Hiroshima Journal of Medical Sciences
Vol.36, No.1, 113~120, March, 1987
HIJM 36-16

Functional Imaging of Hepatic Masses Using Computed Tomography

Koichi FUJIKAWA[1], Kosuke YAMANE[1], Tadashi NAKANISHI[1] and Shizutomo KATSUTA[2]

1) Department of Radiology, Hiroshima Hospital of Japanese National Railways, 3-1-36 Futabanosato, Higashi-ku, Hiroshima 732, Japan

2) Department of Radiology, Hiroshima University School of Medicine, 1-2-3, Kasumi, Minami-ku, Hiroshima 734, Japan

(Received December 20, 1986)

Key words: Functional imaging, Hepatic tumor, Computed tomography, CT data processing

ABSTRACT

In order to assess the usefulness of CT functional images, twenty one cases with liver masses were studied. We tried to minimize the motion artifacts by immobilizing the patients with a girdle in performing dynamic CT scans, and by discarding some of the segmented images with serious artifacts before constructing functional images. The qualities of images obtained were considered satisfactory. Of the several transit parameters obtained from the dynamic CT scans, we found the first moment (M1) to be most useful and the effectiveness of M1-functional images were studied. In all cases with hepatocellular carcinomas (12 cases) and intrahepatic cholangiocarcinomas (2 cases), the M1-functional images showed the viable portions of tumors as accumulations of dark pixels reflecting rapid transit times due to arterial blood supply. In three cases with hepatic cavernous hemangiomas, the lesions were represented as bright areas with a well-defined border. In two cases with hepatic abscesses, the M1-functional images suggested the presence of hyperemia in the surrounding tissue as demonstrated by bright pixels around the lesions.

CT functional imaging was proved to be useful for evaluating the circulatory dynamics of contrast material and the differential diagnosis of liver tumors when conventional or dynamic CT studies failed to provide enough information. This technique enabled overall analysis of time-density curves for the entire plane of an image semiautomatically and without the subjective maneuver of setting ROI's (regions of interest).

Dynamic computed tomography (dynamic CT) is rapid sequence CT scanning immediately following the administration of a bolus contrast material. The technique made it possible to explore some of the physiological events such as blood flow by comparing serial images obtained. It broadened the application of CT, which previously was directed at the detection of structural abnormalities, and had made a considerable contribution to the differential diagnosis of space occupying lesions of the liver[1,3,6-8].

More recent advances in CT technology have made it possible to create a synthetic image which directly visualizes the time course of contrast enhancement in a single image. Several parameters related to the dynamics of contrast material are calculated for all the pixels within the entire scan plane and these values are mapped and displayed by the gray scale. These synthetic images derived from data of dynamic CT scans are called CT functional images. Original methods of CT functional imaging were developed by Axel[2], Berninger and their coworkers[4], but the clinical value of this diagnostic modality is not well established because of limited experience, various artifacts, and the

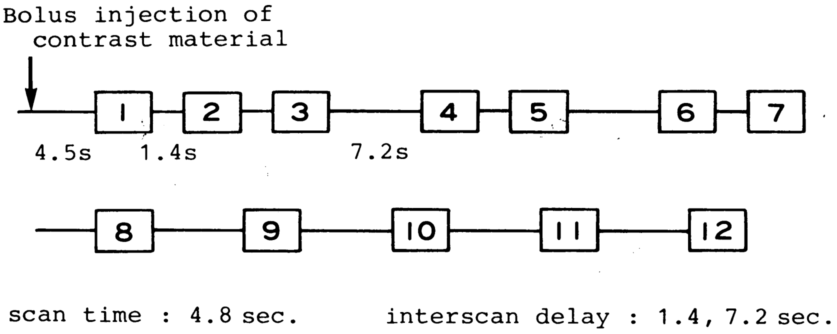

Fig. 1. Serial scan program for dynamic CT

time-consuming process.

In this report, we describe the standard technique to decrease the artifacts and discuss the clinical usefulness of CT functional images in the study of space occupying lesions of the liver.

MATERIALS AND METHODS

Twenty one cases of liver masses were studied. Patients were examined at the Department of Radiology of Hiroshima Hospital of the Japanese National Railways during the period of March 1984 to October 1984. They included hepatocellular carcinomas (12 cases), intrahepatic cholangiocarcinomas (2 cases), cavernous hemangiomas (3 cases), abscesses (2 cases) and cysts(2 cases). In each case, a dynamic CT scan was performed and CT functional images were created from the intrinsic data obtained during the consecutive scanning. Dynamic CT scans were performed on a GE CT/T8800 scanner and CT functional images were constructed by utilizing the special display program "GEDIS 6.22".

Patients were tightly bound to the CT table with a girdle to reduce the movement of abdominal organs. Immediately after the rapid intravenous administration of contrast material, twelve consecutive scans were taken from the liver according to the scan program illustrated in Fig. 1. The single scan time was 4.8 sec and the interscan delay was either 1.4 sec or 7.2 sec. During the seven longer interscan delays (7.2 sec) patients were allowed to breathe. The total duration of the scan sequence reached approximately 120 sec. The contrast material used was 40—60 ml (0.8 ml/kg of body weight) of 60% Urografin and was injected into the antecubital vein by hand as rapidly as possible.

CT functional images were constructed in five steps: 1) The numerical data obtained from each full 360° scan, were separated into two consecutive but overlapping 212° segments, each of which was processed using standard reconstruction methods (segmentation). 2) Among the 24 images obtained by the segmentation, those with poor quality were discarded by visual inspection and the rest with less artifacts were reregistered for further processing. 3) Each reregistered image was smoothed by averaging the CT number

FITTING EQUATION

$$C(t) = K \cdot (t-AT)^{\alpha} \cdot e^{-(t-AT)/\beta}$$

$C(t)$ = increment of CT numbers
t = time after start of scan
K = constant scale factor
α, β = fitting coefficients
AT = arrival time of contrast

TRANSIT PARAMETERS

Rise time $= \alpha\beta$
Peak time $= AT + \alpha\beta$
Decay time $= \beta$
Area $= K \cdot \beta^{(\alpha+1)} \cdot \Gamma(\alpha+1)$
Inflections $= AT + \beta(\alpha \pm \sqrt{\alpha})$
First moment $= AT + \beta(\alpha+1)$

Fig. 2. Gamma variate function as the fitting equation and transit parameters. Two coefficients (alpha and beta) of the equation are determined by the least squares method to best fit the changes in time-density values of each pixel. The values of the transit parameters are in turn calculated from the two coefficients, and the functional image can be created from any one of the parameters by displaying the values by the grey scale.

of each pixel with its immediate neighbors in order to reduce the effects of noise. 4) For each spatially corresponding pixel, changes of CT values during the scan sequence were calculated. A gamma variate curve was then fitted to the time-density values obtained. Several transit parameters reflecting the dynamics of contrast material were derived from the fitting equation (Fig. 2). 5) One of the parameters was chosen and a CT functional image was constructed by assigning a shade of gray to each corresponding pixel depending on the numerical value of the selected parameter at the pixel. The procedures from 3) to 5) were accomplished semiautomatically.

The principal parameters used in the construction of CT functional images included rise time, peak time, decay time, area under curve, inflection points and first moment (M1). In this study, we focused our attention on the CT functional images of M1, which appear to be most useful for evaluating the dynamics of contrast material. The value of M1 is usually considered to correspond with the mean transit time in conventional indicator transit studies[10], but this concept may be inapplicable to the present type of study of the liver because of the dual blood supply. The values of M1 obtained by dynamic CT scanning of the liver may be better termed as "apparent transit time".

In CT functional images of M1 (M1-functional image), brightness of pixels is proportional to the value of M1, i.e., a brighter region has a larger M1 (longer apparent transit time or slower apparent transit) than a darker region. Those portions excluded from functional imaging were displayed as black.

RESULTS

In all cases with malignant hepatic tumors, twelve hepatocellular carcinomas and two intrahepatic cholangiocarcinomas, the viable portions of tumors were demonstrated by dark pixels. The results are indicative of rapid transit of contrast material through them and are compatible with arterial blood supply of the tumors. In three cases with hepatic cavernous hemangiomas, the lesions were represented as a bright area with a well-defined border, and this indicated delayed transit of contrast material through hemangiomas. In two cases with hepatic abscesses, the CT functional images suggested the hyperemia of the surrounding tissue by demonstrating bright pixels around the lesions.

CT functional imaging was proved to be a useful technique for evaluating the circulatory dynamics of contrast material and to be helpful in the differential diagnosis of hepatic masses with altered blood flow.

REPRESENTATIVE CASE REPORTS

Case 1. A 76-year-old woman with hepatocellular carcinoma. She had been suffering from liver disease for twelve years and was referred to our hospital for the evaluation of her liver status and the investigation of a possible complicating neoplastic disease. Ultrasonography revealed a space occupying lesion in the left lobe of her liver. On a dynamic CT scan (Fig. 3A), the ventral portion of the tumor was slightly enhanced, but the patchy stains were obscured within 40 sec after the injection of contrast material. Fig. 3B shows gamma variate fitted time-density curves obtained from the tumor and the uninvolved parenchyma. The M1 value of the tumor was significantly smaller, indicating the more rapid apparent transit of contrast material through the tumor. This finding might imply that this tumor received most of its blood supply from the hepatic artery[5,9]. In the M1-functional image (Fig. 3C), the viable portion of the tumor was recognizable as a darker (more rapid apparent transit) area than the uninvolved parenchyma and the necrotic portion within the tumor was distinctly depicted by the brightest pixels. The liver parenchyma adjacent to the tumor was found to be brighter (slower apparent transit) than that of the right lobe. The finding was thought to suggest that the contrast material is retained near the tumor by the mass effect and venous involvement of the tumor.

Case 2. A 64-year-old man with cholangiocarcinoma. He was referred to our hospital for investigation of obstructive jaundice. Precontrast CT scans revealed an area of low attenuation value near the hepatic hilus and dilated bile ducts distal to it. On a dynamic CT scan (Fig. 4A) subsequently performed, the contrast enhancement of the tumor was not discernible but its contour became clearer. The time-density curve (Fig. 4B) obtained from the tumor showed

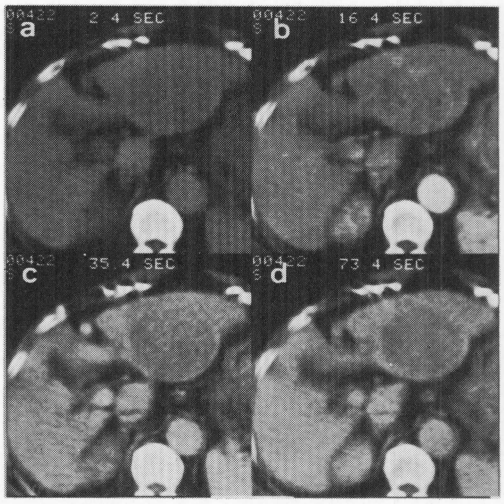

Fig. 3A

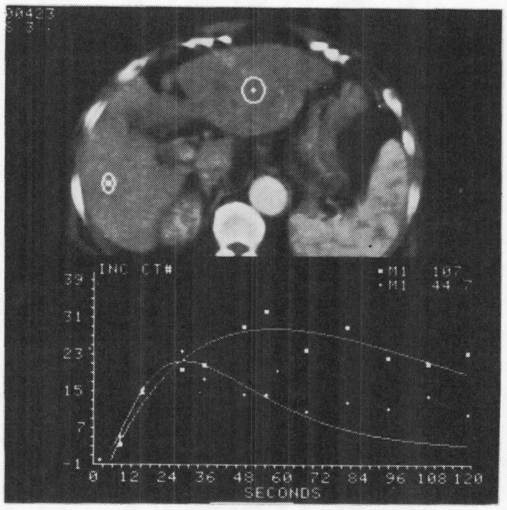

Fig. 3B

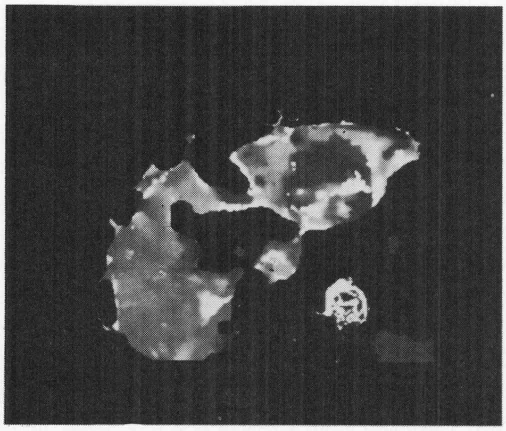

Fig. 3C

Fig. 3. Case 1. A 76-year-old woman with hepatocellular carcinoma. **A:** Selected scans from the dynamic CT series: 2.4 sec (a), 16.4 sec (b), 35.4 (c), and 73.4 sec (d) after start of scan. The ventral portion of the tumor is slightly enhanced. **B:** The M1 value of the tumor is smaller than that of the uninvolved parenchyma. **C:** In the M1-functional image, the viable portion of the tumor appears as a darker area and the necrotic tissue is clearly depicted as a bright area.

a low peak value, and a significantly different pattern of rise and fall was noted from that obtained in the surrounding liver parenchyma. The M1 value of the tumor was smaller than that of the uninvolved parenchyma. In the M1-functional image (Fig. 4C), the tumor appeared as a darker area than the uninvolved parenchyma, and this suggested different blood supplies between the tumor (with arterial supply) and the uninvolved parenchyma (with both arterial and portal supply).

Case 3. A 35-year-old man with hepatic cavernous hemangioma. During a routine ultrasonographic examination, a small space occupying lesion with high echogenicity was noted in the right lobe of his liver. On precontrast CT scans, it appeared as a small well-defined triangular area with low density in the right hepatic lobe. Sequential images obtained by a dynamic CT scan (Fig. 5A) showed a centripetally advancing border of enhancement as the area of low density became progressively smaller. An analysis of time-density curves (Fig. 5B) revealed that the M1 value derived from the lesion was significantly larger than that of normal parenchyma. In the M1-functional image (Fig. 5C), the lesion was depicted by brighter pixels suggestive of a marked delay in apparent transit of contrast material through it.

Case 4. A 59-year-old man with hepatic abscess. He was admitted because of abnormal liver function tests and remittent fever for two months. Ultrasonography revealed a space occupying lesion with mixed echogenicity in the right lobe of his liver. On precontrast CT scans, the lesion was demonstrated as a low density

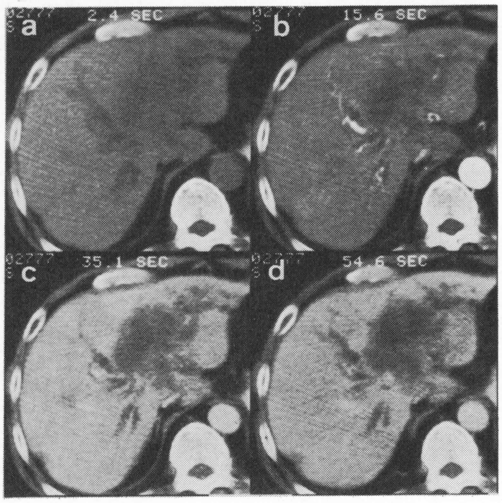

Fig. 4A

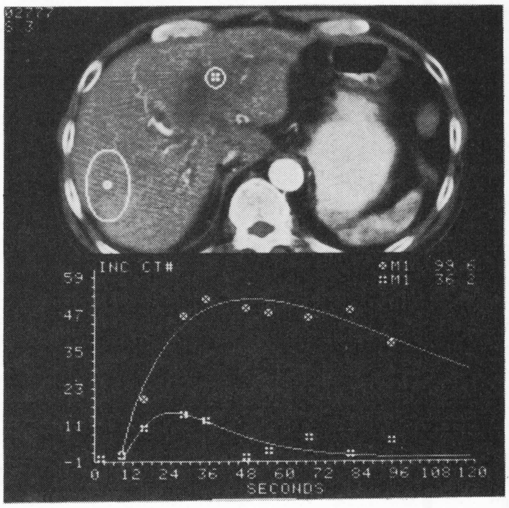

Fig. 4B

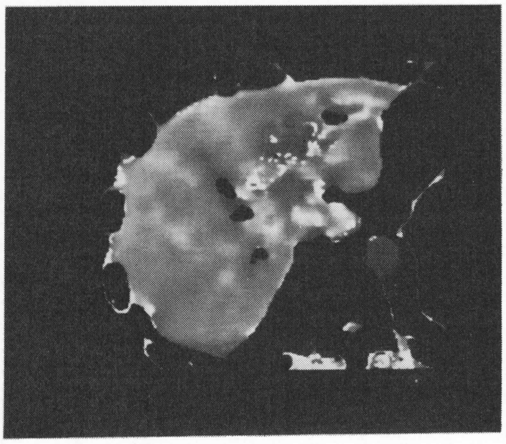

Fig. 4C

Fig. 4. Case 2. A 64-year-old man with cholangiocarcinoma. **A:** Selected scans from the dynamic CT series: 2.4 sec (a), 15.6 sec (b), 35.1 sec (c), and 54.6 sec (d) after start of scan. The enhancement of the tumor is not discernible. **B:** An analysis of time-density curves demonstrates a rapid transit (smaller M1 value) and lower peak height of the curve from the tumor than that of the uninvolved parenchyma. **C:** The M1-functional image clearly visualizes areas of low M1 and suggests an arterial nature of the blood supply.

area with an ill-defined border. A dynamic CT scan (Fig. 6A) showed a faint enhancement of the periphery of the lesion, and it persisted into the venous phase. The time-density curve (Fig. 6B) obtained from the periphery of the lesion had a delayed rise and a gradual fall indicating a slow apparent transit of contrast material through the region. The M1-functional image (Fig. 6C) showed bright pixels scattered around the lesion. This feature appeared to correspond to the presence of hyperemia in the surrounding tissue and was thought to be helpful in making a differential diagnosis of abscess from other non-inflammatory cystic lesions (Fig. 7).

DISCUSSION

Dynamic CT scanning has added a new dimension to conventional CT studies. It has made possible the imaging of abdominal organs and tumors at the time when contrast enhancement values are at their peak[8]. This method has been used in differential diagnosis of hepatic space occupying lesions by characterizing them in terms of vascularity and relative perfusion[1,3,8]. However in some hepatic lesions, the enhancement can not be appreciated and the information obtained by visual inspection of dynamic CT images is not always helpful for the detection and the differential diagnosis of the lesions. A more quantitative assessment can be obtained from the analysis of time-density curves by placing regions of interest (ROI's) at the sites to be compared. It is difficult to achieve fully objective results because the shapes of the time-density curves are largely dependent upon the ranges and the positioning of the ROI's, and

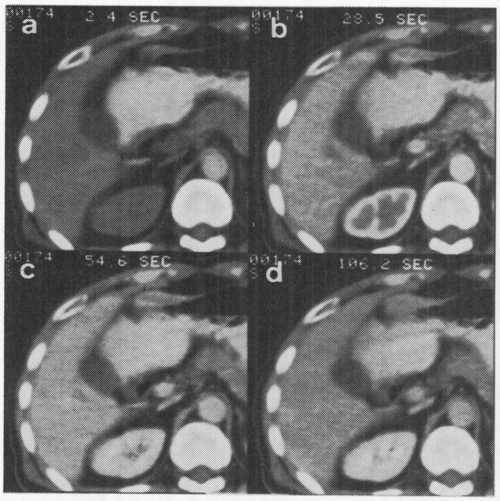

Fig. 5A

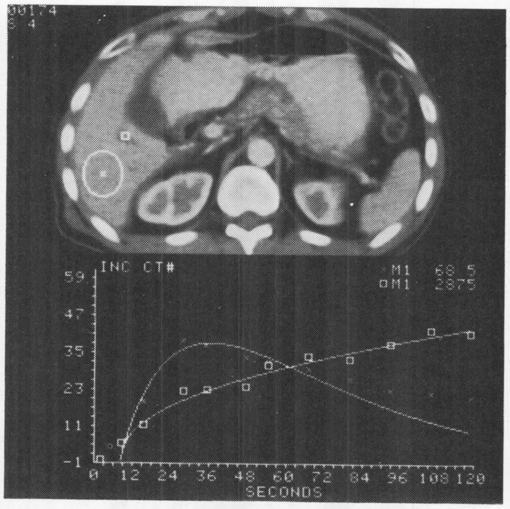

Fig. 5B

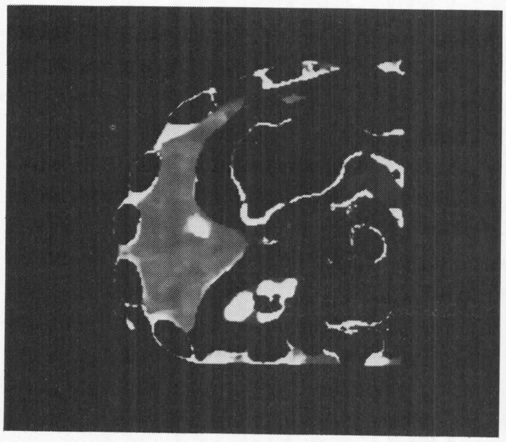

Fig. 5C

Fig. 5. Case 3. A 35-year-old man with hepatic cavernous hemangioma. **A:** Selected scans from the dynamic CT series: 2.4 sec (a), 28.5 sec (b), 54.6 sec (c), and 106.2 sec (d) after start of scan. The sequential images show a centripetally advancing border of enhancement and the lesion becomes obscured in the later phases of the series. **B:** In an analysis of time-density curves, the M1 value of the lesion is found to be significantly larger than that of normal parenchyma. **C:** In the M1-functional image, the lesion is depicted by brighter pixels which represent a marked delay in apparent transit of the contrast material through it.

significant amounts of unintentional operator's prejudice may develop from manual ROI setting. Overall analysis of time-density curves for the entire scan plane is unfeasible for it might require extensive time and effort.

CT functional imaging makes it possible to demonstrate the time course of contrast enhancement as a visual image by grey-scale presentation of the values of a certain transit parameter for all the pixels within the entire scan plane. It allows an evaluation of the dynamics of contrast material without the subjective maneuver of setting ROI's. It can demonstrate the dynamics of contrast material even in the areas where the change in density is visually undiscernable and the setting of ROI's is almost impossible. It can also provide the informations about the surrounding tissue which may, otherwise, often escape our attention. One of the most serious drawbacks in CT functional imaging was poor image quality due to the creation of artifacts caused by patient motion during the examination. The respiratory motion is inevitable particularly in patients with advanced ages or diseases. We could successfully minimize the artifacts by immobilizing the patients using a girdle and by discarding some of the segmented images with serious artifacts. Actual procedures for the creation of CT functional images are still somewhat complex and time-consuming, which currently precludes a widespread use of this method. However, the objective demonstration of the circulatory dynamics of contrast material offers otherwise unobtainable clinical information. With the shortened scan time and the

Fig. 6A

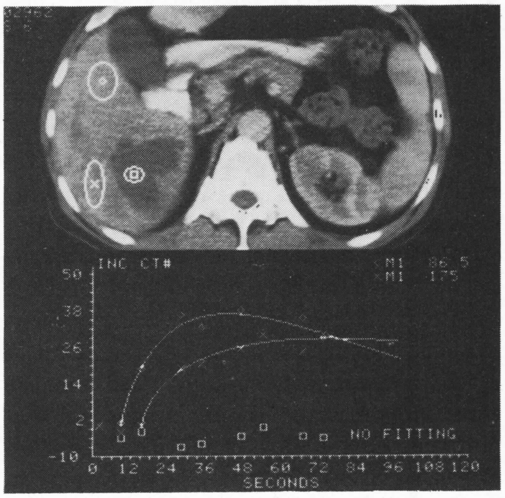

Fig. 6B

Fig. 6C

Fig. 6. Case 4. A 59-year-old man with hepatic abscess. **A:** Selected scans from the dynamic CT series: 2.4 sec (a), 8.6 sec (b), 44.0 sec (c), and 63.2 sec (d) after start of scan. The periphery of the low density lesion is faintly enhanced in the later phases. **B:** The time-density curve obtained from its periphery is characterized by a delayed rise and a gradual fall. **C:** In the M1-functional image, bright pixels which suggest the presence of hyperemia are scattered around the lesion.

more sophisticated systems of the newer CT scanners, most of these problems might be resolved and we believe that this method will become more useful for evaluating hepatic and other lesions with variously altered blood flow.

ACKNOWLEDGEMENTS

The authors thank Miss Yoko Hisatomi and Mr. Hiroyuki Muranaka for their secretarial assistance.

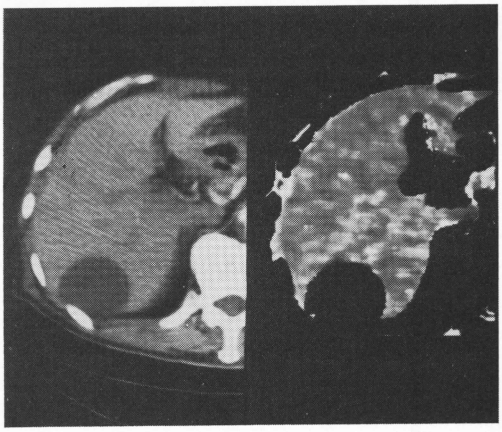

Fig. 7. A conventional CT image of a hepatic cyst and its M1-functional image. The lesion is well demarcated and no abnormal delay or rapid transit of the contrast material are found.

REFERENCES

1. **Araki, T., Itai., Y., Furui, S. and Tasaka, A.** 1980. Dynamic CT densitometry of hepatic tumors. A.J.R. **135**: 1037—1043.
2. **Axel, L., Dean, P.B., Moss, A.A. and Stansberry, D.** 1984. Functional imaging of the liver, new information from dynamic CT. Invest. Radiol. **19**: 23—29.
3. **Baert, A.L., Marchal, G.J., Wilms, G.E., Usewils, R.M. and Fevery, J.M.** 1982. A comparative study of angiography and dynamic computed tomography in liver angioma, a report of 15 cases. J. Comput. Tomogr. **6**: 245—255.
4. **Berninger, W., Redington, R., Leue, W., Axel, L., Norman, D. Brundage, E., Carlsson, E., Herfkens, R. and Lipton, M.** 1981. Technical aspects and clinical applications of CT/X, a dynamic CT scanner. J. Comput. Assist. Tomogr. **5**: 206—215.
5. **Breedis, C. and Young, G.** 1954. The blood supply of neoplasms in the liver. Am. J. Pathol. **30**: 969—977.
6. **Hosoki, T., Toyonaga, Y., Araki, Y. and Mori, S.** 1984. Dynamic computed tomography of isodense hepatocellular carcinoma. J. Comput. Assist. Tomogr. **8**: 263—268.
7. **Mathieu, D., Vasile, N., Fagniez, P.L., Segui, S., Grably, D. and Larde, D.** 1985. Dynamic CT features of hepatic abscesses. Radiology **154**: 749—752.
8. **Moss, A.A., Dean, P.B., Axel, L., Goldberg, H.I., Glazer, G.M. and Freidman, M.A.** 1982. Dynamic CT of hepatic masses with intravenous and intraarterial contrast material. A.J.R. **138**: 847—852.
9. **Okudaira, M., Sasaki, K. and Naka, H.** 1979. Vascular architecture of malignant neoplasms. Angiology **19**: 229—232.
10. **Thompson, H.k., Starmer, C.F., Whalen, R.E. and McIntosh, H.D.** 1964. Indicator transit time as a gamma variate. Circulation Res. **14**: 502—515.