slit like (1), normal (2), mild (3), moderate (4), or severe (5) dilatation, and no visualization (1) or visualization of catheter tip (2), respectively by observers. Size comparisons of ventricles were performed using Evans index (maximal frontal horn ventricular width divided by the interparietal distance) and the frontal and occipital horn ratio (the average of the frontal and occipital horn width divided by the interparietal distance) [14, 15].

Currently, the radiation dose of each CT scan is calculated as dose length product (DLP) by the CT device. DLP is associated with stochastic (malignity or genetic abnormality) risk directly related to radiation. The patient exposure in our study was estimated using the average effective dose/DLP ratio (2.2 μSv/mGy·cm) of unenhanced brain CT scan calculated

in the previous studies for the CT device, which was the same as the device we used (16-slice, Toshiba America Medical Systems) [9, 16–18].

Imaging technique

CT imaging was performed without using a contrast material with the following parameters: 100–120 kV, slice thickness ≤ 2 mm, matrix 512 × 512 pixels, gantry angle 0°, and by choosing the kilovolt according to the patients' age (< 2 years, 100 kV; > 2 years, 120 kV) with automatic tube current modulation. All MRI was performed on 1.5 T scanner (GE Healthcare, Milwaukee, WI) with a multi-channel head coil and axial single-shot echo-planar DWI (applied with two b-values with a maximum of 1000 s/mm^2, TR/TE = 7300–7400/70–80 ms, field of view 22 cm, matrix 128 × 128, slice thickness 4 mm, gap 1 mm). The MRI examinations took an average of 45–60 s for each patient without sedation. The patients were usually on the imaging table for 3 min or less.

Statistical analysis

Categorical variables are presented as number and percentage and analyzed using Fisher's test. Numerical variables are presented as mean ± standard deviation and analyzed using Kruskal-Wallis, Mann-Whitney *U*, and Wilcoxon tests. Correlation analysis was conducted between the follow-up duration, number of hospital admission, and CT scans. The agreement between imaging modalities for the catheter visualization, the assessment of the ventricular system on DWI, and for the image quality of DWI was estimated by using the kappa statistic (κ, ranges from − 1 to + 1). Inter-observer agreement for each CT and MRI measurements were calculated using the intraclass correlation coefficient (ICC, ranges from − 1 to + 1). The kappa and ICC values are interpreted as follows: < 0.40, poor to fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and 0.81–1.00, almost perfect agreement. Using Bland-Altman analysis, we compared each CT and MRI measurement by the radiologists and neurosurgeon for the 18 patients who had CT and only DWI. All analyses were performed using SPSS (version 22.0, SPSS Inc., Chicago, IL), and $p < 0.05$ was considered statistically significant.

Results

There was no statistically significant difference between boys (3.3 ± 4.8 years, range 0.1–17 years) and girls (2.5 ± 3 years, range 0.1–11 years) in terms of age ($p = 0.930$, Mann-Whitney *U* test). Shunts were placed due to abnormalities related to congenital (Chiari, 55.6% [30/54]; non-Chiari (corpus callosum agenesis [$n = 3$], Dandy-Walker malformation [$n = 1$]), 7.4% [4/54]) and hypoxic ischemic encephalopathy (37% [20/54]) (Table 1). During the study period, the mean number of hospital admissions per patient was 5.8 (range, 1–19). Symptoms and findings that indicated the requirement of neuroimaging were seizure in 11.1% (29/261), vomiting in 8% (21/261), fever in 7.2% (19/261), general deteriorated condition in 1.9% (5/261), bulging fontanelle in 0.7% (2/261), and leaking from shunt reservoir in 1.2% (3/261) of patients. Twelve patients had some of the listed symptom and findings simultaneously. In nine patients (16.7%), complications that required shunt revision were detected and treated due to mechanical complications (obstruction [$n = 12$], equipment malfunction [$n = 3$], and malposition [$n = 1$]) and infection ($n = 5$). Shunt-related complications were treated more than twice in four patients (cases 2, 7, 35, and 53), and shunt revision was performed on three patients (5.5%) without clinical symptoms or newly developing imaging findings (cases 28, 36, and 39) (Table 1).

During the entire study period, the mean number of CT scan per patient was 4.8 (total CT scans = 261, range 1–28), and 69.5% of CT scans (181/261) were acquired for follow-up assessment of hydrocephalus after placement of a shunt (Table 2). Of the 261 CT scans obtained, 37 revealed interval ventricular enlargement, 44 demonstrated slit or small ventricles, and 180 revealed unchanged ventricles. There was no statistically significant difference between shunt indications and the number of CT scans ($p = 0.863$, Kruskal-Wallis test). But, the number of CT scans was higher in patients with shunt complications (mean number = 15) than in those without (mean number = 2.8) ($p < 0.001$, Mann-Whitney *U* test). No significant correlation was found between the follow-up duration and the number of CT scans ($r = 0.194$, $p = 0.161$). However, there was a significant linear correlation between the number of hospital admissions of patients and the number of CT scans ($r = 0.288$, $p = 0.035$). The mean DLP and effective dose of patients per CT scan were 493.56 ± 162.60 mGy·cm (333–890 mGy·cm) and 1.08 ± 0.35 mSv (0.73–1.95 mSv), respectively (Table 1). The cumulative effective dose per patient was 4.96 ± 6.17 mSv (0.73–29.56 mSv) (Tables 1 and 2). The cumulative effective dose per patient was higher in patients with shunt complications (median 16.13 mSv [interquartile range, 8.06–21.06 mSv]) than in those without (median 1.71 mSv [interquartile range, 1.23–3.65 mSv]) ($p < 0.001$, Mann-Whitney *U* test).

Eighteen of 54 patients who were asymptomatic presented for follow-up assessment in the neurosurgery clinic and a total of 21 DWI (mean 1.1 images per patient) instead of CT scanning were acquired and compared to the latest CT scan (Fig. 1). Of the 21 images obtained, 17 revealed unchanged ventricular sizes. In four asymptomatic patients, DWI demonstrated interval ventricular enlargement, and one of four patients underwent shunt revision due to the significant increase in ventricular size. An increase in ventricular size was mild in

Table 1 The table showed the demographic characteristics, number of CT scan and hospital admission, and estimated radiation dose of the all patients

Case	Sex	Age (y)	Abnormalities	The number of		Radiation dose		
				Hospital admission	CT scan	DLP	ED	Cumulative ED
1	M	2	Chiari II	2	1	421	0.926	0.926
2*	M	1	Chiari II	2	21	376	0.827	17.371
3	F	4	HIE	17	11	580	1.276	14.036
4	F	0.3	Chiari II	4	3	400	0.880	2.640
5	M	1	Chiari II	3	3	356	0.783	2.349
6*	F	0.3	Chiari II	2	7	384	0.844	5.913
7*	F	0.5	Chiari III	14	28	405	0.891	22.275
8	F	6	Chiari I	1	1	778	1.711	1.711
9	F	0.1	HIE	11	2	333	0.732	1.465
10*	F	5	Chiari II	9	14	524	1.152	16.139
11	M	10	Chiari II	9	2	721	1.586	3.172
12	M	0.8	Chiari II	4	1	442	0.972	0.972
13	F	1	Chiari II	2	1	389	0.855	0.855
14	F	1.5	Chiari II	5	1	387	0.851	0.851
15	M	0.1	HIE	6	3	414	0.910	2.732
16	F	3	HIE	1	1	560	1.232	1.232
17	F	0.7	HIE	6	6	368	0.809	4.857
18	M	5	Chiari II	19	1	560	1.232	1.232
19	M	0.7	HIE	1	1	335	0.737	0.737
20	M	0.4	Chiari II	2	2	365	0.803	1.606
21	M	10	Chiari II	9	1	800	1.760	1.760
22	M	17	HIE	3	2	890	1.958	3.916
23	F	7	HIE	6	3	778	1.711	5.134
24	M	0.1	HIE	10	1	386	0.849	0.849
25	M	16	HIE	2	2	878	1.931	3.863
26	M	1	HIE	1	1	340	0.748	0.748
27	M	0.6	HIE	5	6	356	0.783	4.699
28*	M	11	Chiari II	5	12	752	1.654	19.852
29	M	7	HIE	3	1	781	1.718	1.718
30	M	0.1	DWM	7	2	341	0.750	1.500
31	M	6	Chiari II	2	1	765	1.683	1.683
32	F	11	Chiari III	1	2	742	1.632	3.264
33	F	1	Chiari II	14	2	345	0.759	1.518
34	F	1	HIE	1	3	375	0.825	2.475
35*	M	0.7	Chiari II	9	28	480	1.056	29.568
36*	F	9	Chiari II	7	3	712	1.566	4.699
37	F	0.1	HIE	3	5	406	0.893	4.466
38	F	0.1	HIE	1	13	436	0.959	12.469
39*	M	0.3	HIE	2	10	464	1.020	10.208
40	M	5	Chiari III	3	1	589	1.295	1.295
41	M	0.1	HIE	14	7	412	0.906	6.344
42	F	4	Chiari II	1	1	560	1.232	1.232
43	M	0.1	CCD	1	1	336	0.739	0.739
44	F	0.5	Chiari II	7	2	356	0.783	1.566
45	F	0.1	Chiari II	9	2	386	0.849	1.698
46	M	1	CCD	12	3	390	0.858	2.574
47	F	2	Chiari II	17	4	428	0.941	3.766

Table 1 (continued)

Case	Sex	Age (y)	Abnormalities	The number of		Radiation dose		
				Hospital admission	CT scan	DLP	ED	Cumulative ED
48	M	0.3	Chiari II	3	3	418	0.919	2.758
49	M	0.3	CCD	8	7	408	0.897	6.283
50	M	0.1	Chiari II	4	3	442	0.972	2.917
51	M	0.2	HIE	1	2	386	0.841	1.698
52	M	4	HIE	8	1	562	1.236	1.236
53*	F	0.3	Chiari II	8	13	452	0.994	12.927
54	F	2	Chiari II	7	4	402	0.884	3.537

Asterisk means the presence of shunt-related complications

y years, *HIE* hypoxic ischemic encephalopathy, *DWM* Dandy-Walker malformation, *CCD* corpus callosum dysgenesis, *ED* effective dose

the other three patients and there was no evidence of shunt dysfunction in these patients. All shunt catheters were detected on DWI. No DWI studies demonstrated evidence of movement artifact sufficient to obscure ventricular anatomy except in four cases. DWI studies were repeated to achieve satisfactory results in these four patients. There was almost perfect agreement for the catheter visualization ($\kappa = 1$, $p < 0.001$) and the assessment of the ventricular system on DWI ($\kappa = 0.811$, $p < 0.001$), substantial agreement for the image quality of DWI ($\kappa = 0.712$, $p = 0.001$) between radiologists. The agreement between radiologist and neurosurgeon was substantial for all of these ($\kappa = 0.717$, 0.704, 0.774, respectively) ($p \leq 0.001$). No significant difference was found between CT and DWI for the measurements of Evans index (31 ± 4% [25–39%], 31 ± 4% [25–38%], respectively, $p = 0.343$, Wilcoxon test) and the frontal and occipital horn ratio (42 ± 5% [35–56%], 42 ± 6% [34–58%], respectively, $p = 0.749$, Wilcoxon test) (Table 3) (Fig. 2). Inter-observer agreements between radiologists, and between radiologist and neurosurgeon were almost perfect for the Evans index and the frontal and occipital horn ratio (ICC = 0.94–0.99, $p < 0.001$) (Figs. 3 and 4).

Discussion

Studies have reported that nausea, vomiting, deteriorated general condition, erythema or leaking surrounding shunt reservoir, increased fontanel size, and developmental delay have a positive predictive value between 78 and 100% following the shunt placement [5–7, 19]. In our study, only three patients with shunt-related complications had these symptoms (vomiting, deteriorated general condition, and increased fontanel size). Although seizures are prevalent in children with hydrocephaly, a large number of seizures (90%) were not related to shunt-related complications in our study, which is consistent with a previous study [5]. It has been reported that the symptoms mentioned above may not occur in 9–29% of patients with shunt-related complications, as found in our study (5%) [10]. Our findings show that the most of symptoms observed in shunt-related complications are not specific and causes difficulties in the diagnosis, which is consistent with previous studies [5, 10, 20, 21]. On imaging, shunt-related complications do not cause ventriculomegaly in every case, and there may be shunt problems despite a decrease in the size of ventricles [22]. Shunt problems were detected in our three patients with no ventriculomegaly on CT (cases 28, 36, and 39). This result shows that shunt-related complications that may not be detected by radiologic evaluation.

Imaging techniques used in diagnosis of shunt-related complications vary among centers due to various factors, such as choices of clinicians, presence of imaging devices-equipments [23]. Of these techniques, CT is the most preferred method because of its easy accessibility, fast imaging, and high diagnostic accuracy [24, 25]. In the recent years, there has been an increase in the number of CT examinations and radiation exposure due to medical imaging, especially with CT [9, 26]. Radiation exposure can induce transformation of cells (stochastic effects) that may become malignant after a long

Table 2 The table showed the categorical number of CT scan and patients, and the categorical cumulative estimated radiation dose of the all patients

Number of CT scan	Number of patients (%)	Cumulative estimated dose, mSv	Number of patients (%)
1	17 (31.4)	< 1	8 (14.8)
1–5	23 (74.1)	1–5	33 (61.1)
5–10	5 (9.3)	5–10	4 (7.4)
≥ 10	9 (16.7)	≥ 10	9 (16.7)

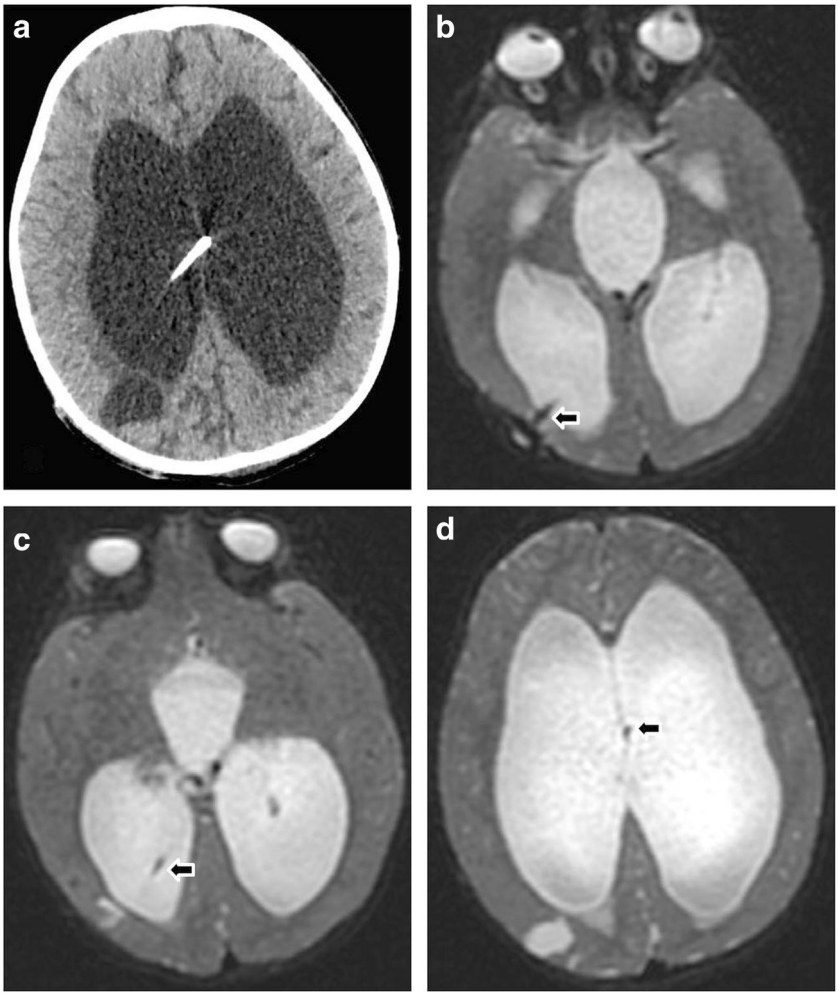

Fig. 1 Case 36, a 9-year-old girl who was born with a lumbosacral meningocele presented for routine medical examination. **a** Axial computed tomography image shows the catheter tip near the septum pellucidum. **b** Axial diffusion weighted images with b-value of 0 s/mm^2 show shunt catheter that placed via right occipital approach (*arrow*) and course of the catheter (**c**, *arrow*). The catheter tip is seen near the septum pellucidum on axial diffusion weighted image (**d**, *arrow*)

latency period (several years to decades) [8]. The risk of developing cancer from low-level radiation is not known with certainty; however, some studies suggest that exposure to ionizing radiation increases the risks of some cancers including leukemia, brain, breast, skin, and thyroid cancers following exposures [9, 27]. The latency period varies with the type of malignancy that leukemia has a shorter period (approximately ≤ 10 years) than solid malignancies [28]. The probability of developing cancer is presumed to increase with radiation dose and there is no threshold value for cancer development [8, 27] and the lifetime attributable risk that can be defined as a risk of incidence or mortality from a cancer attributable to radiation exposure is higher in children compared to adults, with infants at the greatest risk. One study has reported that children with VS have an average of 2.6 brain CT scans per year [7]; another study has reported that 48% of children underwent brain CT scans after being admitted to the emergency department [29]. In our study, the average number of CT scans (4.8) and the CT scan rate after hospital admission (82%) was much above those reported in the literature. Also, in our study, if the patient had a shunt complication, the number of CTs was significantly higher. Brenner [30] reports that the lifetime cancer mortality risk attributable to a single head CT in a 1-year-old patient was 0.07% and this risk becomes especially important in children with VS who require several CT examinations during their lifetime. According to Brenner's calculations [30], in our study, the mortality rate due to radiation-induced neoplasia has increased by 0.33% in the past 3 years and this rate has increased by 0.70% in the nine patients who underwent CT examinations more than ten scans. The estimated radiation exposure was > 10 mSv in 16.7% of our patients and the radiation exposure > 10 mSv has been reported to cause an additional one cancer risk per 1000 individuals [31].

In our study, the DWI allowed adequate information about the ventricular system at least as much as CT and quick-brain MRI, as found in previous studies [12, 32]. Previous studies with quick-brain MRI, total imaging time ranged from 150 s to 22 min. In our study, this time was less than 60 s. Scott et al. [33] reported that an 8-s T2 diffusion weighted scan that produced 10 to 12 images provided adequate ventricular evaluation, as found in our study. Unlike this study, our DWI protocol produced 26–28 images that allowing the assessment of catheter localization. In our study, shunt catheters can be detected as in CT in our all patients. In the setting of infections such as the

Table 3 Table shows that the measurements performed on CTs and DWIs by the three examiners

Case	Evans index						Frontal and occipital horn ratio					
	CT (%)			DWI (%)			CT (%)			DWI (%)		
	R^1	R^2	Ns	R^1	R^2	Ns	R^1	R^2	Ns	R^1	R^2	Ns
1	35	34	33	34	36	35	57	56	56	58	59	58
2	33	32	31	30	32	33	48	49	50	53	52	45
3	25	24	26	27	26	25	42	42	43	41	40	43
4	35	36	37	37	37	36	42	41	42	40	43	41
5	34	35	35	33	32	34	45	46	44	45	47	47
6	39	38	38	37	40	39	50	51	50	51	50	51
7	36	35	36	37	37	36	43	42	42	43	43	42
8	28	26	27	28	29	28	40	40	41	43	41	41
9	28	28	29	30	29	27	40	39	39	40	40	41
10	26	26	27	28	27	25	37	36	37	35	38	39
11	35	34	36	38	35	36	39	40	41	38	41	42
12	36	37	35	36	36	35	45	44	43	45	45	44
13	31	32	33	32	32	31	39	38	37	38	36	36
14	29	28	30	29	29	30	37	39	38	37	37	39
15	25	26	24	25	26	25	35	34	35	34	35	33
16	26	24	24	26	25	26	38	37	36	38	39	39
17	32	33	33	32	33	32	40	41	40	39	40	41
18	34	33	35	34	35	32	42	42	42	40	43	44

CT computed tomography, *DWI* diffusion weighted image, *R^1 and R^2* radiologist, *Ns* neurosurgeon

collections, ventriculitis, the DWI is more sensitive than CT in detecting these inflammatory changes in the shunt-related infections [34]. Also, the T2* susceptibility features of DWI with b-value 0 making it relatively sensitive to blood products, air, calcification, and implanted devices (Fig. 5). MRI and DWI may not be as good as CT in predicting some pathologies due to technical reasons, such as hematoma size. If there is no major intraventricular hemorrhage and/or pneumocephalus, this technical limitation will not cause any restriction in the evaluation of ventricular size (Fig. 5). The using of DWI in our study for the evaluation of patients allowed us to reduce the radiation and sedation related risks. According to Brenner's calculations [30], in our study, if CT scanning were used instead of DWI, the mortality rate due to radiation-induced neoplasia would

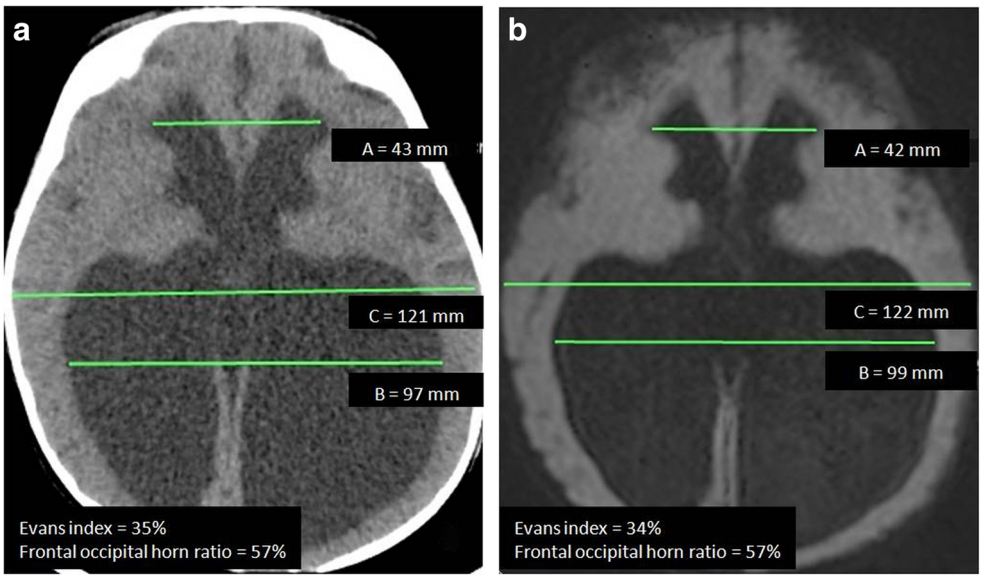

Fig. 2 Case 14, a 16-month-old girl with shunt catheter. **a** Axial CT scan and **b** diffusion weighted image show the measurement of Evans index (A/C), and the frontal and occipital horn ratio (A + B/2C)

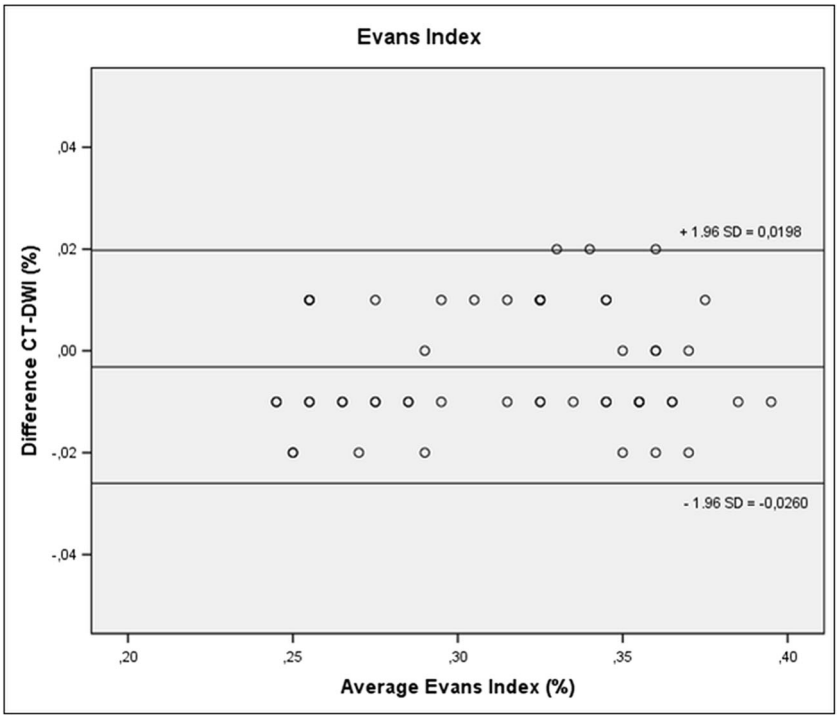

Fig. 3 Bland-Altman plot shows the inter-observer variability for the Evans index. The 95% confidence limits of agreement are between − 2 and 1%

have increased. Despite several attempts to reduce radiation dose [9, 10, 18, 26], many patients were exposed to large cumulative doses of ionizing radiation over the study time periods. Our result shows that radiation-related risks are not considered as important as those of shunt-related complications and in clinical practice. The use of CT is based on its easy accessibility and suitability to contribute towards solving clinical scenarios. However, the benefits of CT imaging must be weighed against the potential risks of the radiation exposure.

There are some limitations to our study: (a) emergency department admittance reasons of some patients may have differed, (b) the number of CT scans and estimated radiation exposure reported may be low because CT examinations of patients performed in other centers could not be obtained, (c)

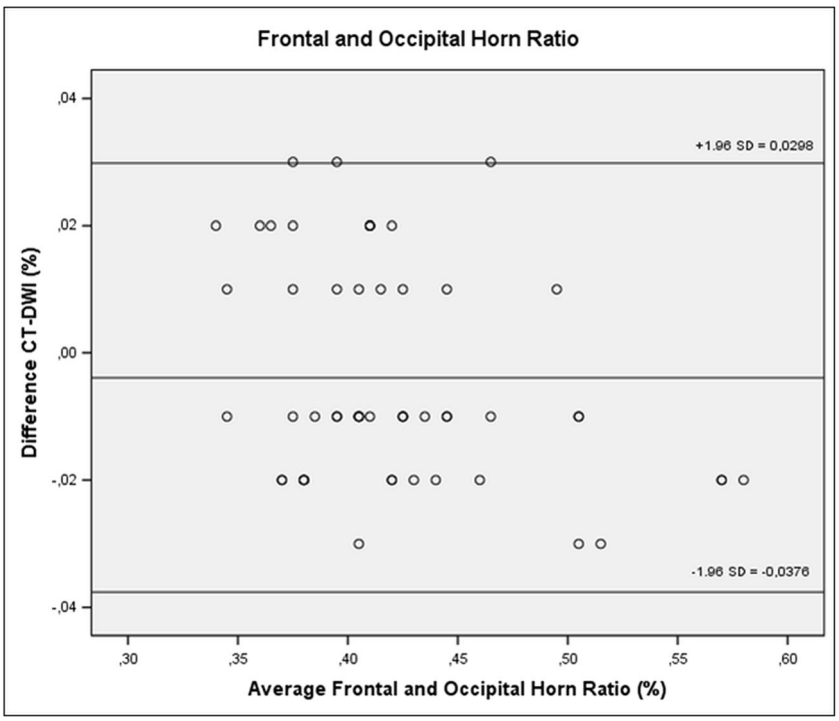

Fig. 4 Bland-Altman plot shows the inter-observer variability for the frontal and occipital horn ratio. The 95% confidence limits of agreement are between − 3 and 2%

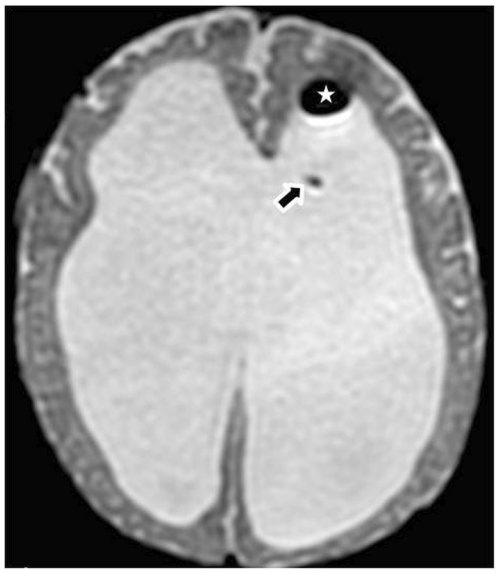

Fig. 5 Axial diffusion weighted image with b-value of 0 s/mm^2 shows shunt catheter (*arrow*) and artifact caused by the air (*star*)

radiation doses in our study are estimations and not real personal exposure measurements, (d) quick-brain MR imaging should not be considered a full diagnostic MR imaging protocol and it is optimal for evaluation of ventricular anatomy, however, it is not optimal for evaluating the characterization of lesions such as tumors or migration abnormalities, (e) the number of CT scans and the number of DWI did not match due to the fact that these studies were not taken with near time intervals. This mismatch can reduce statistical power, and (f) in a few cases, gross movement artifact resulted in movement-degraded images and made it difficult to evaluate the imaging findings.

Conclusion

An awareness of the use of CT in children is still inadequate and difficulties in the diagnosis of shunt-related complications probably cause the overuse of CT. DWI should be preferred in the diagnosis of shunt-related complications and the follow-up of patients. Otherwise, the increase in the prevalence of several diseases, particularly neoplasia, may be inevitable because of the over use of CT.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Statement of informed consent was not applicable since the manuscript does not contain any patient data.

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