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Hepatocellular carcinoma: multidetector row helical CT

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Hepatocellular carcinoma (HCC) usually is a hypervascular tumor [1–3], and helical computed tomography (CT) has improved detection sensitivity of HCC because it can obtain biphasic (hepatic arterial dominant and portal venous dominant) images during separate breath-holds [4–8]. Many investigators have initiated arterial phase imaging with a scan delay of 20–30 s [4–10]. However, the determination of the optimal timing for the arterial dominant set of images is difficult because it can be influenced by numerous variables, such as the patient's size and cardiovascular status. Helical CT data with thinner sections has been reported to have better detection sensitivity of hypervascular HCCs [11]. However, when using single-detector row helical CT, extended pitch must be employed to obtain thin-slice images of the entire liver during a single breath-hold, and approximately 25 s was needed to cover the entire liver.

Multidetector row helical CT is a newly developed helical CT scanner that can acquire multiple CT data sets with each rotation of the x-ray tube [12] and scan through large anatomic areas three to ten times faster than single-detector row helical CT scanners. Thus, this system can scan through the entire liver in 10 s or less with thinner section collimation than the single-slice helical CT scanner, and two separate sets of CT images of the liver within the period generally regarded as the hepatic arterial dominant phase can be obtained during a single breath-hold [13]. These imaging techniques are expected to reduce the temporal misregistration of the arterial phase scan and improve the diagnosis of HCC.

Moreover, the helical CT data with thin-section collimation and three-dimensional displays could demonstrate the major visceral arteries [14–17]. Multidetector row helical CT can obtain thinner section collimation with higher temporal resolution than the single-slice helical CT scanner. These images are thought to be useful for reconstruction in three-dimensional CT angiography, which is helpful for vascular anatomic information and vascular invasion of HCC.

With this article, we introduce our technique for liver imaging with multidetector row helical CT and discuss its efficacy for the diagnosis of HCC.

CT imaging techniques of the liver

Dynamic study

Dynamic study of the entire liver in sequences is a very important and indispensable examination for the diagnosis of liver tumor because it can improve the detection sensitivity and the diagnostic accuracy of tumor characterization and staging [4–8]. By improving temporal and spatial resolutions with multidetector row CT, we can expect to improve the accuracy of the detection and diagnosis for HCC.

Scan parameters

We use the LightSpeed QX/i (GE Yokogawa Medical Systems, Tokyo, Japan) CT scanner. The detector configuration is 4 × 2.5 mm in the interspaced HS mode, in which four interspaced helical data sets are collected from eight 1.25-mm detector rows. The HS mode is equivalent to a pitch of 6, with the table speed set at 15 mm/rotation. One rotation of the x-ray tube is 0.8 s. The axial images are reconstructed and displayed as 40 5-mm-thick slices for each phase set. Each phase helical CT data set is retrospectively reconstructed with a standard soft algorithm at 1.25-mm increments, a 2.5-mm section thickness, and 30-cm field of view. The data are then transferred to a workstation (Advantage Windows 3.1, GE Medical

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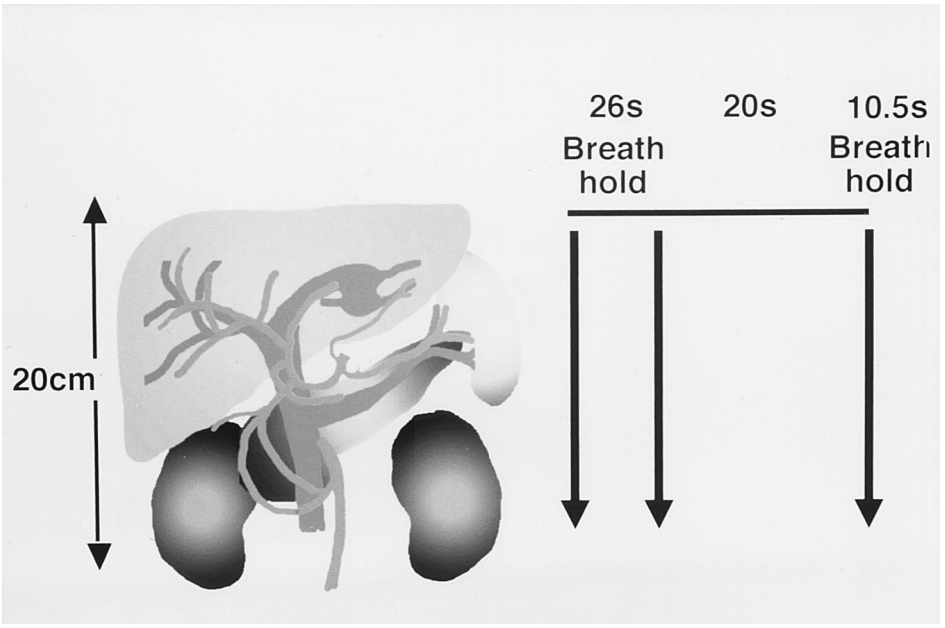

Fig. 1. At the time of measured delay after intravenous administration of 2 mL/kg of the contrast medium at a rate of 5 mL/s, the early and late arterial phase images are obtained serially during a single breath-hold with interscan delay of 5 s. The portal venous phase images are obtained 20 s after the end of late arterial phase imaging.

Systems, Milwaukee, WI, USA) for reconstruction CT angiography.

Dynamic study protocol

Contrast medium, 300 mgI/mL, is injected intravenously by power injector at a rate of 4 or 5 mL/s through a 20-gauge plastic intravenous catheter placed into an antecubital vein. An injection rate of 4 or 5 mL/s has been shown to have better detection sensitivity than a rate of 2 or 3 mL/s [18]. The volume of delivered contrast agent is usually 2 mL/kg according to the patient's size. Scanning begins from the dome of the liver (location determined by the scout digital radiograph) and proceeds in a caudal direction for 10.5 s, covering a *z*-axis distance of 20 cm. These CT images constitute the early arterial phase. After an interscan delay of 5 s for table movement, scanning resumes from the dome of the liver in a caudal direction. This constitutes the late arterial phase. The total acquisition time is 26 s and is accomplished in a single breath-hold. For a single arterial set of CT images, we might reduce the volume of the contrast medium because we can shorten the duration of the arterial phase imaging. However, for double arterial phase images consisting of the early and late arterial phases, we use 2 mL/kg of contrast medium to continue the injection during the arterial phase imaging. Twenty seconds after finishing the late arterial phase of the scan, the portal venous phase images are obtained with the same parameters (Fig. 1).

The exact definition and optimal timing of the hepatic arterial dominant phase remain somewhat uncertain and controversial. Different investigators have recommended scan delays of 20–30 s after initiating the intravenous

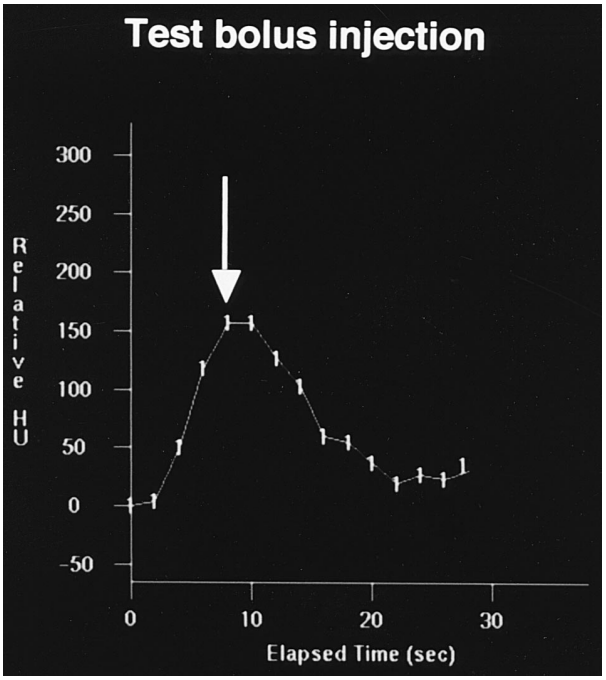

Fig. 2. The scanning time delay is determined by using a test bolus (15 mL at 5 mL/s) of contrast medium followed by a series of single-level CT scans at a low dose (120 KVp, 10 mA). The scan location is 20 cm below the dome of the liver and the monitoring scans are acquired every 2 s from 10 to 40 s. A cursor is placed over the abdominal aorta at this level and the interval to peak aortic enhancement is used to determine the scan delay for the early arterial phase images.

contrast bolus injection, with an injection rate of 4 or 5 mL/s [7, 8]. However, because of variables such as the patient's size and cardiovascular status, CT images may show different degrees of hepatic arterial, portal venous, hepatic venous, and parenchymal enhancement. To deter-

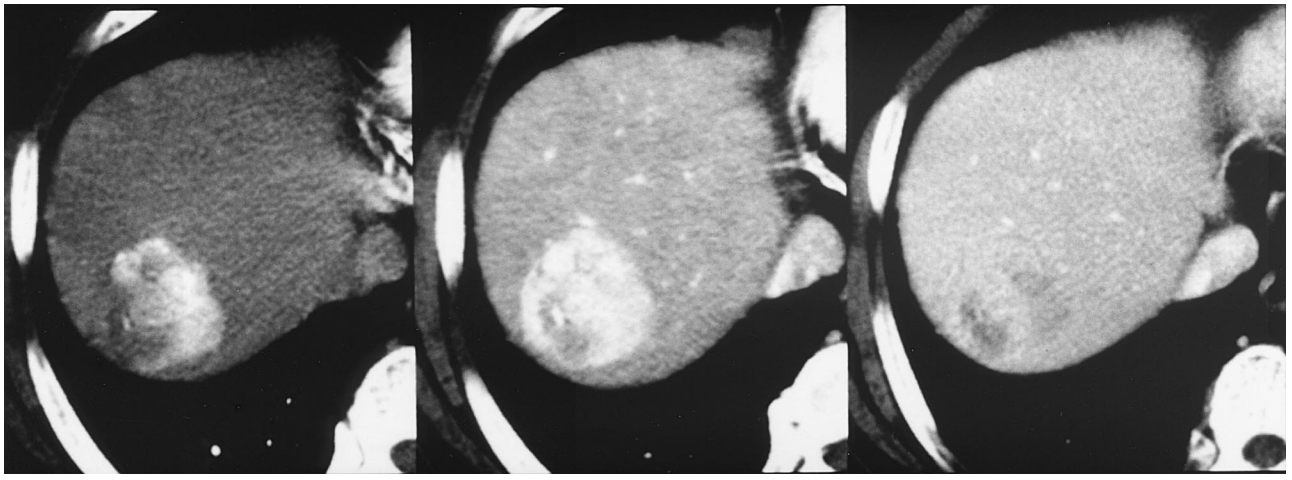

Fig. 3. A 55-year-old man with hepatocellular carcinoma 35 mm in diameter in the right anterior segment of the liver. *Left:* Early arterial phase. *Middle:* Late arterial phase. *Right:* Portal venous phase. The tumor shows marked contrast enhancement on the early and late arterial phase images and washout of contrast medium on the portal venous phase image.

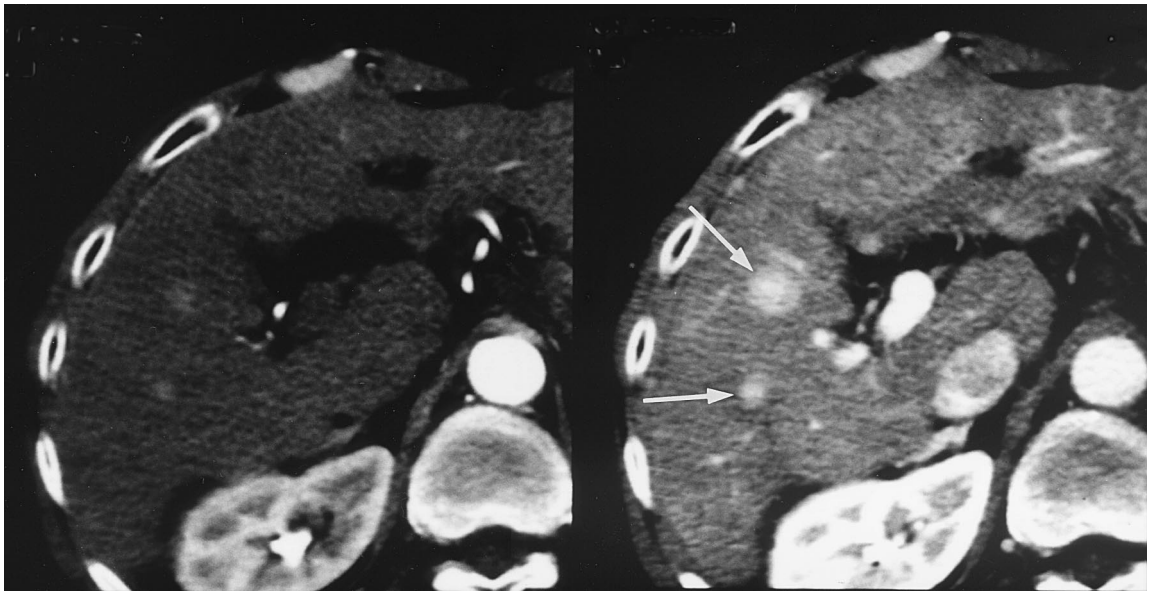

Fig. 4. A 66-year-old woman with two hepatocellular carcinomas 7 and 15 mm in diameter in the right anterior segment of the liver. *Left:* Early arterial phase. *Right:* Late arterial phase. The late arterial phase image shows the tumor more clearly than the early arterial phase (*arrows*).

mine the optimal delay time before scanning, a test bolus injection or automatic bolus tracking can be used. The scanning time delay is determined with a test bolus (15 mL at 5 mL/s) of 300 mgI/mL of non-ionic contrast medium through a 20-gauge intravenous catheter placed into the antecubital vein followed by a series of single-level CT scans at low dose (120 KVp, 10 mA). The scan location is 20 cm below the dome of the liver and the monitoring scans are acquired every 2 s from 10 to 40 s. A cursor is placed over the abdominal aorta at this level and the interval to peak aortic enhancement is used to determine the scan delay for the early arterial phase images (Fig. 2). As a result of this bolus tracking technique in our study [19], the scanning delays for the two arterial phases were quite variable, ranging from 14 to 36 s for the first arterial phase and from 29.5 to 51.5 s for the second. Therefore, we doubt that a standard scan delay would reliably result in optimal timing for either arterial phase set of CT images.

If full automatic bolus tracking technique is available, adjusting the timing of arterial phase CT scan of the liver may be useful. The scan should be started automatically

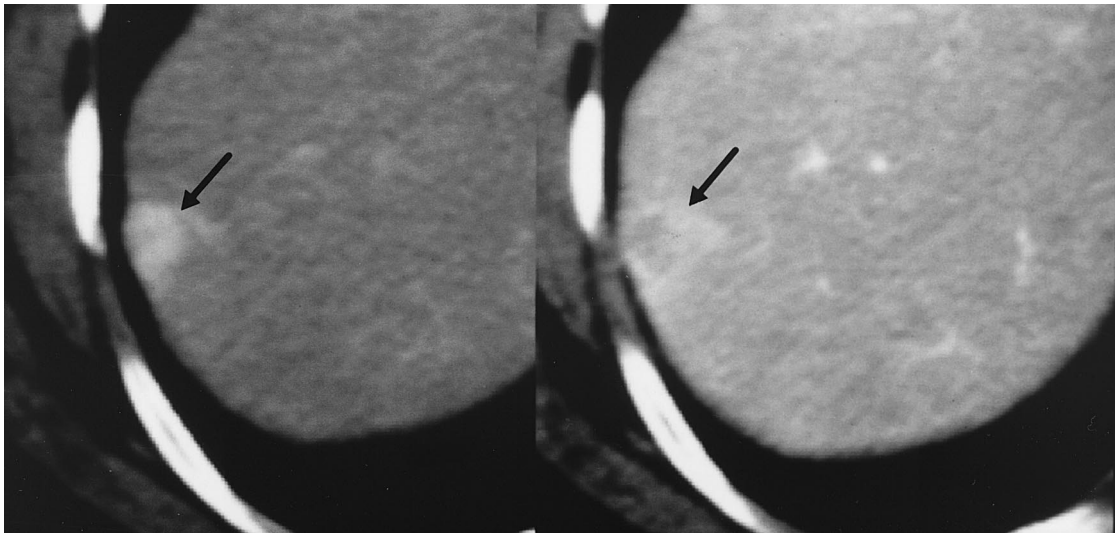

Fig. 5. A 70-year-old woman with a hepatocellular carcinoma 15 mm in diameter in the right anterior segment of the liver. *Left:* Early arterial phase. *Right:* Late arterial phase. The early arterial phase image shows hyperenhanced tumor, which is obscure on the late arterial phase image (*arrows*).

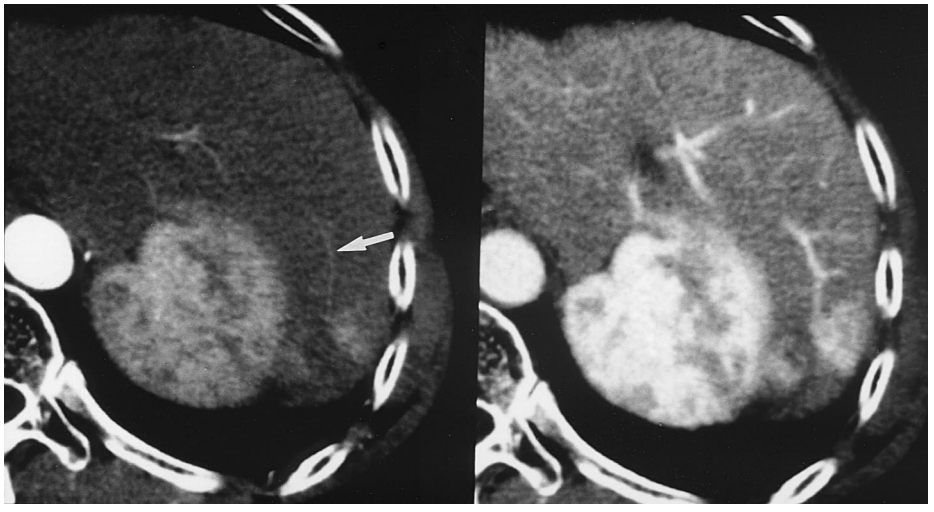

Fig. 6. A 59-year-old man with an arterial–portal venous shunt in the lateral segment of the liver. *Left:* Early arterial phase. *Right:* Late arterial phase. The late arterial phase image shows a hyperenhanced lesion in the lateral segment, which is considered a pseudolesion of the arterial portal venous shunt because the early phase image shows early portal venous enhancement (*arrow*) without tumor enhancement.

at a minimum of 7 s, including the time for breath-holding and table movement, etc., after triggering at a threshold of 50–100 HU relative to enhancement of the abdominal aorta. However, when using semiautomatic bolus tracking, it takes at least 10 s (depending on the CT scanner) to start scanning after triggering. This delay of 10 s is not a problem for obtaining the arterial phase images with markedly enhanced HCC, but might degrade the arterial phase images to make CT arteriographic images.

The multidetector row helical CT can acquire two complete sets of images through the liver during a single breath-hold. By controlling for patient-related variables, we can study the relative contributions of two separate hepatic arterial phase imaging sequences in the detection of HCC. Patient size is minimized as a variable by administering the contrast medium at a volume of 2 mL/kg. Cardiovascular status as a variable is controlled by using a test dose of contrast medium and acquiring a set of bolus tracking CT sections [19].

Tumor detection and characterization

In general, early arterial phase CT images show intense hepatic arterial enhancement, minimal portal venous enhancement, and essentially no hepatic venous or parenchymal enhancement. Late arterial phase images demonstrate substantial portal venous, slight parenchymal, and no hepatic venous enhancement [20]. In theory, hypervascular hepatic tumors, such as HCC, are detected best

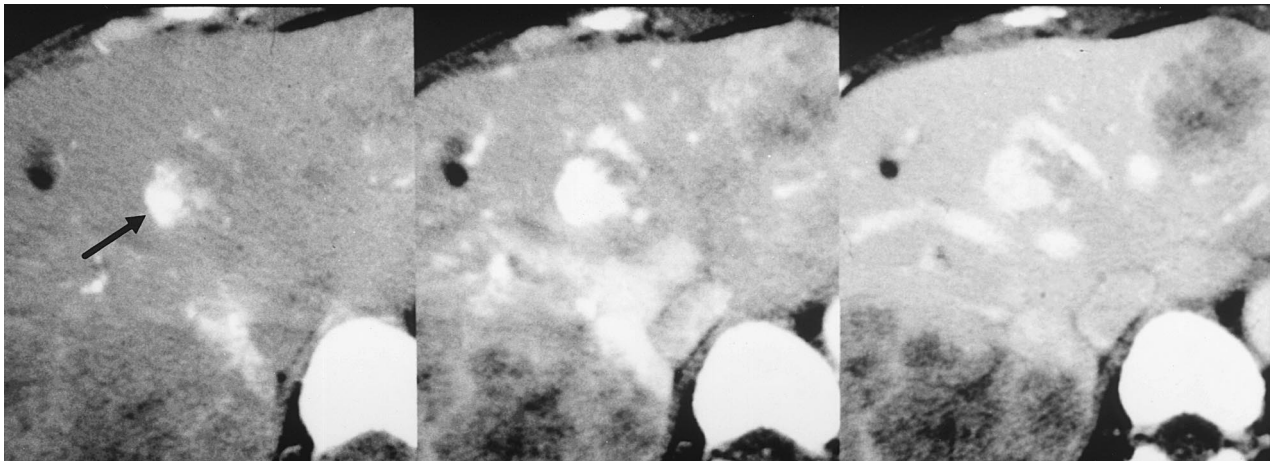

Fig. 7. A 66-year-old man with small hemangioma in segment 4 and metastatic liver tumor in segments 6, 7, and 3. *Left:* Early arterial phase. *Middle:* Late arterial phase. *Right:* Portal venous phase. The hemangioma in segment 4 shows the same total enhancement in the late arterial phase as in the portal venous phase, but peripheral globular enhancement seen only in the early arterial phase (*arrow*) strongly indicates the diagnosis of hemangioma. Higher temporal and spatial resolution imaging can demonstrate a typical enhancement pattern and characterize the tumor.

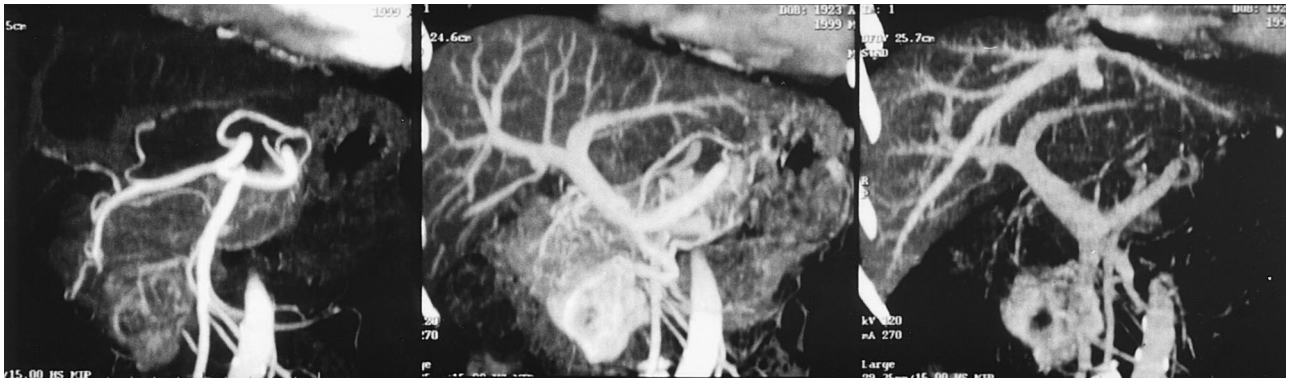

Fig. 8. CT angiography with multidetector row helical CT. *Left:* CT arteriography reconstructed from the early arterial phase images with an oblique thick-slab maximum intensity projection technique. *Middle:* CT portography from late arterial phase images. *Right:* CT hepatic venography from portal venous phase images. Early arterial phase images are useful for hepatic and pancreatic CT arteriography, late arterial phase images for hepatic CT portography, and portal venous phase images for hepatic CT venography.

during a phase of maximal tumor enhancement and minimal hepatic parenchymal enhancement. Multiphasic imaging is useful for visualizing specific tumor vascularity and helpful for tumor characterization. However, HCC may show variable vascularity because of its histologic tumor grade; therefore, multiphasic imaging can show HCC with variable vascularity on some phase images [21]. HCC also shows washout of contrast medium in the portal venous and equilibrium phases.

When we obtained two complete sets of arterial phase images through the liver during a single breath-hold (double arterial phase), the late compared with the early arterial phase images showed significantly superior contrast-to-noise ratio between the hypervascular tumor and the liver parenchyma [13] and were significantly superior for the detection sensitivity of hypervascular HCC [19] (Figs. 3, 4). However, the early arterial phase images sometimes showed HCC more clearly than the late arterial phase (Fig. 5). We think that this phenomenon reflects another variable that is impossible to predict or control, namely tumor variability and vascularity. Some hypervascular tumors became nearly isoattenuating to hepatic parenchyma during the late arterial phase [19].

Double arterial phase imaging showed significantly superior sensitivity to the late arterial phase for detecting HCC, especially for detecting HCC smaller than 2 cm in diameter [19]. Even when using the test injection technique, as we did, some of the late arterial phase images showed substantial hepatic venous and parenchymal enhancement; therefore, it is better to obtain early and late (double) arterial phase images.

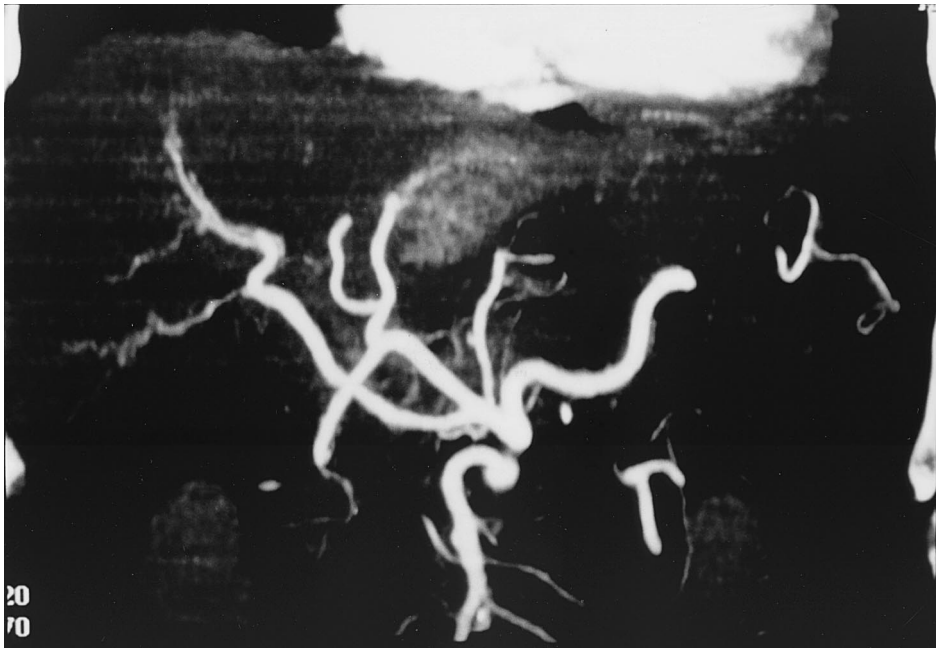

Fig. 9. CT arteriography of the celiac arterial branches of normal variant, reconstructed from early arterial phase images. Note the major arterial trunk and its small branches, the right hepatic artery arising from the celiac axis, middle and left hepatic arteries, left gastric artery, and gastroduodenal artery.

Moreover, double arterial phase imaging showed better positive predictive values than early or late arterial phase imaging alone, indicating fewer false positive lesions [19]. Some of arterial and portal venous shunts were misinterpreted as foci of HCC when using only one arterial set of CT images because these images showed focal areas of hyperattenuation. However, when reviewing the double arterial phase images, we could reduce these false positive lesions because the early arterial phase images showed arterial and premature portal venous enhancement without a focal hypervascular mass (Fig. 6) [19].

We believe that portal venous phase images should be obtained routinely in any CT evaluation for known or suspected primary or metastatic tumor [6–8, 22]. Some "hypervascular" tumors may demonstrate little enhancement, especially after treatment. In addition, the portal venous phase is usually optimal for additional characterization of liver tumors and demonstration of vascular anatomy and pathology.

Because cirrhosis markedly alters hepatic hemodynamics, we cannot predict whether the double arterial phase CT technique or timing that we used would be effective in the evaluation of hypervascular metastases occuring in normal liver.

When a tumor is small, specific findings of each of tumor become obscure due to partial volume effect, etc. Dynamic study with higher temporal and spatial resolution with multidetector row helical CT clearly can show the specific findings (Fig. 7).

Multidetector row helical CT allows acquisition of early and late arterial sets of liver images. Whereas late arterial phase images depict more hypervascular HCC lesions than the early phase, review of both arterial phase images produces the greatest sensitivity and positive predictive value [19].

CT angiography

There are few reports that describe the usefulness of CT angiography with a single helical CT for evaluating the hepatic arterial anatomy [16, 17]. Because the patient populations of the studies were transplantation candidates, the basic types of hepatic arterial blood supply were evaluated. Multidetector row helical CT enables us to obtain thinner section collimation with higher temporal resolution than the single-slice helical CT scanner and it is expected to be useful for three-dimensional CT angiography.

When reviewing the two separate sets of hepatic arterial dominant phase and portal venous phase CT images of the liver that we made during our liver CT protocol, we noted that the small branches of the hepatic arteries often could be visualized without portal venous enhancement during the early arterial phase, that the peripheral branches of the portal vein could be demonstrated during the late arterial phase without the hepatic venous enhancement, and that the hepatic vein was clearly demonstrated during the portal venous phase [13, 20] (Fig. 8). Because of the limitation of the scan speed of single-slice helical CT scanner, the second phase has to begin approximately 1 min after the initiation of contrast medium,

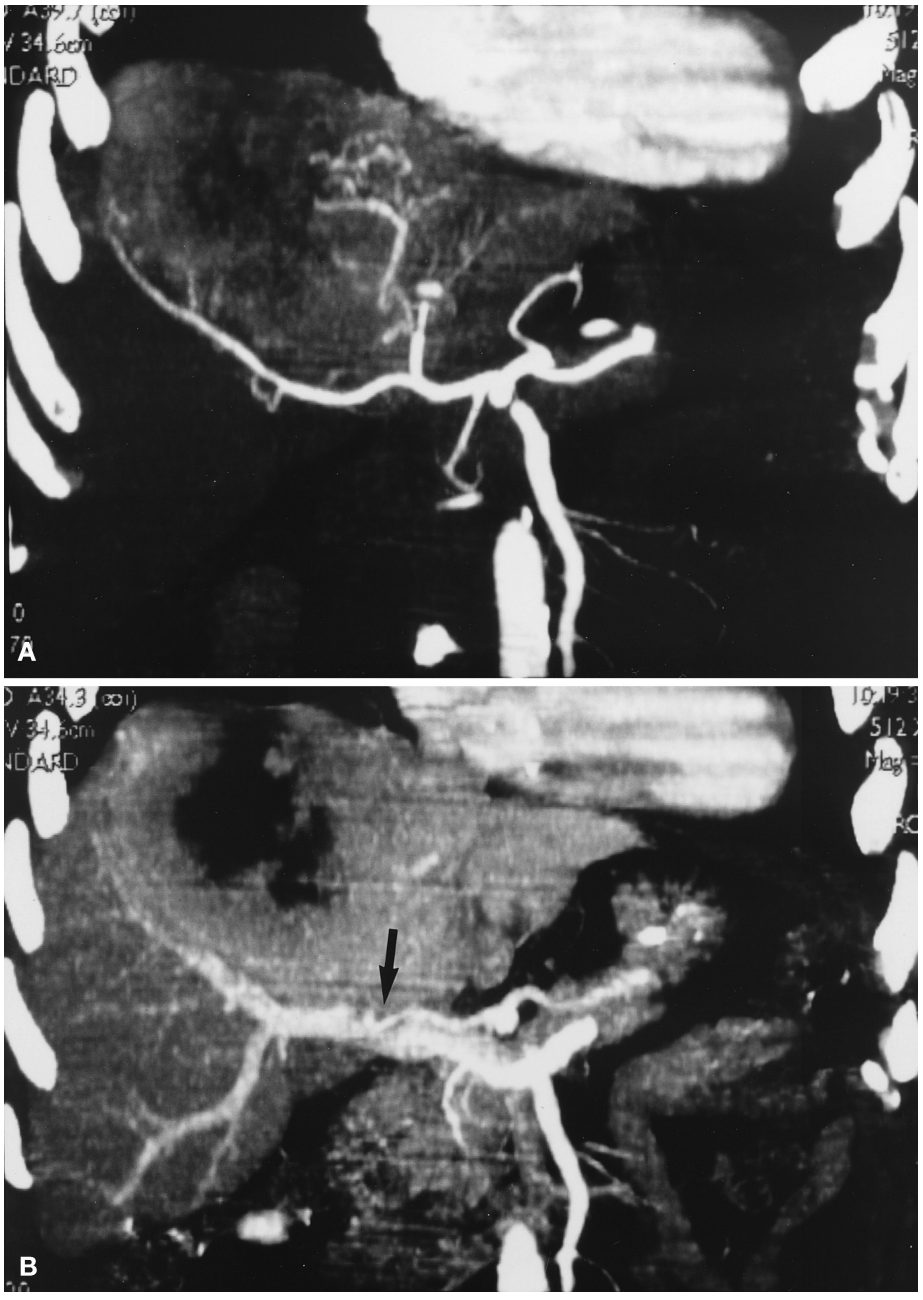

Fig. 10. A 65-year-old man with large hepatocellular carcinoma in hepatic segments 4 and 8. **A** CT angiography reconstructed from early arterial phase images shows the tumor stain and feeding artery of the tumor. **B** CT angiography from the late arterial phase shows left portal vein occlusion by tumor thrombus (*arrow*).

corresponding to the portal venous phase, when biphasic dynamic study is applied. However, the late arterial phase obtained by multidetector row helical CT is better than the portal venous phase for demonstrating the intrahepatic branches of the portal vein [13, 20]. Kim et al. [23] reported that the hepatic parenchyma started to enhance approximately 16 s after the enhancement value of aorta reached 100 HU with the injection rate of 5 mL/s. Therefore, the second arterial phase in our protocol corresponds to the starting time of enhancement of hepatic parenchyma. Takahashi et al. observed 100% of major arterial trunks in all cases and detected approximately 80% or more of the small branches of the hepatic and pancreatic arteries in the early arterial phase [20]. They also observed 100% of the major portal venous systems and detected more than 85% of the small branches of the portal system in the late arterial phase [20].

Little attention has been paid to the CT appearance of small branches of the hepatic artery, such as the middle hepatic artery, cystic artery, and right gastric artery (Fig. 9). However, these small arteries might be important for intervention procedures, such as transarterial chemother-

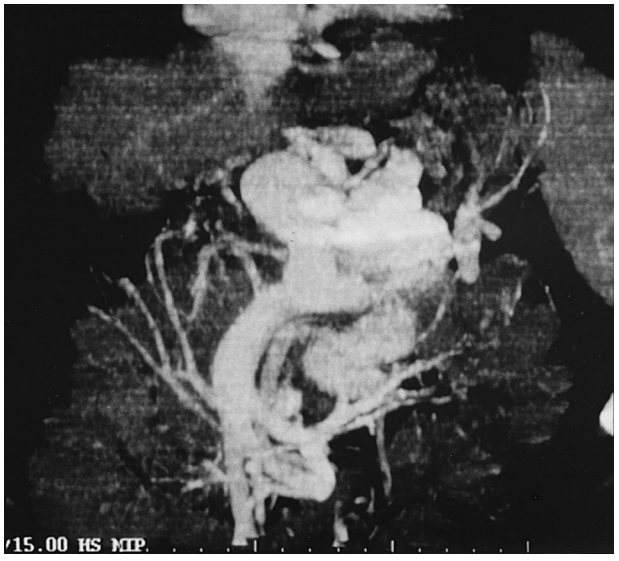

Fig. 11. CT angiography reconstructed from portal venous phase images clearly shows the anatomic information of the varices due to portal hypertension in cirrhotic patients.

apy and transarterial embolization. HCC is usually hypervascular and sometimes invades the portal vein. Portal or hepatic venous invasion due to tumor thrombus is recognized on CT portography from the late arterial phase images or hepatic CT venography from the portal venous phase images, respectively (Fig. 10).

Cirrhotic patients with HCC usually have collateral vessels (varices) due to portal hypertension. CT angiography reconstructed from late arterial or portal venous phase images can show the anatomic information of the varices very clearly (Fig. 11). It is also very useful for intervention procedures, such as transjugular intrahepatic portosystemic shunt and balloon occluded retrograde transvenous obliteration.

The imaging technique for CT angiography with the use of multidetector row helical CT is also useful for detecting hypervascular hepatic neoplasms. It is very beneficial that detailed assessment of hepatic arterial anatomy and lesion detection can be achieved in a single study.

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