4D-CT Of Brain Tumors: Feasibility In Hemodynamic Depiction

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Citation

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Abstract

Purpose: 4D-CT can provide both static and dynamic 3D images. The purpose of this study was to evaluate clinical usefulness of 4D-CT for brain tumors. Methods:
The subjects included 24 consecutive patients with brain tumors comprising glioblastomas (n=5), fibrillary astrocytoma (n=1), oligodendroglioma (n=1), anaplastic oligodendrogliomas (n=3), anaplastic oligoastrocytoma (n=1), medulloblastoma (n=1), meningiomas (n=5), anaplastic meningioma (n=1), craniopharyngioma (n=1), hemangioblastoma (n=1), and malignant lymphomas (n=4). Continuous 1.0-sec scanning was performed using a 64-row MD-CT. Serial volume rendered (VR) images were displayed in cine mode. 4D-CT was evaluated in depiction of feeding arteries, tumor staining, and early appearance of draining veins, and compared with IADSA in 14 patients. Pertinent facts: 4D-CT was able to depict tumor staining in all of 13 patients who showed tumor staining by IADSA. Feeding arteries were visualized in 9 patients by IADSA and in 7 patients by 4D-CT. Early appearance of draining veins was visualized in 8 patients by IADSA, but in 7 patients by 4D-CT. Early appearance of draining veins was seen in patients with pathologically malignant tumors except for a patient with hemangioblastoma. In 11 patients who did not undergo IADSA, 4D-CT was able to depict tumor staining in 10 patients, feeding arteries in 3 patients, and early appearance of a draining vein in 3 patients. Conclusions: 4D-CT provides hemodynamic information about tumors, such as presence of feeding arteries, tumor staining, and early appearance of draining veins. 4D-CT is a feasible alternative to IADSA in hemodynamic depiction of brain tumors.

INTRODUCTION

Three-dimensional CT (3D-CT) and CT-angiography (3D-CTA) have been applied to intracranial diseases such as aneurysms [1-3], steno-occlusive diseases [4,5], arteriovenous malformations [6,7], and tumors [7, 8]. 3D-CTA for the diagnosis of cerebral aneurysms has replaced transcatheter intra-arterial digital subtraction angiography (IADSA). These techniques provide static 3D-CTA in the arterial or venous phase. For brain tumors, IADSA also produces static and dynamic vascular information about the tumor, such as the presence of feeding arteries, draining veins, and tumor vascularity. Although diagnostic IADSA for brain tumors has not often been performed due to its invasiveness [9], it is feasible to use this technique to differentiate malignant tumors from benign ones [10-13]. Visualization of arteriovenous shunting and early appearance of draining veins [11,12] can aid the diagnosis of pathologically malignant tumors. The newly developed CT scanning technique of dynamic 3D-CT [8] after a bolus injection of contrast material is known as four dimensional CT (4D-CT) [14], due to the inclusion of time resolution into the 3D-CT. 4D-CT provides both static and dynamic 3D- and 2D-images of the tumor. A comparison of 4D-CT with IADSA in brain tumors has not been previously reported, and thus we compared 4D-CT with IADSA in brain tumors, and evaluated the usefulness of 4D-CT.

MATERIALS AND METHODS

PATIENTS

A total of 24 consecutive patients (13 men and 11 women; age range, 18 to 78 years; mean, 60.2 years) with primary intracranial neoplasm underwent 4D-CT between October 2008 and September 2009. The tumors comprised glioblastomas (n=5), diffuse astrocytoma (n=1), oligodendroglioma (n=1), anaplastic oligodendrogliomas (n=4), medulloblastoma (n=1), meningiomas (n=5), anaplastic meningioma (n=1), craniopharyngioma (n=1), hemangioblastoma (n=1), and malignant lymphomas (n=4). In 22 patients, their pathology was proved by surgery (total removal of the tumor was performed in 6 patients, subtotal removal of the tumor was performed in 3, partial removal of the tumor was performed in 4 patients, and biopsy was performed in 9 patients) after 4D-CT. Two patients did not undergo surgery, and they were diagnosed with meningiomas by CT and MRI. Informed consent was obtained from each patient prior to 4D-CT.

CT

All 4D-CTs were performed using a 64-row CT system (LightSpeed VCT; GE Healthcare, Milwaukee, WI), equipped with a detector width of 40 mm. Scan parameters were as follows: 120 kV, 100 – 437 mAs (automatic tube current modulation [15]), 1.0 sec per rotation, 512 x 512 matrix, 64 sections of 0.625 mm section thickness. Continuous scanning was started 10 sec after the injection of nonionic contrast material (Iopamiron 370, Bayer Healthcare, Osaka Japan) at a flow rate of 4 mL, chased by 40 mL saline, injected using a dual-head power injector (Dual Shot GX, Nemoto Kyorindo, Tokyo, Japan). Total scan time ranged from 18 to 40 sec. The location of the scan depended on the location of the tumor. The orbit was not included in the scan volume to avoid radiation exposure to the lens.

POSTPROCESSING

All postprocessing was performed by two radiologists using a 3D workstation (GE Advantage Workstation 4.3, Milwaukee, WI). Original CT data were rearranged at each time phase. 3D-CTA at 1.0-sec intervals was generated by volume-rendered (VR) images using software in the workstation (VolumeViewer). Serial VR images were displayed in cine mode. In several cases, subtracted 3D-CTA images were generated by means of subtraction of mask images before injection of contrast material from images after injection of contrast material. Perfusion maps of cerebral blood flow, cerebral blood volume, and mean transit time can be acquired using this CT technique; however, those maps were not evaluated in the present study.

COMPARISON OF 4D-CT WITH IADSA

IADSA was performed in 14 patients (3 patients with glioblastomas, 1 with diffuse astrocytoma, 3 with anaplastic oligodendrogliomas, 1 with hemangioblastoma, 3 with meningiomas, 1 with anaplastic meningioma, 1 with medulloblastoma, and 1 with malignant lymphoma). IADSA was performed using a C-arm angiography system equipped with an image intensifier tube (matrix: 1024 x 1024) (DIGITEX 2400CX, SHIMADZU Corp, Kyoto Japan). Stereoscopic anteroposterior and lateral projections were acquired with 15 frames per second. All IADSA included bilateral internal carotid and unilateral or bilateral vertebral angiography. 4D-CT was compared with IADSA in visualization of the feeding arteries, tumor staining, and early appearance of draining veins. Three neuroradiologists conjointly reviewed both 4D-CT and IADSA on a CRT monitor.

RADIATION EXPOSURE

The computed tomographic index ($CTDI_{vol}$) [15] was noted as defined in the scan protocol.

RESULTS

4D-CT was acquired in all patients without any major adverse effects. 4D-CT was able to depict tumor staining (Fig. 1) in all 13 patients who showed tumor staining in IADSA. Feeding arteries were visualized in 9 patients by IADSA and in 7 patients by 4D-CT (Fig. 2). 4D-CT was unable to depict fine feeding arteries of the tumor in one case of meningioma (Fig. 3) as well as in one case of medulloblastoma (Fig. 4). Early appearance of draining veins was visualized in 8 patients by IADSA and in 7 patients by 4D-CT (Fig. 2). In one case of glioblastoma, early appearance of draining veins was not seen on 4D-CT. Early appearance of draining veins was seen in patients with pathologically malignant tumors except for a patient with hemangioblastoma (Fig. 5). In 11 patients who did not undergo IADSA, 4D-CT was able to depict tumor staining in 10 patients, feeding arteries in 3 patients (2 glioblastomas and 1 anaplastic oligodendroglioma), and early appearance of a draining vein in 3 patients (2 glioblastomas and 1 anaplastic oligodendroglioma). In patients with meningioma, fine tumor vessels and tumor staining were seen by 4D-CT (Fig. 3). In patients with malignant lymphoma (Fig. 1), 4D-CT was able to visualize prominent medullary veins in the tumor. $CTDI_{vol}$ ranged from 578 to 1143 mGy with a mean of 895.8 mGy.

Figure 1

Fig. 1 A case of malignant lymphoma involving the splenium of the corpus callosum. An arterial phase (a) of 4D-CT shows tumor staining (arrowheads) and early appearance of a draining vein (arrows) (the straight sinus). A venous phase (b) reveals multiple dilated medullary veins (arrows).

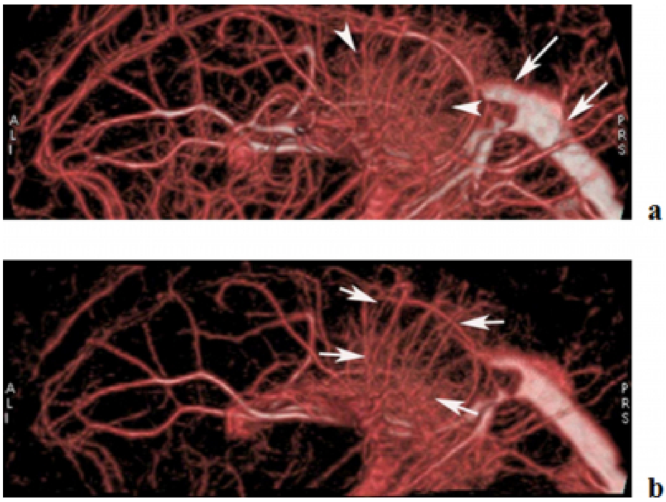
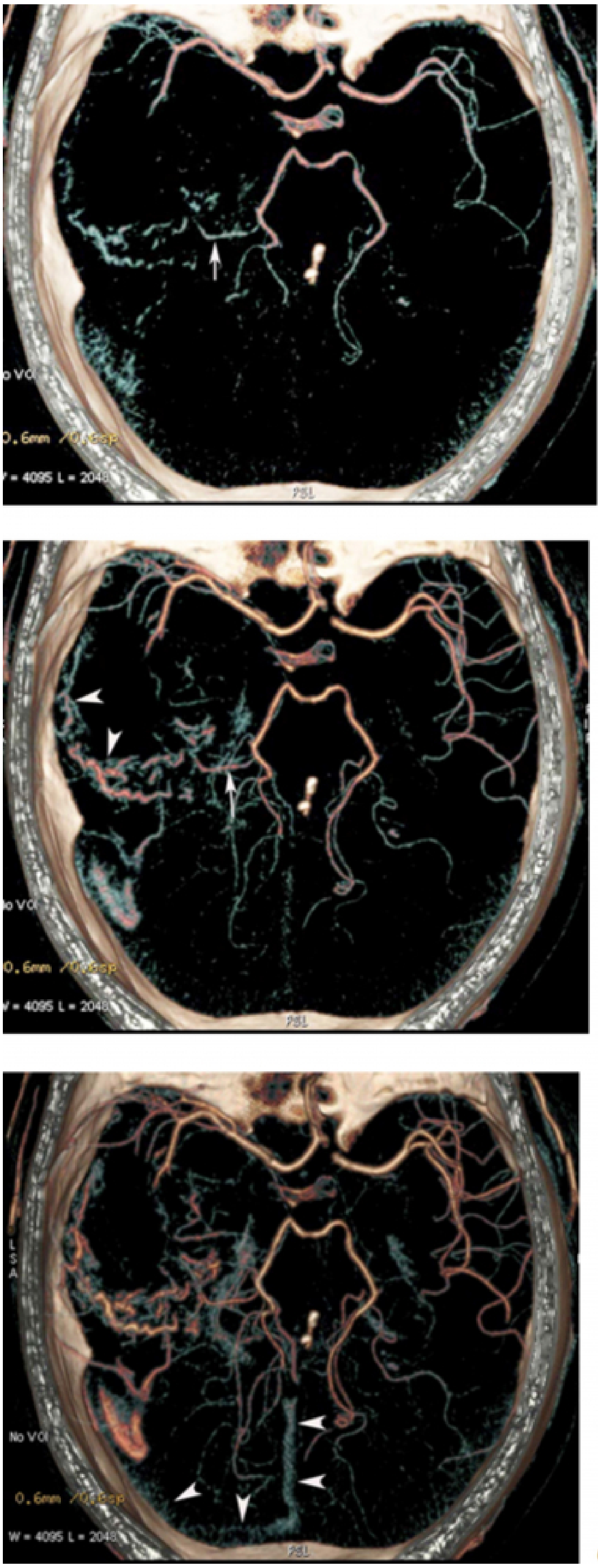


Figure 2

Fig. 2 A case of glioblastoma involving the right temporal lobe. The first (a) and second (b) arterial phases show a feeding artery arising from the right posterior cerebral artery (arrows). Early appearance of a draining vein (arrowheads) is seen on the second and third (c) arterial phases.



a

b

c

Figure 3

Fig. 3 A case of meningioma involving the left parasellar region. Although the first arterial phase (a) does not show tumor staining, the second (b) and third (c) arterial phases depict tumor staining (arrows). Although 4D-CT does not show any feeding arteries, IADSA (lateral view) (d) shows a fine feeding artery (the meningohypophyseal artery) arising from the internal carotid artery (arrow).

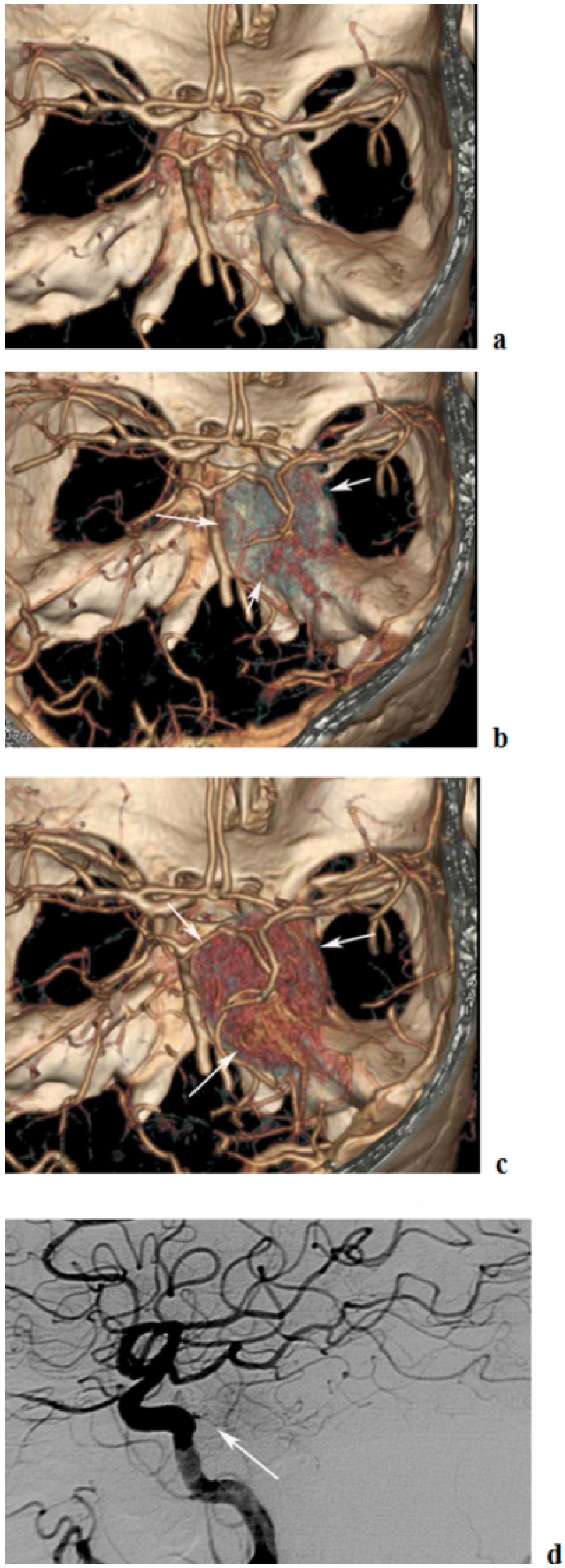
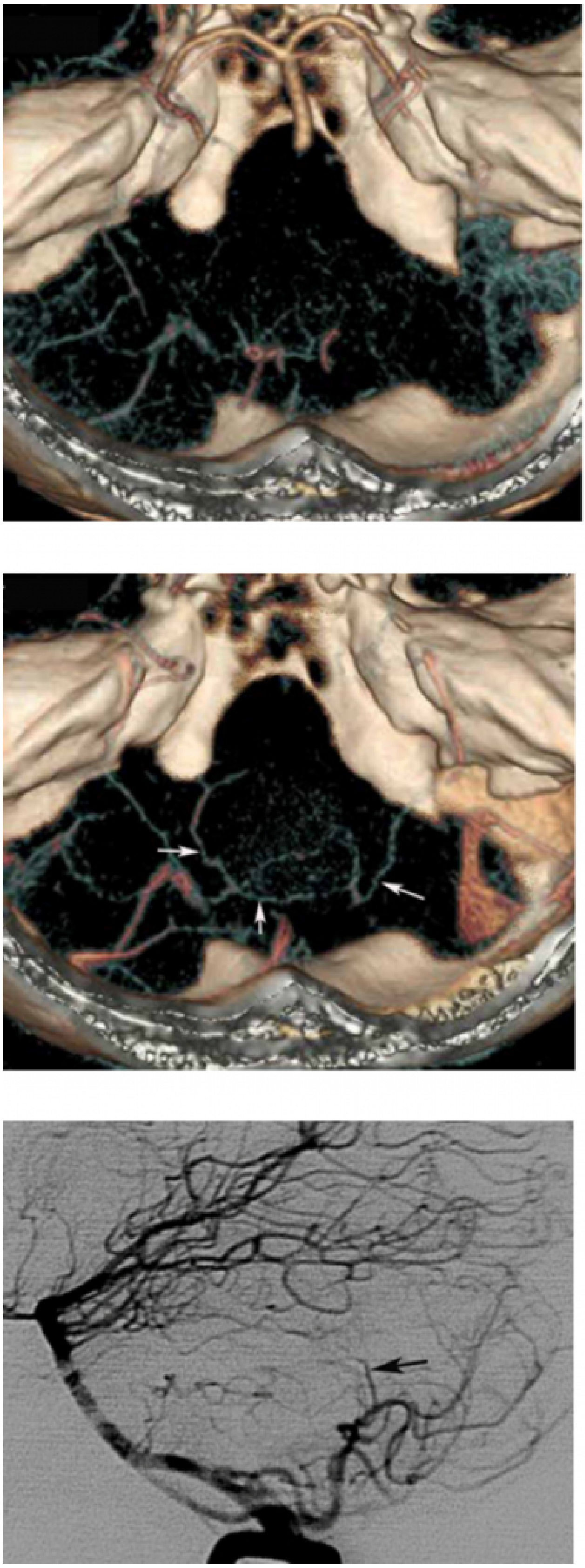


Figure 4

Fig. 4 A case of medulloblastoma involving the cerebellar vermis. An arterial phase (a) does not depict any feeding arteries. A venous phase (b) depicts faint tumor staining and draining veins surrounding the tumor (arrows). A lateral IADSA image (c) shows a feeding artery arising from the posterior inferior cerebellar artery (arrow).



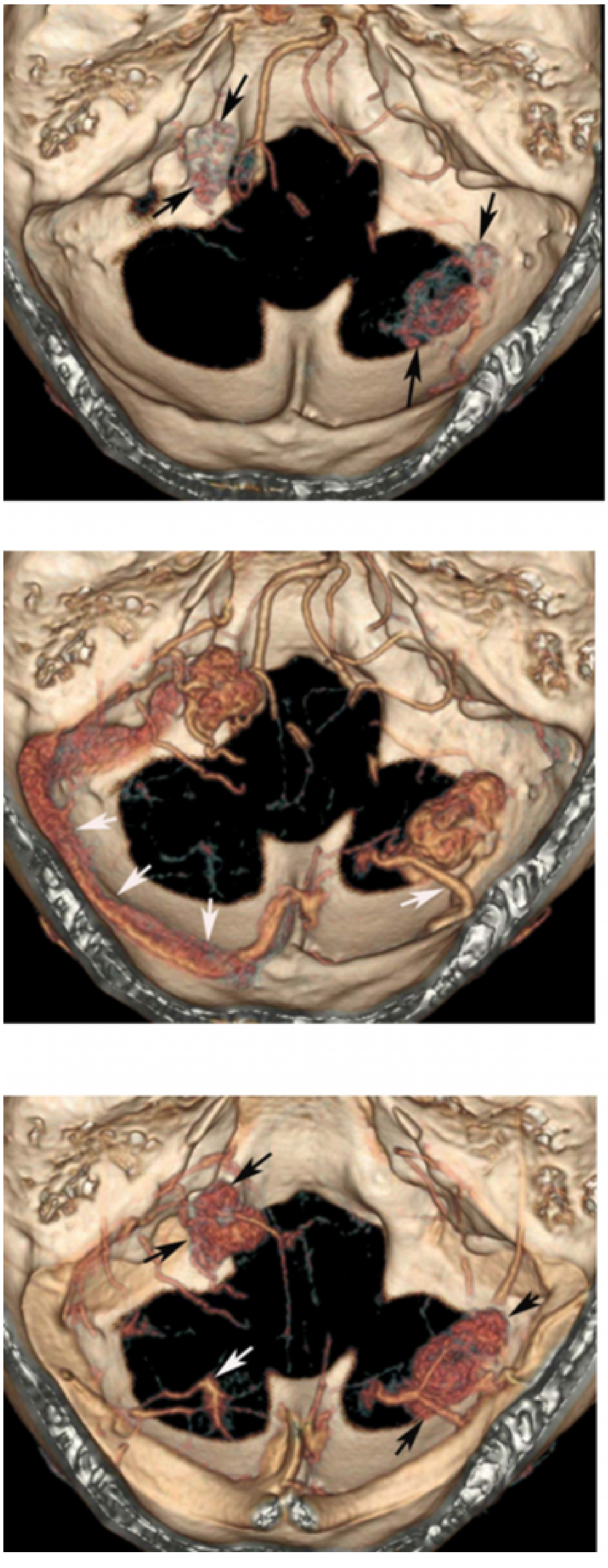
a

b

c

Figure 5

Fig. 5 A case of multiple hemangioblastomas involving the cerebellar hemispheres. The first arterial phase (a) shows two hypervascular tumors (arrows). The second arterial phase (b) shows early appearance of draining veins (arrows). A venous phase (c) shows tumor staining in three tumors (arrows).



a

b

c

DISCUSSION

Conventional 3D-CTA has been useful to depict vascular and neoplastic lesions, however, this technique produces static arterial and venous images. Recently, IADSA has become less and less used for the diagnosis of brain tumors because of its invasiveness. Thus, for preoperative information, CT, 3D-CTA, 2D- or 3D-MR imaging, and MR-angiography have usually been performed before surgery. However, IADSA is able to visualize dynamic images of arteries and veins within and surrounding the tumor, and these images could provide the degree of tumor vascularity [10,13] as well as the nature of the tumor [11,12]. An early appearance of draining veins from a tumor suggests the possibility of malignancy of the tumor, such as glioblastomas, anaplastic astrocytomas, anaplastic oligodendrogliomas, and so forth [11,12]. In pathologically benign tumors, this finding can be used to diagnose hemangioblastomas. Depiction of feeding arteries and draining veins provides neurosurgeons important information before surgery, and knowledge of tumor vascularity could be also important [16]. The present study demonstrated that 4D-CT was almost equal to IADSA in depiction of the feeding arteries and early appearance of draining veins. 4D-CT was superior to IADSA in anatomical visualization of feeding arteries and draining veins, because 4D-CT can visualize brain tissue and bony structures in addition to the vessels. However, IADSA was superior to 4D-CT in time resolution. Both anteroposterior and lateral projections were acquired in 15 frames per second by IADSA in the present study. If necessary, more frames per second can be imaged by IADSA. Scan time was 1.0 sec per rotation, although a 0.4-sec scan time is possible with the CT scanner used in the present study. The image quality can produce with a 1.0-sec scan time seems superior to that by 0.4 sec, however, we did not perform comparisons of image quality. 4D-CT was superior to IADSA in visualization of tumor staining (contrast enhancement) because of the better contrast resolution of 4D-CT. The tumor staining seen by 4D-CT may be used to differentiate high grade astrocytomas from low grade astrocytomas, similar to conventional CT. 2D images in any direction as well as at any phase can be visualized, because 4D-CT data has 2D and 3D image data at any phase.

Recent reports of 4D-CT using 64- [8], 256- [17], and 320-detectors [14] have been published. These reports include arteriovenous malformations, stenoocclusive disease of the cervical internal carotid artery and intracranial arteries, cerebral venous thrombosis, and brain tumors. However, there have been no reports looking solely at brain tumors. The present study is the first to assess the feasibility of 4D-CT for brain tumors in comparison with IADSA. In tumors larger than 40 mm, 256- or 320-slice scanners are superior to a 64-slice scanner, because 4D-CT using 256- or 320-slice scanners permits whole brain coverage in a single rotation. Shuttle scanning, a newly developed CT technique [18], enables the CT table to travel back and forth during scanning with real-time control. Shuttle CT scanning conquers the limited anatomic coverage of conventional CT because it can provide double-width coverage of 80 mm.

4D-CT will also be useful to depict cerebral arteriovenous malformations, large aneurysms, and the stenooccclusive diseases of the major arteries such as the internal carotid artery, middle cerebral artery, posterior cerebral artery, basilar artery and vertebral artery, and could feasibly replace IADSA for these diseases.

However, 4D-CT has a major limitation. Wintermark et al. [19] reported that the cerebral effective radiation dose of CT-perfusion was 1245 mSv for cerebral coverage of 4 cm with an acquisition of 36 sec at a temporal sampling interval of 2 sec and with acquisition parameters of 80 kVp and 120 mAs. Hirata et al. [20] evaluated radiation dose in cerebral perfusion studies on various voltage and current settings, and reported that the highest surface dose was 2264.6±123.7 mGy at 140 kV and 200 mA. Compared with these previous CT-perfusion studies, the radiation dose used in the present 4D-CT method is not higher. As for the radiation dose by diagnostic IADSA, Eguchi et al. [21] reported that the mean radiation dose of the skin was 805.4 mSv in diagnostic cerebral IADSA, which is almost equivalent to that by 4D-CT in the present study. The radiation dose due to IADSA depends on the equipment and DSA technique. In their study the radiation dose at the surface due to the DSA unit used was 0.88 mGy per frame. In the majority of the procedures, approximately 200 frames were acquired for one projection. Thus, patients were exposed to more than 1000 mGy for one procedure, including DSA of the bilateral internal carotid arteries and unilateral vertebral artery. Recently, a flat panel detector system has become available for angiography. Hatakeyama Y et al. [22] measured the radiation dose of the skin produced by angiography with a flat panel detector system and reported that it was much less than that produced by an image intensifier system.

Radiation exposure may be permitted in patients with malignant tumors who are scheduled for radiotherapy. However, in patients with benign tumors such as meningiomas, hemangioblastoma, and craniopharyngioma, the radiation dose should be lowered. In the 23 patients in the present study who had automatic tube current modulation (149 to 437 mA), the $CTDI_{vol}$ was relatively high (704.76 to

1142.86 mGy). In a patient with meningioma, $CTDI_{vol}$ was 578 mGy using a tube current of 100 mA which was also set by automatic modulation. Although image quality may be lower, tube current should be decreased to reduce radiation exposure. Murayama et al. [17] combined CT scanning with continuous dynamic scanning in the arterial phase and intermittent scanning in the venous phase using a 256-slice CT scanner to reduce the radiation dose. Their scanning protocol was 80-kV tube voltage and 80-mA tube current. Klingebiel R et al. [14] also performed 4D-CT in cerebrovascular disorders using a 320-slice CT scanner with a combination of continuous and intermittent scanning to reduce the radiation dose. Shuttle scanning, now applied by us, can reduce the radiation dose because its scan technique is also intermittent for the double coverage.

CONCLUSION

In patients with brain tumors, 4D-CT provides hemodynamic information about the tumor, such as the feeding arteries, tumor staining, and early appearance of draining veins. 4D-CT can also provide better anatomical information than IADSA. Thus, 4D-CT is a feasible alternative to IADSA in hemodynamic depiction of brain tumors.

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