



Hybrid Surgery for Pediatric Neurosurgery: Preliminary Experiences of a Single Center

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Background: The real-time image-guided system can aid us in localization for complex neurological diseases. **Aim:** The study aimed to survey the advantages and novel techniques of hybrid surgery in pediatric neurosurgery. **Methods:** Study design involves a retrospective cohort study. At our hybrid operation room (OR), 10 children at the ages from 16 months to 17 years underwent brain or spine surgery. Eight of them received procedures assisted with real-time images of flat-panel detector (FD)-based computed tomography, DynaCT: three patients underwent cerebrospinal fluid diversions, three frameless stereotactic aspirations (brain abscess 2, intracerebral hemorrhage 1), one frameless stereotactic skull and sinus biopsy, and one spine and neck surgery. Two of them received intraoperative digital subtraction angiography and three-dimensional rotational angiography (3D-RA) for arteriovenous malformation surgery. **Results:** All of our patients tolerated the whole procedures well. Frameless stereotactic aspiration with navigation was performed for one patient with brain abscess first, but the abscess progressed with mass effect later. The child underwent frameless stereotactic aspirations at the hybrid OR and recovered well within 2 weeks. One patient having neck and high cervical spinal lipoblastoma with the presentation of stridor received surgeries twice before. The patient was quite well without airway compression after tumor resection as maximal as possible with safety at the hybrid OR. **Conclusions:** For the treatment of complex neurological diseases in children, hybrid surgeries can be considered to be feasible, good alternative, or salvage surgical procedures.

Key words: Hybrid, three-dimensional, stereotactic, aspiration, rotational angiography

INTRODUCTION

Neuronavigation systems (NNS) with the real-time images benefits in the localization of lesions such as tumors and vascular lesions.¹ Hybrid operative suites with intraoperative computed tomography (CT) or magnetic resonance imaging (MRI) and biplane angiography lead to the improvement of the access to these imaging modalities and intraoperative assessment.² Intraoperative three-dimensional (3D) images guidance during cerebrovascular surgery with accuracy can be provided in hybrid operating suites equipped with flat-panel detector (FD) CT, 3D rotational angiography (3D-RA) facilities. To the best

of our knowledge, this is the first retrospective study about the hybrid techniques for pediatric neurosurgery.

METHODS

From March 2013 to September 2016, 10 children received surgeries at our hybrid OR equipped with a robotic angiographic fluoroscopy system, the Artis Zeego FD system (Siemens AG, Forchheim, Germany) in Taichung Veterans General Hospital [Table 1]. Artis Zeego FD system is a C-arm-mounted cone-beam CT system utilizing high-spatial resolution digital

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Table 1: Summary of the patient information and surgeries

Patient	Age at surgery at hybrid room (years)	Gender	Diagnosis	Surgery	Order of surgery at hybrid room	Mode of Artis Zeego FD system	Follow-up after hybrid surgery (months)
1	1.33	Male	Ependymoma in the third ventricle with obstructive hydrocephalus	VP shunt placement	Second	FD-CT	11
2	8	Female	Brain abscess left frontal	Stereotactic aspiration	Second	FD-CT	54
3	8	Male	Ganglioneuroma, left anterior and middle skull base	VP shunt placement	Second	FD-CT	48
4	17	Female	Encephalitis and status epilepticus	Stereotactic external ventricular drainage as ICP monitor	First	FD-CT	38
5	11	Male	Brain abscess, right occipital region	Stereotactic aspiration	First	FD-CT	0.03, died of congenital heart disease
6	3.5	Female	Lipoblastoma, C2-4 levels, and left neck tumor	Left lateral retropharyngeal and transoral approaches with the removal of tumor	Third	FD-CT	34
7	9	Male	Right sphenoid ridge lesion and AML	Stereotactic biopsy	First	FD-CT	42
8	2.25	Male	AVM rupture with ICH and right frontoparietal region	Craniotomy	Second	3D-RA	39
9	5	Female	Spontaneous ICH and left temporal region	Stereotactic aspiration	First	3D-RA	23
10	10	Male	AVM rupture and ICH, right temporal region	Craniotomy	First	3D-RA	31

AVM=Arteriovenous malformation; ICH=Intracerebral hemorrhage; VP=Ventriculoperitoneal; ICP=Intracranial pressure; FD=Flat-panel detector; CT=Computed tomography; AML=Acute myeloid leukemia; 3D-RA=Three-dimensional rotational angiography

FD, which is capable of providing projection radiography, fluoroscopy, digital subtraction angiography (DSA), and volumetric CT in a stationary patient within a single compact suite. There were six boys and four girls, and their ages at surgery ranged from 16 months to 17 years, with a mean age of 6.3 ± 3.7 years. Eight of them received procedures with real-time images of DynaCT: three patients underwent cerebrospinal fluid diversions, three frameless stereotactic aspirations (brain abscess 2, intracerebral hemorrhage [ICH] 1), one frameless stereotactic skull and sinus biopsy, and one spine and neck surgery. Two of them with arteriovenous malformation (AVM) received intraoperative 3D DSA and 3D-RA. This retrospective cohort study was performed under the guidelines of the Helsinki Declaration and approved by the Institutional Review Board of Taichung Veterans General Hospital, Taichung, Taiwan (IRB TCVGH No. CEA17182A-1).

RESULTS

All patients tolerated the whole procedures well. Five children received the procedure in the hybrid room for the first surgery. Four children underwent the procedure for the

second surgery, one for the third one, and some of them took advantage of the Artis Zeego FD system compared with previously conventional surgery such as Case 2 and 6.

Case 2

An 8-year-old girl had brain this study was conducted in accordance with the Declaration of Helsinki. The study was approved by the Institutional Review Board (IRB) of Taichung Veterans General Hospital (IRB: CE17182A-1) abscess in the left frontal lobe with the presentations of headaches, dizziness, drowsy, and right hemiparesis [Figure 1a and b]. She received frameless stereotactic aspiration with neuronavigation first. Her symptoms and signs got improved and her consciousness became clear within 1 week. However, the symptoms and signs recurred, and the abscess progressed 2 weeks after the first surgery [Figure 1c]. The patient received the other frameless stereotactic aspirations at our hybrid OR, and the ideal target of aspiration catheter was confirmed with real-time 2D images of DynaCT [Figure 1d and e]. Pathological examination showed necrotic debris and acute and chronic inflammation. The patient recovered well in 2 weeks. The total course of antibiotics was 8 weeks. She was well at the follow-up time of 4 months [Figure 1f], 3 years, and 8 months after the second surgery.

Case 6

A 3-year and 6-month-old girl had neck and high cervical spinal lipoblastoma with the presentations of the enlarged left side of the neck and stridor. She underwent surgeries twice before. Because the tumor extended from the skull base to the left epidural space of C5 level and encased the vital structures [Figure 2a], it was really tough to be resected totally without morbidity. The patient received staged anterior approach for tumor resection as maximal as possible with safety at the hybrid OR at the third surgery. The airway was

compressed by the huge tumor, and the resection extent was checked with real-time 2D images of DynaCT [Figure 2b]. The airway was decompressed after tumor debulking (black arrow), and the air near the tumor was visible, which meant the change after resection [Figure 2c]. We also used the hybrid OR to provide a rescue backup if intraoperative transarterial embolization is necessary immediately for massive bleeding during excision. She had symmetric both sides of the neck and no stridor postoperative and was still quite good 6 months after the third surgery [Figure 2d].

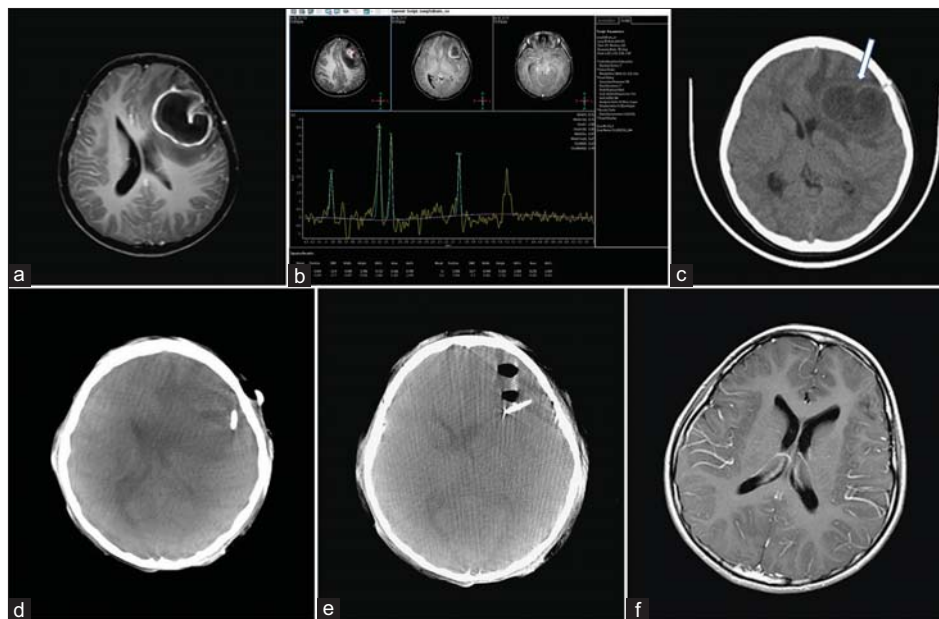


Figure 1: Neuroradiological imaging of case 2 (a) axial contrast-enhanced T1-weighted magnetic resonance imaging demonstrating one regular thin-walled ring-enhanced lesion in the left frontal region. (b) Magnetic resonance spectroscopy showing mild elevated Cho/Cr and mild decreased N-acetylaspartate/Cr. (c) Computed tomography demonstrating brain abscess progressed (white arrow) 2 weeks after the first surgery. Intraoperative real-time two-dimensional images of DynaCT disclosing our stereotactic aspiration catheter was not in the center of the abscess. (d) Thereafter, the catheter was adjusted to the ideal position in the center of the abscess. (e) Magnetic resonance imaging showing resolved brain abscess. (f) Four months after the surgery with the Artis Zeego flat-panel detector system



Figure 2: Neuroradiological imaging of case 6 (a) sagittal T2-weighted magnetic resonance imaging disclosing one huge high signal mass in the deep neck and high cervical spine. (b) Real-time two-dimensional images of DynaCT showing the huge tumor with low-density compressed the airway (black arrow). (c) It revealing less airway compression after tumor debulking shown in the smaller extent of low density (black arrow), and the air bubbles near the tumor were also visible after resection. (d) Six months after the third surgery and sagittal T2-weighted magnetic resonance imaging demonstrating one residual tumor with uneventful clinical conditions

Case 1

A 16-month-old boy had ependymoma in the third ventricle and obstructive hydrocephalus with the presentations of drowsiness and enlarged head [Figure 3a]. He underwent ventriculoperitoneal shunt at the hybrid OR after hypervascular tumor debulking with easy bleeding. The optimal position of the ventricular catheter was confirmed with real-time 2D images of DynaCT [Figure 3b and c] to prevent its impeding and bleeding from the residual, hypervascular tumor.

Case 10

A 10-year-old boy had seizure and conscious change, and AVM rupture with ICH in the right temporal lobe was diagnosed at a local hospital. He was transferred to our hospital. Preoperative DSA aided us to identify the feeding artery and drainage vein. Intraoperative 3D-RA was applied to design the extent of craniotomy [Figure 4a]. The residual AVM was checked and localized with 3D roadmap [Figure 4b]. The total excision of AVM was confirmed [Figure 4c]. The boy recovered very soon.

DISCUSSION

Fusion of the images from intraoperative 3D fluoroscopy and those from the preoperative MRI has been applied for stereotactic functional neurosurgery in subthalamic nucleus deep brain stimulation (STN DBS) for Parkinson's disease.³ Without specific morbidities related to their procedures, their results are comparable to those in the literature in the improvement of Unified Parkinson's Disease Rating Scale scores. The decreased rate of complications may come from the significant decrease in duration of surgery. For cerebrovascular diseases, our institute illustrated the novel technical details and benefits of hybrid surgery for recanalization of symptomatic chronic total occlusion of the internal carotid artery, and the efficacy of the neurosurgical hybrid operating suite for the tough dural arteriovenous fistula (AVF).^{4,5} Intraoperative 3D image guidance during cerebrovascular surgery with marvelous accuracy even without the demand for preoperative angiography can be provided by hybrid operating suites equipped with FD-CT, 3D-RA, and NNS capabilities.¹ Because the fiducial markers move at intervals or the positions of patients change,

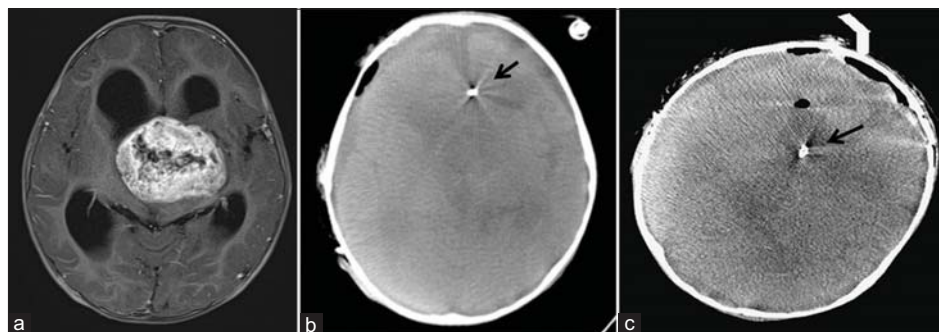


Figure 3: Neuroradiological imaging of cases 1 (a) axial contrast-enhanced T1-weighted magnetic resonance imaging demonstrating one well-enhanced tumor in the third ventricle, which resulted in obstructive hydrocephalus. (b) Real-time two-dimensional images of DynaCT showing the wrong position (black arrow) of the ventricular catheter. (c) Two-dimensional images of DynaCT showing the optimal position (black arrow) of the ventricular catheter after insertion again under the guidance the Artis Zeego flat-panel detector system



Figure 4: Neuroradiological imaging of case 10 (a) before scalp incision, intraoperative three-dimensional-rotational angiography disclosing one arteriovenous malformation nidus (white arrowhead) and its feeding artery and drainage vein which aided us in localization, precise and smaller craniotomy design. (b) Three-dimensional roadmap showing the residual nidus. One aneurysm clip (white arrowhead) was placed to realize the orientation of the residual nidus. (c) Three-dimensional-rotational angiography revealing the completion of arteriovenous malformation resection (white arrowhead)

the accuracy of image registration in NNS is often reduced with the preoperative image data. After the operative patients are positioned, the errors can be minimized to the degree observed with intraoperative CT and intraoperative MRI auto-registration by real-time FD-CT images for registration.

It is extremely important for children to minimize the radiation dose by reason of the relatively increased lifetime cancer risk as compared with adults.⁶ Because of the less total radiation exposure from a single rotational run than from CT or a conventional angiography examination that involving more than one view, 3D-RA benefits pediatric patients with complex intracranial lesions in the evaluation and decisions of the modest treatment strategies.⁷ The whole loading of contrast declines compared with CT or conventional angiography. In larger series, in 100 studies of 93 patients with the age ranged from 0 to 88 years, DynaCT was practiced successfully for cerebrovascular diseases, intracranial lesions, or spinal disease.⁸ DynaCT is a potentially powerful tool for neurosurgical and endovascular procedures. In a series of 78 pediatric patients with congenital heart diseases, 3D-image fusion with live fluoroscopy, including 3D-RA, can be successfully in catheter-based interventions.⁹ DynaCT and 3D-RA are also very useful tools in the diagnosis and invention for pediatric cardiology.^{10,11}

For a 2½-year-old boy with vein occlusion, the ventriculoatrial shunt was implanted under the guidance of fluoroscopy of a 3D single plane angiography machine.¹² FD-CT is able to aids in the investigation for congenital heart disease for most of the pediatric patients.¹³ The hybrid technique can be utilized for very complicated pediatric cases. Brain abscesses led to a high mortality rate in the pre-CT scanning era; nevertheless, after the CT scanning in the 1970s, the rate declined dramatically.¹⁴ Because of early detection, localization, and guidance for surgery, CT techniques improved the management of brain abscesses in many aspects. Aspiration may be the first choice in patients with supratentorial brain abscesses in this review of 78 years from 1930 to 2008. After 1990, the mean mortality for aspiration was 6.6%, and for surgical excision by craniotomy was 12.7%. Cranial imaging, neurosurgical technique, and antimicrobial regimen ameliorated the prognosis of patients with brain abscesses over the past 60 years.¹⁵ The advances in cranial imaging promote the less invasive and more exact neurosurgical procedures such as stereotactic aspiration of abscesses. In the series of brain abscesses in children, 70% of them underwent drainage through a burr hole without the need for craniotomy.¹⁶ In our patients, Case 2, the brain abscess was aspirated inadequately with conventional NNS and it progressed. Hence, she received the frameless stereotactic aspiration at the hybrid OR for the second surgery. The real-time images of DynaCT assisted us

to get the ideal target for stereotactic aspiration and further drainage. The patient got improvement after complete treatment with antibiotics.

Our Case 6 had huge lipoblastoma compressing the airway and vital blood vessels for head and neck, and complete resection without complications was not easy to be achieved. Radical resection of lipoblastoma is the gold standard, but it is not always easy to do it.¹⁷ On the basis of the benign nature of lipoblastoma, potential maturation to normal fat, management of the residual tumor can be conservative. She received surgeries for two times and had good respiration without stridor at the intervals of these surgeries. She underwent staged anterior approach for tumor resection as maximal as possible with safety under the guidance of DynaCT at the hybrid OR at the third surgery. Therefore, she had symmetric both sides of the neck and no stridor. Hybrid surgery may be the salvage procedure.

In conventional facilities, postoperatively, DSA after AVM surgery is usually on different days. Complete AVM resection is not always practical, and hence, second surgery or other modalities of treatment are necessary possibly. The accuracy of the NNS can be improved significantly with the use of 3D-RA images intraoperatively.¹ For the confirmation of treatment completion in cerebrovascular diseases, intraoperative DSA and 3D-RA are effective. Routine intraoperative angiography was proved to be the most cost-effective form of completion angiography after aneurysm clipping, and routine postoperative angiography was the least cost-effective.¹⁸ The number of subsequent surgery for residual AVM nidus or AVF, separate preoperative angiograms can be reduced in the hybrid cerebrovascular operative suite.¹⁹ As our case 10, incomplete resection of AVM was found with intraoperative DSA and 3D-RA, and then, complete treatment was verified with further DSA and 3D-RA. Subsequent surgery for residual AVM nidus can be avoided with intraoperative DSA and 3D-RA at the hybrid OR.

CONCLUSIONS

In cerebrovascular diseases, brain abscess, brain tumor, and neck tumor, hybrid surgery with real-time intraoperative images may provide precise and benefits for the complete or adequate treatments. Our pediatric patients took advantage of FD-CT or 3D-RA in their surgical treatments at our hybrid OR. For the treatment of complex neurological diseases in children, the hybrid surgeries can be considered to be feasible, good alternative or salvage surgical procedures.

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Conflicts of interest

There are no conflicts of interest.

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