Usefulness of Three-dimensional Stereoscopic Images for Cerebral Endovascular Treatment

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Purpose: Reconstructed three-dimensional (3-D) images are essential for cerebral endovascular treatment. Conventional reconstructed 3-D images are no more than planar images projected onto a monitor. In this study, we prepared 3-D stereoscopic images before cerebral endovascular treatment, and conducted preoperative simulation to examine their usefulness (the subjects were six cases with cerebral aneurysms and eight with arteriovenous shunts).

Case Presentations: Case 6: The patient was a 60-year-old male with an unruptured paraclinoid aneurysm. Case 8: The patient was a 64-year-old male with a spinal dural arteriovenous fistula. To prepare 3-D stereoscopic images, 3-D stereoscopic image-converting Work Station/a 3-D monitor was used. The first surgeon performed a preoperative simulation using 3-D stereoscopic images. Subsequently, usual cerebral endovascular treatment was conducted, and the usefulness of 3-D stereoscopic images was evaluated with free comments after surgery.

Conclusion: The application of 3-D stereoscopic images for cerebral endovascular treatment was useful for recognition of spatial orientation. In particular, it was highly assessed in arteriovenous shunt disease patients with a complex vascular structure. Therefore, 3-D stereoscopic images may be appropriate for training for non-skilled specialists in cerebral endovascular treatment and student education.

Keywords ► 3-D rotational angiography, cerebral aneurysm, cerebral arteriovenous malformation, dural arteriovenous fistula

Introduction

Recently, three-dimensional (3-D) stereoscopic images have commonly been used for surgery. In particular, many studies reported their usefulness in the field of laparoscopic surgery.^{1–3)} Recently, 3-D stereoscopic images have also been used for a surgery-assisting robot, “da Vinci,” and adopted in many institutions in Japan.^{4–6)} Furthermore, 3-D stereoscopic images in combination with a surgery-assisting navigation system for neuroendoscopic surgery⁷⁾ or microscopic surgery were also introduced in the field of neurosurgery, and several studies indicated their usefulness.^{8–11)}

For cerebral endovascular treatment, 3-D rotational angiography (3-D RA) is essential as a diagnostic tool.

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However, 3-D reconstructed images made from 3-D RA (3-D images) are no more than planar images. In this study, we applied 3-D stereoscopic images for cerebral endovascular treatment, and examined their usefulness based on surgeons' evaluation.

Case Presentation

Materials and methods

The subjects consisted of 6 cases with cerebral aneurysms (unruptured: 5 cases, ruptured: 1 case) and 8 with arteriovenous shunts with a complex vascular structure (cerebral arteriovenous malformation (AVM): 2 cases, dural arteriovenous fistula (dAVF): 3 cases, and spinal AVF: 3 cases) (total: 14 cases) (**Table 1**). 3-D stereoscopic images were prepared using a surgery-assisting imaging system (Plissimo XV) developed by Panasonic Medical Solutions Co., Ltd. Concerning procedures to prepare 3-D stereoscopic images, the raw data obtained on 3-D RA before cerebral endovascular treatment are initially output to a CD-R in the DICOM (Digital Imaging and Communication in Medicine) mode, and open on the Plissimo XV system. 3-D stereoscopic images are completed in a few

Table 1 List of patients and comments of first surgeon

Case	Age	Sex	Diagnosis	Treatment	Operative experience of the first surgeon	Comments of first surgeon
1	62	M	Unruptured ICA anterior wall AN	Coil embolization using balloon assist technique	Over two decades	Not available
2	65	M	Spinal dAVF	TAE using 13% NBCA and coil embolization	Over two decades	Much improved spatial understanding of feeder
3	77	F	Unruptured ICA large AN	Coil embolization using double catheter technique	Over two decades	Not available
4	55	M	Spinal dAVF	TAE using 13% NBCA and coil embolization	Over two decades	Much improved spatial understanding of feeder
5	76	M	Transverse-sigmoid sinus dAVF	TVE using coil embolization and TAE using 13% NBCA	Over two decades	Spatially recognition of the depth of parasinus and the configuration of shunt point
6	60	M	ICA-paracilinoid AN	Coil embolization using balloon assist technique	2 years	Spatially easy recognition of tortuous carotid siphon
7	58	M	AVM (feeder aneurysm)	Coil embolization	Over two decades	Spatially easy recognition of complicate feeder structure
8	64	M	Spinal dAVF	TAE using 13% NBCA and coil embolization	Over two decades	Much improved spatial understanding of feeder
9	37	M	AVM	TAE using Onyx 18	Over two decades	Spatially easy recognition of complicate feeder structure
10	72	M	Transver-sigmoid sinus dAVF	TVE using coil embolization and TAE using 13% NBCA	Over two decades	Spatially recognition of the depth of parasinus and the configuration of shunt point
11	73	F	Transver-sigmoid sinus dAVF	TAE using coil embolization and 13% NBCA	Over two decades	Identification of shunt point
12	66	F	Unruptured IC-optthalmic AN	Stent assisted coil embolization using double catheter technique	2 years	Spatially easy recognition of tortuous carotid siphon and accurate micro catheter shaping
13	75	F	Ruptured BA-SCA AN	Coil embolization	Over two decades	Not available
14	69	F	Unruptured carotid cave AN	Coil embolization using balloon assist technique and double catheter technique	Over two decades	Not available

ICA: internal carotid artery; AN: aneurysm; dAVF: dural arteriovenous fistula; AVM: arteriovenous malformation; BA: basilar artery; SCA: superior cerebellar artery; TAE: transarterial embolization; TVE: transvenous embolization; NBCA: n-butyl 2-cyanoacrylate

Fig. 1 First surgeon runs a preoperative simulation on access to lesion and depth of lesion etc. using 3-D stereoscopic system.

seconds, and projected onto a 3-D stereoscopic image-matched liquid crystal display (LCD) monitor developed by Panasonic Medical Solutions Co., Ltd. The surgeon wore polarized glasses for 3-D images, and conducted preoperative simulation of an access to the lesion or the lesion depth using stereoscopic images while moving a mouse on the monitor (**Fig. 1**). Subsequently, usual treatment was started. After treatment, the first surgeon evaluated the therapeutic usefulness of preoperative simulation using 3-D stereoscopic images with free comments.

Results

In all 14 cases, 3-D stereoscopic images could be readily prepared using the Plissimo XV system. With respect to the usefulness of 3-D stereoscopic images for cerebral endovascular treatment, the surgeon indicated that these images were useful for recognition of spatial orientation involving the vascular structure in the deep direction and branches duplicated with working angle. Concretely, it was possible to get the picture as the torsion of a flexed vessel and the distance between two adjacent blood vessels, which may be missed on a planar image in the presence of AVM. In the presence of a dAVF at the transverse sinus, the depth of several parasinuses and shape of the junction were three-dimensionally visualized, and 3-D stereoscopic images were useful for determining an approaching angle and direction. In cerebral aneurysms, the usefulness of 3-D stereoscopic images in comparison with standard treatment was not demonstrated when the surgeon was a skilled instructor regarding cerebral endovascular treatment. This was possibly because the vascular structure of cerebral aneurysms was not complex, differing from that of shunt disease, facilitating 3-D structure imaging; the usefulness for skilled instructors was not demonstrated. However, when the surgeon was a non-skilled specialist in cerebral endovascular

treatment, the depth of an access route to the cerebral aneurysm (tortuous shape at the siphon region) and shaping of a microcatheter (MC) could be more accurately clarified. However, there was a time lag between manual operations on a mouse and stereoscopic image motions on a 3-D stereoscopic image-matched LCD monitor; some surgeons felt stressed.

Case 6

Patient: A 60-year-old male.

Present illness: He consulted a local clinic with dizziness. Head magnetic resonance imaging (MRI)/magnetic resonance angiography (MRA) revealed a left internal carotid artery aneurysm. He was referred to our hospital. In our department, cerebral angiography was performed. The maximum diameter of the aneurysm exceeded 5 mm. Based on the age/size and his wishes, coil embolization was selected. Treatment: The location was paraclinoid aneurysm (**Fig. 2A**), with a maximum diameter of 5.30 mm. The neck diameter was 3.95 mm, being relatively broad (dome/neck ratio: 1.35). Balloon-assisted coil embolization was selected for the following reasons: paraclinoid aneurysm, the distance from the siphon region was very short, making it difficult to insert a MC into the aneurysm (engagement); and an MC was expected to be unstable during coil embolization. Treatment was performed under general anesthesia. A 6 Fr guiding catheter (GC) was inserted into the left cervical internal carotid artery (C1 level). Subsequently, the raw data obtained on preoperative 3-D RA were output to a CD-R in the DICOM mode, and opened on the Plissimo XV system. 3-D stereoscopic images were completed in approximately 10s (**Fig. 2B**). After the surgeon (non-skilled specialist in cerebral endovascular treatment) freely operated them on a 3-D stereoscopic image-matched LCD monitor using a mouse for preoperative simulation, he conducted MC shaping and engagement. A total of five

Fig. 2 Case 6. (A) Pre-operative 3-D rotational angiography (left internal carotid angiogram, antero-posterior view). (B) Pre-operative 3-D stereoscopic angiography (left internal carotid angiogram, antero-posterior view).

coils were used, and final angiography confirmed complete obliteration of the aneurysm.

Evaluation: The depth of the siphon region was considered to be deeper than recognized on standard 3-D RA. For this reason, a MC three-dimensionally preshaped in accordance with 3-D RA findings was guided by converting the direction with a microguidewire. At this point, a MC was guided while visually evaluating or feeling wire resistance at the siphon region, but the depth of the siphon region was confirmed before surgery; therefore, engagement could be achieved without excessive wire operations while more sensitively feeling their resistance.

Case 8

Patient: A 64-year-old male.

Present illness: As weakness of the bilateral lower limbs and bladder and rectal disturbance had persisted for 4 months, he was admitted to the Department of Orthopedics in our hospital to undergo surgery for hernia of the intervertebral disk. Preoperative MRI of the lumbar vertebrae revealed a flow void and dilated abnormal blood vessel at the thoracolumbar vertebral level; therefore, he was referred to our department. Spinal angiography showed a spinal dAVF feeding by the intercostal artery at the seventh to eighth right thoracic vertebral level (**Fig. 3A**). Endovascular treatment was selected.

Treatment: As described for Case six, the raw data obtained on spinal angiography (3D-RA) before treatment were output to a CD-R in the DICOM mode, and developed on the Plissimo XV system. 3-D stereoscopic images were completed in approximately 10s (**Fig. 3B**). This patient had a

spinal dAVF. The drainer and feeder (T7, T8 radiculomedullary artery) were overlapped with individual stereoscopic images, respectively. After the surgeon (skilled instructor regarding cerebral endovascular treatment) conducted pre-operative simulation on a 3-D stereoscopic image-matched LCD monitor, he started treatment. Under general anesthesia, a GC was inserted into the right T7 intercostal artery using 6 Fr and 4 Fr coaxial systems. Subsequently, the surgeon attempted to insert a MC into the radiculomedullary artery as the feeder, but preoperative 3-D stereoscopic images showed a sharp branching angle from the intercostal artery; therefore, the post-vascular-branching intercostal artery (not feeder) was occluded by coil without excessive wire operations. Subsequently, n-butyl 2-cyanoacrylate (NBCA) was infused before the vascular branch, and the infusion of NBCA into only the feeder was possible. NBCA was also infused through the right T8 radiculomedullary artery. Final angiography confirmed the complete disappearance of the spinal dAVF.

Evaluation: The branching angle of the T7 radiculomedullary artery was sharp, which had been confirmed on 3-D images. However, the angle of the vascular branch on the feeder's side was sharp, with a horizontal hairpin turn; it was possible to accurately evaluate such 3-D information (**Fig. 3**). This facilitated the establishment of an appropriate therapeutic strategy without excessive wire operations.

Discussion

The history of stereoscopic images is long, and stereoscopic imaging with two films has commonly been conducted

Fig. 3 Case 8. (A) Pre-operative 3-D rotational angiography (right 7th intercostal angiogram, antero-posterior view). Arrow shows a hairpin curve of feeder on 3-D rotational angiography. (B) Pre-operative 3-D stereoscopic angiography (right 7th intercostal angiogram, antero-posterior view). Arrow head shows a hairpin curve of feeder on 3-D stereoscopic angiography.

since the beginning of the 20th century, when simple angiography became possible.^{12–14)} Furthermore, Saito et al. reported three-dimensional single-shot angiography in 1930. This procedure made it possible to obtain 3-D images through two sessions of single-shot imaging at different X-ray-tube angles, but required two sessions of contrast-medium infusion. To facilitate 3-D shooting on one session of serial angiography, it was necessary to transfer a single X-ray tube between two positions several times in a short period,^{15–17)} alternately use two X-ray tubes,^{18,19)} or adopt a single X-ray tube with 2 focal points (dual-focus X-ray tube).²⁰⁾ As there were limitations, such as resolution, a method to perform the same type of serial angiography twice by slightly changing a specific angle (convergent angle: 6 degrees to 12 degrees) using a single X-ray tube with one focal point (single-focus X-ray tube) was again commonly used. However, the limitation of two sessions of contrast-medium infusion was not resolved. As a routine method, 2-directional images at different angles were displayed, and a gaze point was regulated in proximal or distal directions using the crossing or parallel methods for unaided vision-based stereoscopic vision.

The 3-D stereoscopic imaging system used in this study facilitates the preparation of stereoscopic images based on raw data on 3-D RA prior to cerebral endovascular treatment. Anyone wearing 3-D polarized glasses can confirm stereoscopic images. Therefore, it is not necessary to perform two sessions of angiography for preparing 3-D stereoscopic images, and skills to make an interpretation of stereoscopic images are also unnecessary. In this study, 3-D stereoscopic images could be readily prepared in a few seconds in all patients. In addition, these images were useful for evaluating the vascular structure and selecting

therapeutic strategies before surgery. In particular, they were useful for evaluating the vascular anatomy and feeder-drainer positional relationship/distance in the shunt disease; their application may prevent complications related to vascular-course underestimation-associated excessive operations and a prolonged treatment-related increase in the exposure dose. On the other hand, there was a time lag between manual operations on a mouse and stereoscopic image motions on a 3-D stereoscopic image-matched LCD monitor, raising an issue regarding operability. In the future, software and hardware should be further improved.

Conclusion

In this study, we used 3-D stereoscopic images for the preoperative simulation of cerebral endovascular treatment, and examined their usefulness. It was easy to prepare 3-D stereoscopic images using 3-D stereoscopic image-converting Work Station/a 3-D monitor. Furthermore, 3-D stereoscopic images facilitated the assessment of spatial orientation in the presence of arteriovenous shunts with a complex vascular structure, suggesting their usefulness. Spatial orientation is an important factor for cerebral endovascular treatment, and the preoperative confirmation of 3-D stereoscopic images may provide information useful for training for non-skilled physicians specializing in cerebral endovascular treatment or student education.

No study has introduced 3-D stereoscopic images for the preoperative simulation of cerebral endovascular treatment, which we performed. We submitted an application to the Ethics Review Board of our hospital. In the future, a prospective study should be conducted to demonstrate the usefulness of 3-D stereoscopic images.

Disclosure Statement

There is no conflict of interest to be disclosed regarding this article.

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