―**Originals**―

4 D-CT: A new development in three-dimensional
hepatic computed tomography

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Abstract

1．Objective: Addition of contrast dynamics to three-dimensional hepatic tumor CT imaging.

2．Materials and Methods: Six patients with hepatic cavernous hemangioma with a mean age of 57 years were included in the study. Two of the patients were male and four were female. Contrast enhanced computed tomography（CT）was carried out on the tumors in six phases by helical CT, using bolus injection of contrast medium intravenously. Using maximum intensity projection（MIP）, a separate three-dimensional image was then reconstructed for each phase, and rotational images around the longitudinal axis of the torso were observed using the CRT monitor.

3．Results: The patterns of contrast enhancement of hepatic cavernous hemangiomas were obtained on 3D-images. In all patients, the reciprocal relations between the tumor and the portal veins and the hepatic veins were clearly imaged three-dimensionally.

4．Conclusions: We have succeeded in adding the dynamic observation of a contrast medium to static three-dimensional imaging. This will be valuable for the diagnosis of hepatic tumors, and it opens up new prospects for diagnostic imaging.（J Nippon Med Sch 2000; 67: 24―27）

Key words: image processing, computer-assisted tomography, X-ray, computed, liver neoplasms, 4D-CT

Introduction

The development of helical CT has made it possible, for the first time, for clinical physicians to carry out three-dimensional（3D）imaging[1]. This represents an important advance. Rapid progress has been made in image-handling technology and the image quality has shown dramatic improvements as a result. Furthermore, 3D diagnostic imaging is now producing important results in surgery of the head and neck, chest, vascular system, and abdominal parenchymal organs, as well as in ophthalmic and plastic surgery[2-5].

However, this imaging, despite being three-dimensional, is static, and is therefore somewhat limited in value.

It is widely accepted that dynamic imaging, using contrast enhanced CT, is required for hepatic tumor diagnosis[6,7].

Therefore, we added the temporal dimension to three-dimensional imaging, thus producing "4D-CT". The value of this technique, and the prospects it opens up, are reported here.

Materials and Methods

Six patients were included in the study, all of whom had already been diagnosed on the bases of imaging and clinical progress as having hepatic cavernous hemangioma（**Table 1**）. CT was performed in order to follow their clinical progress. The patients included

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Table 1　Summary of patients

Case	Age/Sex	Tumor location	Tumor size (mm)	Period of follow up (months)
1	62/M	S8	48 × 25	30
2	45/M	S5	8 × 8	19
3	73/F	S8	18 × 14	13
4	53/F	S8	55 × 38	16
5	63/F	S8	30 × 32	95
6	61/F	S6	62 × 40	12

two males and four females, with maximum, minimum and mean ages of 73, 45 and 59 years, respectively. The maximum, minimum and mean longest axes of the hepatic tumors were 6.2, 0.8 and 3.7 cm, respectively.

The CT equipment used was Xvigor（Toshiba, Tokyo）, with a x-ray tube capacity of 6.5 MHU, and the image-handling equipment was Xtension（Toshiba, Tokyo）. Initially, unenhanced CT was carried out. We decided that the area which could be covered（ie. the largest tumor section area）was 3 or 4 cm. This area was then scanned using helical CT, with bolus injection of contrast medium intravenously.

The area was scanned using helical contrast enhanced CT, three times during the first breath hold, and then twice after 18s of breathing. It was then scanned once more 6 min later. Thus, the same area was scanned a totalof six times.

The bed movement speed during scanning was 5 mm/s. The width of the X-ray beam was 5 mm, with an electric potential of 120 kvp and a current of 200 mA. A 100 ml injection of the contrast medium（300 mgI/ml Iopamidol）was administered at a rate of 2 ml/s, and scanning was obtained begining 20 s or 25 s after the injection.

Two mm interval axial images were reconstructed from the imaging data obtained by 180° supplementary spacing reconstruction, and transmitted to Xtension. Six separate three-dimensional images, one for each phase, were then constructed from these images, using MIP. The image constructed for each phase consisted of 19 frames, one taken at every 10° rotation around the longitudinal axis of the torso. A total of 114 MIP images was therefore obtained from the six phases, and these were observed in rotation on the CRT monitor.

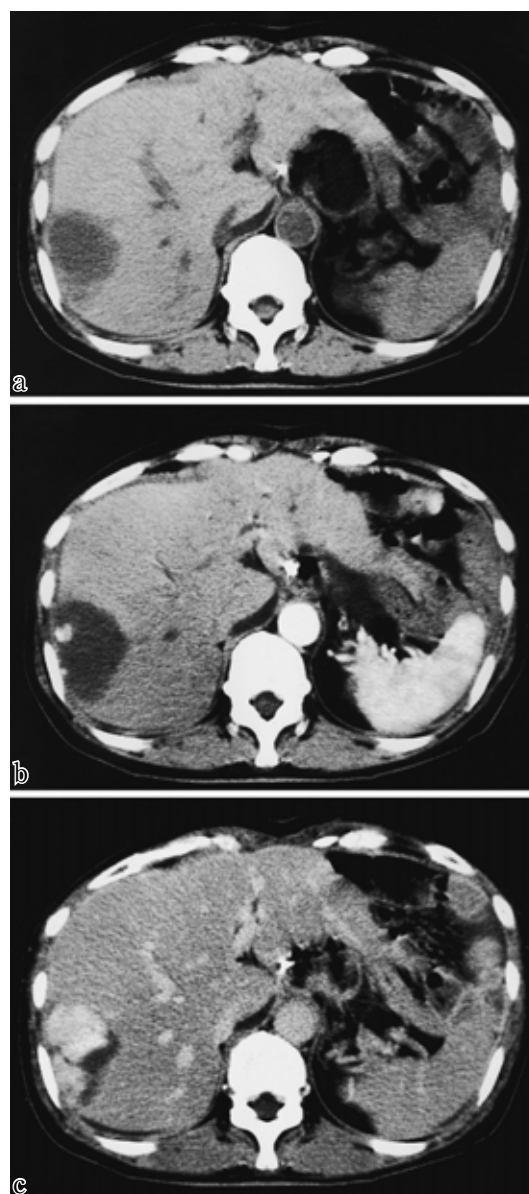The following issues were investigated with re-

Fig. 1　This figure shows an axial image of patient 4. a: Noncontrast CT image demonstrates a 55×38 mm hypodense lesion in the right lobe. b: Twenty seconds after initiation of an intravenous bolus injection of contrast medium, clusters of contrast medium are noted around the periphery of the lesion. c: CT image obtained 6 min after contrast administration shows gradual fill-in of the tumor, persistent hyperdensity relative to surrounding liver does indeed suggest cavernous hemangioma.

spect to the images:（a）The feasibility of observing the pattern of contrast enhancement of the hepatic cavernous hemangioma.（b）The consistency of tumor location with axial CT imaging.
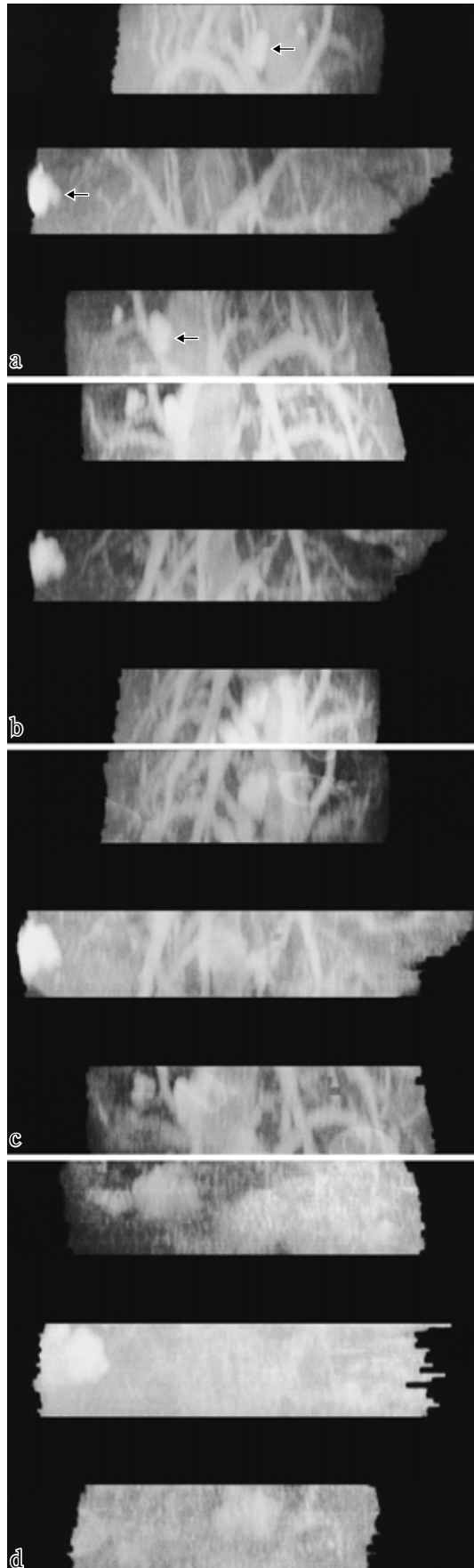
Results

4D-images were constructed for all patients. And patterns of contrast enhancement of the hepatic tumors were obtained on 4D-images. Namely, on 4D-CT imaging, tumors demonstrate brightly enhanced nodular borders. Early during the examination, the nodular border does not form a continuous rim, but has the appearance of bright papillary projections pointing toward the center of the lesion. Enhancement then progresses slowly from the periphery of the lesion toward the center.

Furthermore, in all patients, the reciprocal relations between the tumor and the portal veins and the hepatic veins were clearly imaged three-dimensionally, and the tumor location was well-defined. These results demonstrated that hepatic cavernous hemangioma can be diagnosed from the patterns of contrast enhancement in 4D-CT, and that tumor location images are consistent with axial imaging. Therefore, this 4D-CT technique was shown to facilitate qualitative tumor diagnosis, and also to provide three-dimensional information about tumor location（**Figs. 1, 2**）.

Discussion

Since the development of helical CT, two of its characteristics have been shown to be of great benefit to clinical medicine[1,8].

One of these characteristics, speed, has enabled CT to be performed in a relatively short period of time. This in turn has enabled scanning of organs, in contrast enhanced studies, during the desired enhanced phase.

The other characteristic, namely ease of application to three-dimensional imaging, has meant that the

Fig. 2   This figure shows a rotational MIP image of patient 4. a: Portal dominant phase. b, c: Venous dominant phase. d: Delayed phase.
The connections between the tumor（arrow）and the portal and the hepatic veins can be clearly seen. And patterns of contrast enhancement of the cavernous hemangioma were observed which were maintained until delayed contrast.

technique has proved very effective for providing anatomical information and information about the reciprocal relations between organs and tumors. It has also proved valuable for training medical students and explaining problems to patients. It is thought that this characteristic also makes the technique valuable for hepatic diagnostic imaging.

However, despite these advantages, three-dimensional imaging is a static procedure, and diagnosis must be made on the basis of morphological elongation. Continuous observation with contrast enhancement is definitely important for qualitative tumor diagnosis, and in the case of hepatic tumors in particular, the continuous contrast enhanced pattern is one of the most important grounds for diagnosis[6,7].

Our aim was therefore to add dynamic blood flow information to static three-dimensional images.

In previous hepatic three-dimensional diagnostic imaging, the relations between the location of the tumor and the anatomic structure of the surrounding area, or the collateral vessels, was displayed[4,5]. However, there have been no reports of the reconstruction of three-dimensional images showing the contrast enhanced patterns of hepatic tumors. This study was only concerned with diagnosis of hepatic cavernous hemangioma, but as it involved the additional display of sequential three-dimensional images, it may open up new prospects for "four-dimensional imaging".

In this study, favorable results were obtained with hepatic cavernous hemangioma. However, on the basis of the contrast enhanced pattern characteristics in the MIP images constructed, it might not be possible to achieve comparable results with hepatocellular carcinoma or metastatic hepatic tumors. We therefore plan to carry out a study using a different volume rendering method.

In this study, the area covered was only 3 or 4 cm. It was limited to this by the length of time for which the patient was able to hold his/her breath. The time

for which continuous CT scanning could be carried out was therefore also limited. This meant that the entire tumor could not be covered in some patients. In addition, although the imaging was three-dimensional, the scan was narrow, and was thus concluded to be insufficient. Furthermore, the number of scanning phases was only six.

Multi-detector row CT is a recently developed, and thus widespread application of it has yet to occur. We believe that if this equipment were to be used, it would enable a wider scanning area that covered the entire liver, and also allow for more multiple-phase scanning. We hope that this will result in more detailed 4D-CT images being obtained.

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