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Technical Note

A novel technique for ventriculoperitoneal shunting by flat panel detector CT-guided real-time fluoroscopy

Shinya Kobayashi, Tatsuya Ishikawa, Tatsushi Mutoh, Kentaro Hikichi, Akifumi Suzuki

Department of Surgical Neurology, Research Institute for Brain and Blood Vessels-AKITA, Akita, Japan

E-mail: *Shinya Kobayashi – kobayashi@akita-noken.jp; Tatsuya Ishikawa - teddyish@akita-noken.jp; Tatsushi Mutoh - tmutoh@tiara.ocn.ne.jp; Kentaro Hikichi - sazabi@akita-noken.jp; Akifumi Suzuki - akifumi@akita-noken.jp
*Corresponding author

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Abstract

Background: Surgical placement of a ventriculoperitoneal shunt (VPS) is the main strategy to manage hydrocephalus. However, the failure rate associated with placement of ventricular catheters remains high.

Methods: A hybrid operating room, equipped with a flat-panel detector digital subtraction angiography system containing C-arm cone-beam computed tomography (CB-CT) imaging, has recently been developed and utilized to assist neurosurgical procedures. We have developed a novel technique using intraoperative fluoroscopy and a C-arm CB-CT system to facilitate accurate placement of a VPS.

Results: Using this novel technique, 39 consecutive ventricular catheters were placed accurately, and no ventricular catheter failures were experienced during the follow-up period. Only two patients experienced obstruction of the VPS, both of which occurred in the extracranial portion of the shunt system.

Conclusion: Surgical placement of a VPS assisted by flat panel detector CT-guided real-time fluoroscopy enabled accurate placement of ventricular catheters and was associated with a decreased need for shunt revision.

Key Words: Cone-beam computed tomography, hydrocephalus, shunt failure, ventriculoperitoneal shunt

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INTRODUCTION

Surgical placement of a ventriculoperitoneal shunt (VPS) is the main strategy to manage hydrocephalus. However, the failure rate associated with placement of ventricular catheters remains high. Ventricular catheter placement traditionally involves the identification of external landmarks to determine the catheter entry point and a blind pass via typical trajectories, with the hope that the placement of the catheter is adequate. However, the failure rate of ventricular catheter systems remains as high as 30–40% in the first year,[3,7] leading to a high incidence of shunt removal or revision.[9] Those failures are most commonly related to the proximal occlusion of the shunt catheters.[6,13]

The advantage of the posterior approach for VPS placement is the ease of tunneling via a straight path down to the abdomen.[3,10] In contrast, the frontal approach requires an additional curved path with a separate incision. However, optimal ventricular cannulation from the posterior perspective is more challenging when compared with anterior placement,[11] and the choroid plexus often obstructs the holes located at the tip of the ventricular catheter, especially when the catheter is inserted through the posterior approach. Thus, to prevent potential obstruction by the choroid plexus, the tip of the catheter should not be in proximity to the choroid plexus. In recent years, the use of endoscopic[8,14] and navigation[1,5] assistance has increased the ability to more precisely place shunts, although each of these techniques has its own advantages and disadvantages.

The use of a hybrid operating room (OR) equipped with radiological examination modalities can facilitate neurosurgical procedures. For example, such systems have enabled intraoperative evaluation with two-/three-dimensional (2D/3D) angiography, fluoroscopic imaging, and soft-tissue cross-sectional imaging,[12] thereby improving the efficacy and safety of surgical procedures.

Our institution has utilized C-arm-based real-time fluoroscopy and cone-beam computed tomography (CB-CT) in an effort to facilitate a safer and more accurate ventricular catheter placement. This study describes our 3-year experience using this new technique for VPS surgery.

MATERIALS AND METHODS

Patient population

Thirty-nine patients (11 male and 28 female; age range, 44–80 years; mean age, 65.3 years) who underwent VPS surgery with the new technique between June 2008 and May 2011 were enrolled. VPS surgery was performed for 36 patients with normal pressure hydrocephalus after subarachnoid hemorrhage, for one patient with idiopathic normal pressure hydrocephalus, and for two patients with obstructive hydrocephalus (in one patient after surgery for angioblastoma and another patient after intracerebral hemorrhage; Table 1).

As a comparison, we analyzed 37 patients (13 male and 24 female; age range, 21–83 years; mean age, 64.4 years) who underwent VPS surgery via conventional methods using the standard external landmarks[2,4] between January 2002 and May 2008 [Table 2].

The surgical outcomes and the rate of complications were compared between the two patient groups.

Novel surgical technique

Our hybrid OR has a newly designed, multipurpose radiolucent surgical table with a special radiolucent head clamp system and a digital subtraction angiography (DSA) system with a biplane C-arm. For image viewing, there are seven flat-display monitors equipped for biplane angiographic imaging and 3D imaging. During surgery, the monitor can be easily repositioned to assist visualization. In addition to the apparatus for conventional 2D and 3D DSA, a newly developed C-arm CB-CT imaging system (Dyna CT, Siemens, Germany) has been installed. This advanced device provides bone and soft-tissue images. The high-resolution 3D image data set was reconstructed using the OR 3D Workstation.[12] For 3D image acquisition, the anteroposterior C-arm moved continuously over 220° in 20 seconds.

Surgery was performed with patients under general anesthesia. Patients were placed in this supine position with his/her head rotated to the contralateral side, and the neck was extended with a roll placed under the shoulder. A carbon head clamp adapter and a carbon Mayfield head clamp were used. To reduce artifacts made when C-arm CB-CT imaging was performed, the position of the head pins and the spring of the Mayfield head clamp were kept as far as possible from the expected planes for ventricular catheter placement.

First, copper markers were placed on the glabella and on the conventional entry point of the posterior approach (6 cm above and 3 cm lateral to the inion) as external landmarks, and C-arm CB-CT imaging was performed to provide reconstructed axial, sagittal, and coronal images. The actual point for burr hole, the direction for catheter insertion, and the depth of the catheter was determined based on these images [Figure 1a]. External copper markers placed on the glabella and the conventional entry point were detected with CB-CT to allow correction of the true external landmark relative to the external copper maker based on visual inspection [Figure 1b].

Next, the surgical field was disinfected and draped, and a burr hole was made in the appropriate position. Under fluoroscopic imaging, the ventricle was punctured along the planned trajectory until the tip of the ventricular catheter reached the target position in the anterior horn. Visual corrections regarding the direction of the puncture and catheter insertion were made using a virtual plane constructed by the points of puncture and target as well as the plane parallel to the flat-panel detector [Figure 2]. To prevent obstruction by the choroid plexus, the tip of the catheter was placed 2 cm deep from the foramen of Monro, as the ventricular catheter employed in this procedure had side holes within 1.8 cm from the tip.

Finally, C-arm CB-CT imaging was performed to confirm that the ventricular catheter was situated in an appropriate position [Figure 3]. If necessary, fine adjustment was made under a fluoroscope. Then, all shunt tubes were connected together, and the peritoneal catheter was placed in the abdominal cavity; its positioning was also confirmed using fluoroscopy.

RESULTS

Among the 37 patients undergoing the conventional VPS technique, 11 (29.7%) ventricular catheters were

Table 1: Clinical summary of this novel ventriculoperioneal shunting

Patient No.	Age years	Sex	Indication	Follow-up months	Misplacement of shunt	Malfunction/revision
1	70	F	SAH	1	None	None
2	65	F	SAH	48	None	None
3	71	F	SAH	2	None	None
4	63	M	HBM	42	None	None
5	65	F	ICH	1	None	None
6	59	M	SAH	36	None	None
7	66	M	SAH	40	None	None
8	66	F	SAH	1	None	Distal obstruction and revision
9	80	F	SAH	2	None	None
10	70	F	SAH	31	None	None
11	72	F	SAH	36	None	None
12	68	F	SAH	1	None	None
13	52	F	SAH	21	None	None
14	48	F	SAH	1	None	None
15	70	F	SAH	1	None	None
16	77	F	SAH	2	None	None
17	78	F	SAH	21	None	None
18	63	M	SAH	25	None	None
19	74	F	SAH	15	None	None
20	62	M	SAH	4	None	None
21	69	M	SAH	14	None	None
22	75	F	AT	24	None	None
23	67	F	SAH	21	None	None
24	60	F	SAH	2	None	None
25	79	F	SAH	15	None	None
26	57	M	SAH	21	None	Valve obstruction
27	70	F	SAH	1	None	None
28	80	F	SAH	1	None	None
29	58	F	SAH	21	None	None
30	61	F	SAH	16	None	None
31	68	F	SAH	12	None	None
32	48	F	SAH	12	None	None
33	70	F	SAH	15	None	None
34	69	F	SAH	12	None	None
35	58	F	SAH	12	None	None
36	51	M	SAH	3	None	None
37	68	M	SAH	3	None	None
38	54	M	SAH	12	None	None
39	44	M	SAH	2	None	None

M: Male, F: Female, SAH: Subarachnoid hemorrhage, HBM: Hemangioblastoma, ICH: Intracerebral hemorrhage, AT: Acoustic tumor

placed inappropriately; 9 were placed in the contralateral anterior horn, 1 was placed in the ipsilateral inferior horn, and 1 was placed in the prepontine cistern. In the follow-up period described (mean 28 months, median 12 months, range 1–81months), four (10.9%) revision surgeries have been necessary; two ventricular catheters required revision because of misplacement or proximal obstruction, one peritoneal catheter was revised because of distal obstruction; and one entire shunt system was removed because of infection [Table 2].

Using the new technique, all 39 consecutive ventricular catheters were placed accurately, with the tip of each catheter placed at the target point in the ipsilateral anterior horn. We have not experienced any ventricular catheter failures during the follow-up period (mean 14 months, median 12 months, range 1–48 months). Two (5.1%) patients developed shunt obstruction in the extracranial portion of the shunt system; one required revision of the peritoneal catheter, and the other required reconnection of the shunt valve to the peritoneal catheter [Table 1].

Table 2. Clinical summary of conventional ventriculoperioneal shunting

Patient No.	Age years	Sex	Indication	Follow-up months	Misplacement of shunt	Malfunction/revision
1	71	F	SAH	2	None	None
2	57	M	ICH	1	Contralateral LV	None
3	56	M	ICH	1	Contralateral LV	None
4	70	F	AT	84	None	None
5	73	F	SAH	2	None	None
6	69	F	SAH	2	None	Infection and revision
7	71	M	SAH	81	None	None
8	74	F	iNPH	34	Contralateral LV	None
9	61	M	AT	3	None	None
10	60	M	SAH	57	Contralateral LV	None
11	68	F	SAH	1	Inferior horn of LV	None
12	71	M	iNPH	18	None	None
13	68	M	iNPH	4	Contralateral LV	None
14	47	M	SAH	12	None	None
15	21	F	AVM	1	None	None
16	46	F	SAH	61	Contralateral LV	None
17	68	F	SAH	1	None	None
18	52	M	SAH	1	None	None
19	72	F	AT	69	None	None
20	75	F	SAH	72	None	None
21	83	F	Meningioma	1	None	Distal obstruction and revision
22	52	M	SAH	22	None	None
23	64	F	iNPH	59	None	None
24	70	F	SAH	72	None	None
25	75	F	SAH	1	None	None
26	58	F	AT	72	None	None
27	72	F	SAH	1	Contralateral LV	None
28	56	F	SAH	48	Contralateral LV	None
29	80	M	AT	1	None	None
30	54	M	SAH	64	Prepontine cistern	Proximal revision
31	78	F	SAH	1	None	None
32	80	F	SAH	5	Contralateral LV	Proximal obstruction and revision
33	34	M	ICH	1	None	None
34	64	F	SAH	44	None	None
35	77	F	SAH	48	None	None
36	55	F	AT	48	None	None
37	79	F	SAH	37	None	None

M: Male, F: Female, SAH: Subarachnoid hemorrhage, ICH: Intracerebral hemorrhage, AT: Acoustic tumor, iNPH: idiopathic normal pressure hydrocephalus, AVM: Cerebral arteriovenous malformation, LV: Lateral ventricle

Representative case

A 57-year-old woman developed normal pressure hydrocephalus after subarachnoid hemorrhage. She underwent VPS surgery, in which the ventricular catheter was inserted through the right occipital region using the technique described. The tip of the ventricular catheter was placed at the exact target in the anterior horn, and the VPS system has worked well [Figure 4].

DISCUSSION

The complication rate of VPS surgery ranges from 30% to 40%,[3,7] with shunt infection and malfunction of the ventricular catheter among the most frequent types of major complications.[6,13] Blind insertion of ventricular catheter using an external landmark as a reference is associated with suboptimal positioning and an increased risk of complications. Indeed, as many as 29.7% of our patients undergoing conventional VPS placement experienced inappropriate positioning of the ventricular catheter, and two of these patients required repeat surgery for shunt revision.

Endoscopic- and navigation-assisted shunt techniques have been used to facilitate more accurate shunt placement. Villavicencio *et al.*[14] compared the revision rates of VPS systems in endoscopically and nonendoscopically placed ventricular shunt catheters and concluded that proximal failure was less likely with optimally placed catheters. In contrast, the endoscopic shunt insertion trial reported that the shunt failure rate were not significantly different when comparing

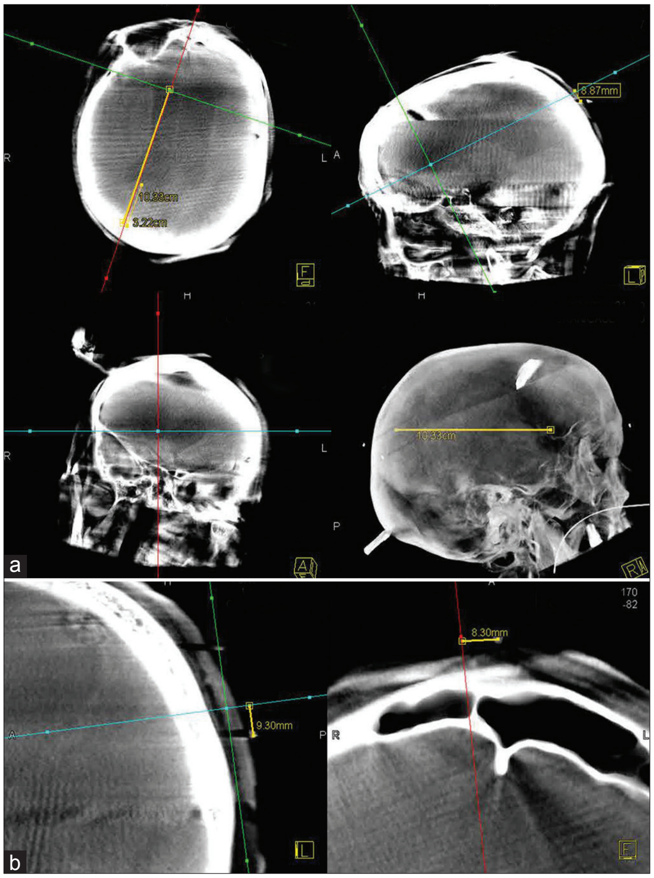

Figure 1: (a) Planning CB-CT produces three-dimensional surgical planes (axial, coronal, and sagittal) and a three-dimensionally reconstructed image, which helps determining the site of the burr hole and the direction and depth for catheter insertion. (b) External copper markers placed on the glabella and the conventional entry point can be detected with planning CB-CT to allow correction of the true external landmark relative to the external copper maker based on visual inspection

the endoscopic and control groups at 1 year after the surgery.[8] In the latter study, placement of the tip of the ventricular catheter away from the choroid plexus did not differ significantly between groups. Moreover, even in the endoscopic shunt insertion technique, the position of the burr hole and the catheter trajectory were based on anatomical landmarks. As a result, inappropriate trajectory of catheter may have affected the final ventricular catheter position.

In terms of navigation-assisted techniques, Azeem *et al.*[1] investigated 34 ventricular catheters that were placed using the Medtronic electromagnetic frameless neuronavigation system and suggested that this method was helpful for accurate insertion of ventricular catheters. Another multicenter prospective cohort study that compared navigated shunt placement with standard blind shunt placement concluded that electromagnetic-navigated shunt placement reduced shunt misplacement, resulting in a significant decrease in the early shunt revision rate.[5] However, this technology cannot generate real-time information to detect any collapse of the ventricles with the loss of cerebrospinal fluid. Moreover, this tool cannot show the position of the tip of the ventricular catheter intraoperatively.

The present study demonstrated that accurate catheter placement was associated with a decrease in the incidence of proximal shunt failure, although this study had a relatively short follow-up period. This study also demonstrated that VPS placement under flat panel detector CT-guided real-time fluoroscopy enabled accurate catheter placement. In addition, this technique makes it possible to reveal and arrange the position of the ventricular catheter intraoperatively. The patient receives some amount of irradiation through CB-CT, but the amount of radiation associated with CB-CT for VPS surgery is similar to that associated with a single CT scan, which is within the safe range for adult patients. Artifacts from pins and coils in the Mayfield head clamp can compromise the quality of the CB-CT image; thus, modifications of the materials may be necessary to improve the diagnostic value of this modality.

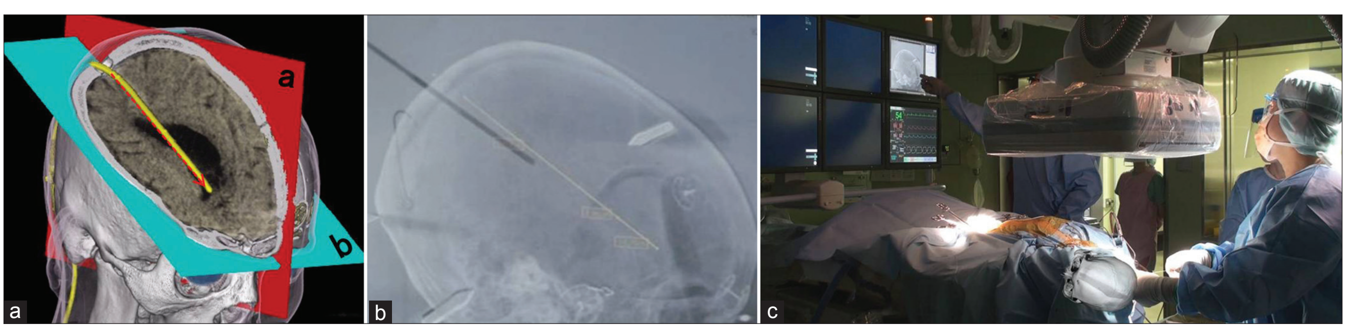

Figure 2: (a) Virtually constructed planes (a and b) cover the points of puncture and the expected final position of the catheter tip. Plane (a) is consistent with the fluoroscopic image. Plane (b) is vertical to plane. (a) The intersection of the planes indicates the appropriate direction for catheter insertion (arrow). (b) Fluoroscopic image during catheter insertion. Accurate direction and depth for catheter insertion (yellow line) is overlaid on the fluoroscopic image. (c) Intraoperative image. The operator punctures the ventricle, referring to the fluoroscopic guidance

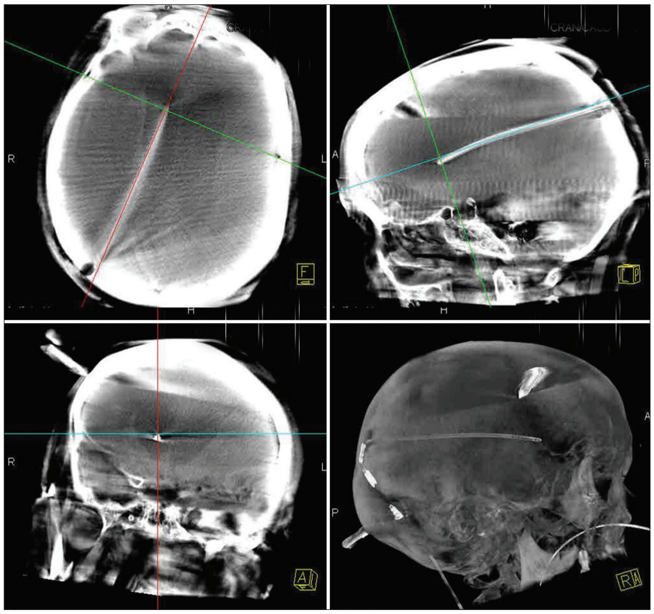

Figure 3: Reconstructed CB-CT images after the catheter insertion. These images allowing confirmation of ventricular catheter positioning. The catheter is inserted along the planned trajectory (red, blue, and green lines), and the tip reaches the target point

CONCLUSIONS

The present study demonstrated the utility of flat panel detector CT-guided real-time fluoroscopy for accurate placement of ventricular catheters during VPS surgery. Accurate shunt placement with this novel technique may help reduce the early shunt revision rate.

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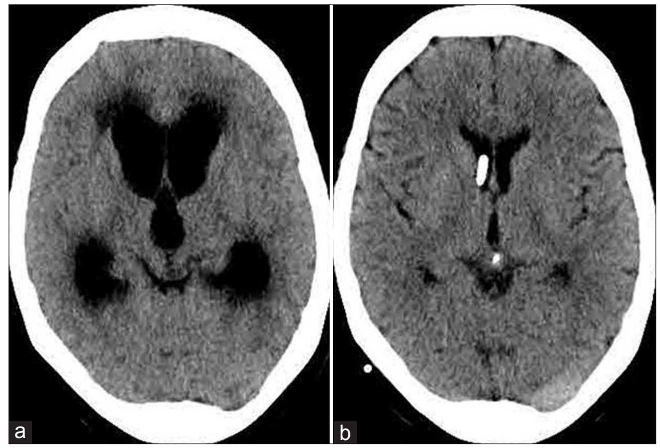

Figure 4: (a) CT scan of a 57-year-old woman who developed normal pressure hydrocephalus after subarachnoid hemorrhage is shown. The ventricles are enlarged and are associated with periventricular lucency. (b) CT after surgery. The tip of the ventricular catheter was placed at the exact target in the anterior horn, and ventricle size returned to normal

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