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The Value of Computed Tomography Imaging of the Head After Ventriculoperitoneal Shunt Surgery in Adults

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BACKGROUND: **Patients with a ventriculoperitoneal shunt for hydrocephalus often undergo multiple follow-up computed tomography (CT) scans of the head, increasing the risk for long-term effects of ionizing radiation. The purpose of our study was to evaluate the necessity as a routine diagnostic procedure and cost analysis of routine postoperative CT scan of the head after ventriculoperitoneal shunt surgery.**

METHODS: **In this study, we comprised adults with ventriculoperitoneal shunt operations who underwent early CT scans within 48 hours postoperatively. We reviewed the correlation between revision surgery rate and the experience of surgeons who performed surgery and provided a cost analysis.**

RESULTS: **In total, 479 surgeries were performed in 439 patients. Early revision surgery was performed in 11 (2.3%) patients. Reason for revision surgery was malposition in 9 cases and intracerebral hemorrhage in 2 patients. There was no significant correlation between the surgeon's experience and the rate of revision surgery. Placement of the ventricular catheter via an approach other than a standard right or left frontal burr hole resulted in risk of need for surgical shunt revision ($P \geq 0.002$, odds ratio 54, confidence interval 13.5–223). A total of 468 CT scans of the head revealed a normal finding; thus, ~$562,000 could be saved by omitting postoperative head CT scans.**

CONCLUSIONS: **Routine postoperative head CT scans after fentriculoperitoneal shunting are not necessary in all cases. The reduction of exposure to ionization radiation and the beneficial economic factor are main advantages.**

INTRODUCTION

In the United States, more than 125,000 ventriculoperitoneal (VP) shunt surgery procedures are performed every year.[1] Computed tomography (CT) scans of the head are used to confirm the suspected diagnosis of hydrocephalus and to reveal the underlying cause. Hence, it is an essential component of preprocedural workup before implantation of a VP shunt system as a treatment for hydrocephalus. For postoperative imaging, CT scans are often the preferred technique because of their wide availability and brief imaging time. However, the widespread use of a CT scan also is associated with the application of ionizing radiation and consequentially a potential risk of diseases related to cancer in later life.[2-10] Doses of ionizing radiation from CT scans are typically in the range of 5–50 mGy to each organ imaged.[11,12] In many institutions, the standard protocol for the evaluation of an appropriate intraventricular placement of the ventricular catheter includes a head CT scan postoperatively. The aim of this study is to evaluate the necessity of postoperative head CT scans after VP shunting and the detection rates of complications associated with VP shunt surgery.

MATERIAL AND METHODS

This is a retrospective, single-center study of all patients undergoing VP shunt surgery between 2010 and 2017. This study was approved by appropriate institutional review board of the Goethe

Key words
- Costs and cost analysis
- Head CT scan
- Radiation protection
- Ventriculoperitoneal shunt

Abbreviations and Acronyms
CI: Confidence interval
CT: Computed tomography
OR: Odds ratio
PGY: Postgraduate year
VP: Ventriculoperitoneal

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Citation: World Neurosurg. (2019) 121:e159-e164.
https://doi.org/10.1016/j.wneu.2018.09.063

Journal homepage: www.journals.elsevier.com/world-neurosurgery

Available online: www.sciencedirect.com

University, Frankfurt. Based on the retrospective character of our study and in accordance with the guidelines, patients' informed consent was not necessary for preparation of the study. From this population of patients, a detailed chart review was performed and the following data were abstracted: age, sex, indication for shunting, valve pressure, site of shunt (frontal or occipital), bifrontal ventricular span (based on preoperative CT scan), Evans ratio (based on preoperative CT scan), and accuracy of ventricular catheter placement (based on postoperative CT scan).

The bifrontal ventricular span was measured as the width of the lateral margin of the right frontal horn to the lateral margin of the left frontal horn at its widest point on an axial image. The Evans ratio was calculated by dividing the bifrontal ventricular span by the maximum width of the inner table of the cranium. Ventricular catheter placement was defined as "accurate" when at least more than 1 cm of the ventricular catheter resided within the intended ventricle or passed through the foramen of Monro into the third ventricle. Placement was considered acceptable if the ventricular catheter tip resided in the contralateral frontal horn (crossover) and as inaccurate if the tip of the ventricular catheter was placed outside of the ventricular system. The accuracy of each ventricular catheter placement was determined by comparing the operative approach to the documented tip position in each of the radiology reports from the postoperative CT scans.

A standard low-dose CT scan of the head was performed in all cases after surgery to evaluate the appropriate position of the ventricular catheter within the ventricle system and to detect VP shunt surgery associated complications, such as intracerebral bleeding. The primary endpoint was return to the operating room within 48 hours after surgery either because of malposition of the ventricular catheter or because of surgery associated complications. To assess whether the experience of the surgeon performing implantation of a VP shunt may influence the rate of early revision surgery (malposition and other complication), we analyzed the correlation between surgeon's experience and rate of revision surgery. The surgery was either performed by a senior neurosurgeon with board certification or by residents (postgraduate year [PGY] 1-7) under the supervision of a board-certified neurosurgeon in patients were included in this study. The aim of the present study is to evaluate the effectiveness and necessity of routinely performed postoperative head CT scan.

Surgical Procedure

The standard approach was puncture of the right or left frontal horn through a small burr hole and was defined a typical approach in this study. In some cases, an occipital or suboccipital burr hole was placed to reach the occipital horn, the temporal horn, or the fourth ventricle, respectively. These procedures were defined as atypical approaches. Only ventricular catheters inserted without the help of navigation devices were included in the present study.

Postoperative Imaging

All patients underwent routine a postoperative low-dose CT scan of the head within 48 hours after surgery. Aim of the performed imaging was to proof the correct position of the ventricular catheter and assessment of any surgery-related intracranial complications. The average national cost of a head CT scan in the United States amounts to \$1200, whereas the cost at our institution is much lower (~\$143).

RESULTS

A total of 479 VP shunt procedures were performed in 439 patients in the aforementioned period. Mean age at the time of surgery was 58.1 years (standard deviation 16.4 years). Of all patients, 205 were male (46.7%) and 234 were female (53.3%). The mean length of the ventricular catheter within the ventricle was 3.2 cm in 476 patients and in 3 patients less than 1 cm. All patients received routine postoperative imaging consisting of low-dose CT scan of the head within 48 hours after surgery. Patient characteristics are summarized in Table 1. Indications for VP shunt placement are presented in Table 2. The main reason for VP shunting was posthemorrhagic hydrocephalus after subarachnoid hemorrhage, followed by hydrocephalus caused by intracerebral tumors, normal-pressure hydrocephalus, intracerebral hemorrhage, and other pathologies listed in Table 2.

Revision Surgery Based on Postoperative CT scans

Of the 479 VP shunt placements, 11 patients (2.3%) required revision surgery within 48 hours after VP shunt implantation based on the result of the routinely performed head CT scan. Mean age in these patients was 57.7 years (standard deviation ±16.1 years). Five were males (45.5%) and another 6 patients (54.5%) were females. The mean valve pressure in this cohort was 4.1 cmH_2O. The indication for revision surgery was malposition, namely placement of the ventricular catheter outside of the ventricular system in 9 patients (81.8%), postoperative intracerebral hemorrhage with the requirement of an additional placement of an external ventricular drain in 1 case (9%), and treatment of intracerebral hemorrhage without the need for ventriculostomy in another case (9%). In the overall cohort, 43.5 head CT scans were performed to obtain 1 CT

Table 1. Baseline Characteristics of 479 Shunt Implantations

Parameters	No Revision	Revision Surgery	*P* Value
No. patients	428	11	
No. VP shunt	468	11	
Age	57.6 ± 16.5	57.7± 16.1	0.9
Sex, male	205	5	1.0
Routine postoperative CT	468	11	
Mean valve pressure	4.0 ± 3.6	4.1± 3.7	0.9
Surgical Approach			
Right frontal	355 (76.2%)	5 (45.5%)	0.03
Left frontal	106 (20.9%)	1 (9%)	0.5
Typical	7 (1.6%)	5 (45.5%)	**>0.002**
Bifrontal ventricular span	47.1 ± 10.2	47 ± 9.3	0.9
Evans ratio	0.38 ± 0.08	0.38 ± 0.08	1.0

Bold value represents atypical approach <0.002. The atypical approach revealed a significant association with the need for revision surgery as compared with a frontal approach.
VP, ventriculoperitoneal; CT, computed tomography.

Table 2. Etiologies of Hydrocephalus

Reason	No Revision	Revision Surgery	*P* value
SAH	118	6	0.09
ICH	32	2	0.2
Tumor	106	1	0.3
TBI	14		
NPH	91		
Aqueductal stenosis	10	1	0.2
Colloid cyst	8		
Meningitis	4		
Chiari malformation	4	1	
Congenital hydrocephalus	10		
Meningeosis (leptomeningeal carcinomatosis)	5		
Basilar aneurysm	4		
CSF fistula	8		
SDH	3		
Pseudotumor cerebri	8		
Cerebral infarction	3		

SAH, subarachnoid hemorrhage; ICH, intracerebral hemorrhage; TBI, traumatic brain injury; NPH, normal-pressure hydrocephalus; CSF, cerebrospinal fluid; SDH, subdural hematoma.

Table 3. Surgeon's Experience and Need for Revision Surgery

Surgery Performed by	No Revision	Revision Surgery	*P* Value
Resident			
PGY-1	68	1	
PGY-2	67	2	
PGY-3	74	3	
PGY-4	46	1	
			0.2*
PGY-5	43	0	
PGY-6	23	0	
PGY-7	12	0	
			0.7†
Senior NS	135	4	

PGY, postgraduate year; NS, neurosurgeon.
*Comparing PGY-1 to PGY-3 surgeons with PGY-4 to PGY-7 surgeons.
†Comparing residents with senior (board-certified) NS.

scan of the head that resulted in an alteration of patient management. Two patients showed a postoperative decline of their neurologic condition. The postoperative CT scan revealed intracerebral hemorrhage in both patients. In patients without newly developed focal neurologic deficits (malposition of the ventricular catheter), a postoperative CT scan of the head resulted in change in postoperative management in 1.9% of the cases. Hence, 240 CT scans of the head were performed to obtain 1 CT scan of the head with clinical impact. Age, sex, valve pressure, bifrontal ventricular span, and Evans ratio were not significantly associated with early surgical revision surgery.

Revision Surgery and Indication for VP Shunt Placement

Of the 11 patients recurring early surgical intervention, 6 patients (54.5%) had undergone initial VP shunting for subarachnoid hemorrhage, 1 patient (9%) for intracerebral hemorrhage, hydrocephalus caused by intracerebral tumor in 2 cases (18.2%), aqueductal stenosis in 1 patient, and congenital hydrocephalus as reason for hydrocephalus in another case. The disease underlying hydrocephalus was not significantly associated with the need for revision surgery for any cause (Table 2).

Revision Surgery and Surgeon Experience

Of the 11 patients undergoing early revision, the initial VP shunt placement was performed by 1 PGY-1 surgeon, 2 PGY-2 surgeons, 3 were performed by PGY-3 surgeons, 1 VP shunt procedure was performed by a PGY-4 surgeon, and 4 procedures were carried out by attending, board-certified neurosurgeons (Table 3). When comparing the group of patients not undergoing revision surgery with patients with the requirement of revision surgery, we found there was no statistically significant difference when comparing resident surgeons with senior surgeons (7 of 333 and 4 of 135, respectively; $P = 0.7$, odds ratio [OR] 0.7, confidence interval [CI] 0.2–2.4; Fisher exact test). Furthermore, comparison of junior and senior residents as well as a comparison of PGY-1 to -3 with PGY-4 to -7 residents (6 of 209 and 1 of 124, respectively; $P = 0.3$, OR, 3.6 CI 0.4–29.9; Fisher exact test) revealed no significant difference in revision rate after primary surgery.

Revision Surgery and Site of Surgical Approach

The right frontal approach was the most preferred surgical approach and was performed in 355 (76.2%) of cases, followed by the left frontal approach, with 106 (20.9%) procedures in the nonrevision cohort. In 7 patients in the nonrevision cohort and in 5 patients in the early revision cohort, an atypical approach (3 occipital, 2 forth ventricle) was chosen for VP shunt implantation. The atypical approach, either occipital or suboccipital, revealed a significant association with the need for revision surgery compared with the right frontal approach (5 of 324 and 5 of 12, respectively; $P \geq 0.002$, OR 54, CI 13.5–223); Fisher exact test.

Imaging Costs

The national average cost of a noncontrast CT scan of the head in the United States amounts for ~$1200. Overall, 479 CT scans of the head after VP shunt surgery were performed in our analyzed patient cohort. Excluding 11 patients, in whom the postoperative CT findings influenced clinical management, 468 patients received a routine CT scan of the head with normal findings totaling ~$562,000 (~67,000 € University Hospital Frankfurt).

Consequently, ∼$52,200 (∼6000 €) was spent to obtain 1 CT scan of the head resulting in early intervention after surgery.

DISCUSSION

Radiographic imaging such as head CT scans or skull radiography often are performed in patients undergoing VP shunt procedures. However, the performance of head CT scans is costly and associated with a 0.07% increased lifetime risk of cancer as a result of radiation exposure after each scan.[12] Previous published studies in the pediatric population reported a greater shunt revision rate within 7 days based on the result of imaging studies. However, the exposure to ionizing radiation was mentioned as burden in these patient's population as well.[13] Therefore, it remains challenging to improve the process of evaluating for ventricular shunt malfunction and minimizing radiation exposure. Alternative diagnostic tools, such as measurement of the optic nerve sheath diameter, intraoperative CT, neuronavigation, and ultrasonography were evaluated for detecting shunt malfunction.[10,13-15] Optic nerve sheath diameter and ultrasonography are promising and cost effective but not well established and require additional examination expertise.

In neurosurgery and in other surgical specialties, current research focuses on the benefits and risks of postoperative diagnostics, including imaging involving ionizing radiation.[10,16-19] In our study, we also investigated the necessity and usefulness of early routine CT scanning of the head. The results of the present study display intriguing results: almost 98% of the patients subjected to postoperative CT of the head after implantation of a VP shunt system revealed an uneventful postoperative course. Only 2 (0.4%) patients revealed a new neurologic deficit with the pathologic finding of intracerebral hemorrhage (Figure 1).

In these 2 patients, early surgery was performed to resolve the postoperative complications. In 9 of 11 patients who ultimately underwent surgery for correction of a misplaced ventricular catheter, no clinical correlation was observed before imaging. That means that these patients with inaccurately placed ventricular catheters did not demonstrate any other signs or symptoms suggestive of shunt malfunction that would have prompted a CT scan if a routine one had not been performed (Figure 2). However, it remains unclear as to whether neurologic deterioration might have occurred over the further course of their hospital stay. But, ultimately, CT scans of the head revealed pathologic findings in these 9 patients, and revision surgery for shunt catheter placement was performed.

One of the concerns in the study is the medical-legal concerns in many countries, such as in ours. Based on the results of our data, routine CT scans of the head would be only omitted in patients with an uneventful postoperative course without signs and symptoms of postoperative complications. Furthermore, we demonstrated that in 98% of patients the postoperative head CT scans lead to no change of their management except for additional exposure to ionization radiation, which is an important issue of the present study. Exposure to ionizing radiation increases ultimately the risk of cancer. As we know from previous studies, patients with an implanted VP shunt undergo many radiographic diagnostic procedures for excluding shunt malfunction, inappropriate valve adjustments, and/or reoccurrence of hydrocephalus. Evaluating the need of radiographic procedures in these patients seems to be an important measure for patient's safety. The use of low-dose CT scans of the head in our investigated population revealed a sufficient alternative to standard CT scans.

To the best of our knowledge, there are no studies addressing the clinical utility and cost analysis of routinely performed CT scans of the head after VP shunt surgery. Most authors published their experience focusing on revision rate, shunt infection, and further complications accompanied with VP-shunt surgery.[20-22] We analyzed possible predictive factors, which were associated with a greater risk of early revision surgery. Next to baseline characteristics and ventricular size, we further investigated the correlation between surgeon's experience and the number of patients undergoing early revision surgery. We found no significant statistical association with shunt revision rates depending on

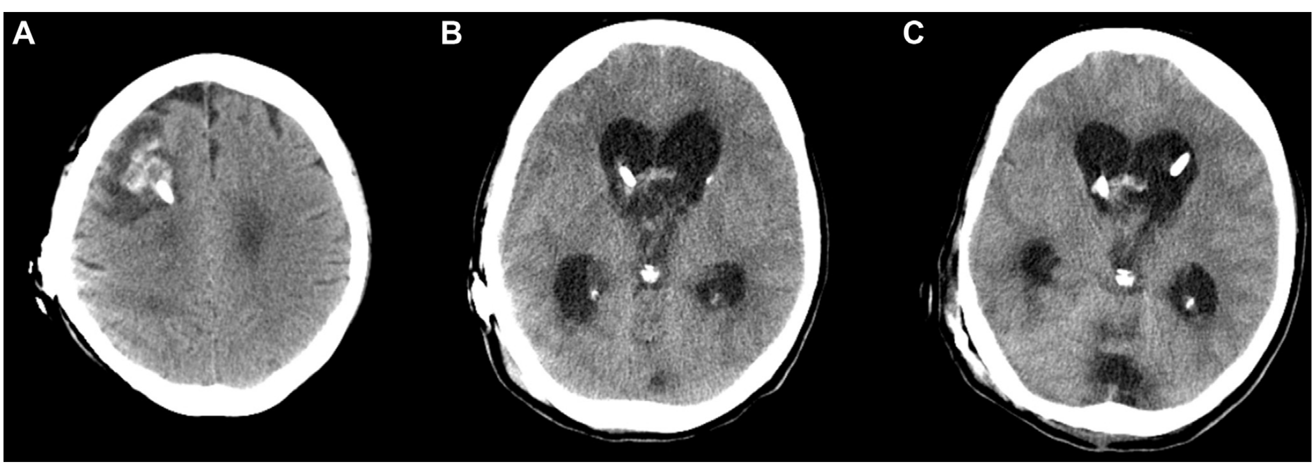

Figure 1. Case of postoperative intracerebral hemorrhage after ventriculoperitoneal shunting. (**A**) Intraparenchymal hematoma along the catheter. (**B**) Intraventricular hemorrhage. (**C**) After revision surgery with insertion of an external ventricular drainage.

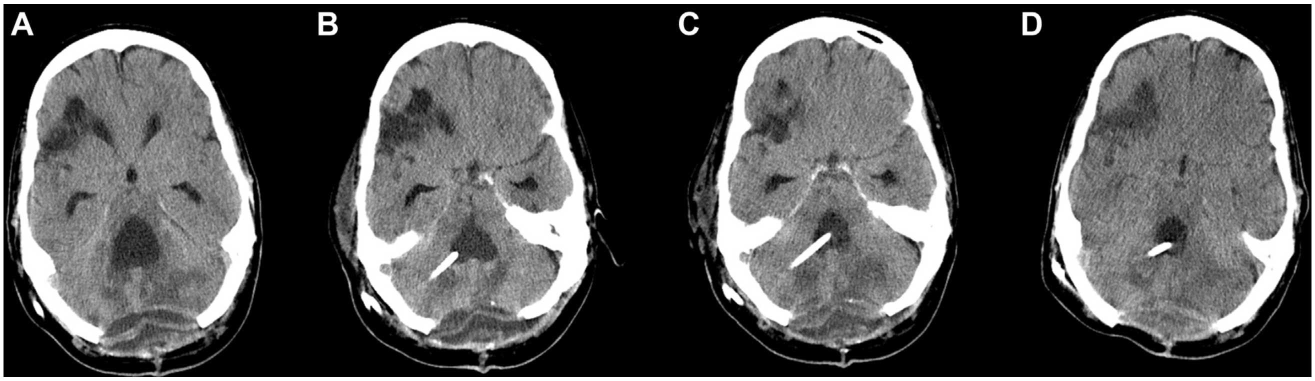

Figure 2. Illustrative case of shunt malposition. (**A**) Preoperative computed tomography (CT) scan of the head. (**B**) Postoperative imaging with malposition of the ventricular catheter. Only the tip of the ventricular catheter is within the fourth ventricle. (**C**–**D**) CT scan of the head after revision surgery. The ventricular catheter was placed adequately.

the level of training of the operating neurosurgeon (between young residents, experienced residents, or senior neurosurgeons).

According to previous published data, here we can also confirm that shunt surgery undertaken by young residents does not harbor an increased rate of complications compared with experienced surgeons.[23] The only predicting factor for early revision surgery was the atypical surgical approach, namely the placement of the ventricular catheter within the occipital horn or the fourth ventricle. In our patient cohort, 5 patients had to undergo revision surgery after insertion of ventricular catheter in atypical position, whereas 7 patients remained stable and the postoperative CT scan of the head revealed a correct position of the ventricular catheter.

The rationale for evaluating the necessity of radiographic procedures is to reduce radiation exposure. This might be either achieved by performing low-dose CT scans or by reevaluation the indication for postoperative imaging.

Excluding 5 patients with a noncommon surgical approach for catheter placement and another 2 patients with newly developed postoperative neurologic deficits in whom a radiographic imaging was performed independently from surgical procedure, only 4 patients (0.8%) in these series were detected with an undesirable finding. As a conclusion, patients with a new neurologic deficit, rarely applied surgical techniques, and in cases of suspicious malposition should undergo postoperative CT scans of the head.

The findings of our cost analysis suggest that the use of routine postoperative head CT scans after VP shunt implantation may contribute to a substantial proportion of the hospital budget. The result of the present study revealed that, in our investigated population, 468 CT scans with normal finding were performed and $561,600 ($66,924 at our institution) was spent. Despite enormous cost differences between Europe and United States for a standard head CT ($1200 vs. $143), the potential benefit for the hospital budget and health systems is emphasized in this study. And even neglecting the potential cost of not identifying misplaced shunts, which are much lower, the main aspect, namely the patient safety, is a main argument to reconsidering the practice of postoperative head CT scans.

CONCLUSIONS

Routine CT scans of the head after VP shunting in an uncomplicated frontal approach in asymptomatic patients are not justified. Excluding longer hospital stay and the cost for revision surgery, more than $0.5 million could be spared in our investigated population when routine CT scans of the head after surgery are omitted.

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Conflict of interest statement: The authors declare that the article content was composed in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received 11 April 2018; accepted 11 September 2018

Citation: World Neurosurg. (2019) 121:e159-e164.
https://doi.org/10.1016/j.wneu.2018.09.063

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***