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Can low-dose CT with iterative reconstruction reduce both the radiation dose and the amount of iodine contrast medium in a dynamic CT study of the liver?

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ABSTRACT

Purpose: To investigate whether low-dose dynamic CT of the liver with iterative reconstruction can reduce both the radiation dose and the amount of contrast medium.
Materials and methods: This study was approved by our institutional review board. 113 patients were randomly assigned to one of two groups. Group A/group B (fifty-eight/fifty-five patients) underwent liver dynamic CT at 120/100 kV, with 0/40% adaptive statistical iterative reconstruction (ASIR), with a contrast dose of 600/480 mg I/kg, respectively. Radiation exposure was estimated based on the manufacturer's phantom data. The enhancement value of the hepatic parenchyma, vessels and the tumor-to-liver contrast of hepatocellular carcinomas (HCCs) were compared between two groups. Two readers independently assessed the CT images of the hepatic parenchyma and HCCs.
Results: The mean CT dose indices: 6.38/4.04 mGy, the dose-length products: 194.54/124.57 mGy cm, for group A/group B. The mean enhancement value of the hepatic parenchyma and the tumor-to-liver contrast of HCCs with diameters greater than 1 cm in the post-contrast all phases did not differ significantly between two groups ($P > 0.05$). The enhancement values of vessels in group B were significantly higher than that in group A in the delayed phases ($P < 0.05$). Two reader's confidence levels for the hepatic parenchyma in the delayed phases and HCCs did not differ significantly between the groups ($P > 0.05$).
Conclusions: Low-dose dynamic CT with ASIR can reduce both the radiation dose and the amount of contrast medium without image quality degradation, compared to conventional dynamic CT without ASIR.

1. Introduction

The recent innovation of multidetector row computed tomography (MDCT) with a bolus injection of contrast medium (CM) allows the hemodynamics of liver tumors and the hepatic parenchyma to be evaluated in detail. However, it entails an increase in the number of abdominal CT examinations performed and the radiation exposure of patients who undergo CT studies [1,2]. Dose reduction techniques with low tube voltages are reported to reduce the patient's exposure to radiation, although they increase the image noise [3–5]. Adaptive statistical iterative reconstruction (ASIR), a newly introduced reconstruction technique for CT, can reduce the quantum noise associated with standard convolution filtered back-projection (FBP) reconstruction algorithms. In previous reports, low-dose CT with ASIR showed diagnostic acceptability similar to that of conventional CT with FBP, thus permitting lower radiation doses during abdominal imaging (mean reduction in the radiation dose of 20–65%) [6–8].

CT scans performed with a low tube voltage can also yield images with improved contrast enhancement using the same dose of CM. Therefore, the amount of CM can be reduced without image quality degradation by reducing the tube voltage in abdominal dynamic CT [4]. Nakayama et al. reported that low-tube-voltage scans are appropriate for patients with lower body weights without renal dysfunction and for heavier patients with renal dysfunction with aortic disease, because the CM volume can be reduced [5]. The results of that study are useful for CT angiography, but it is also necessary to investigate whether low-dose CT is applicable to dynamic CT of the liver.

The purpose of this study is to investigate whether low-dose CT with iterative reconstruction can reduce both the radiation dose and the amount of CM required in dynamic CT of the liver.

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2. Materials and methods

2.1. Subjects

This study was approved by the review board of our institution. Written informed consent to participate in the study was obtained from all patients. During the period between January and July 2011, 124 patients were prospectively enrolled in the study, then randomly assigned to group A and group B. The inclusion criteria for this study were: (a) hepatitis B or C; (b) known hepatocellular carcinoma (HCC) without treatment within the three months preceding the CT examination, suspected space-occupying lesions in the liver on ultrasonography, or elevated tumor marker levels (α-fetoprotein or des-γ-carboxy prothrombin); and (c) absence of renal impairment (serum creatinine level >1.5 mg/dL, glomerular filtration rate <30 ml/min/1.73 m^2) and no contraindication for iodinated CM. A flowchart of the enrollment of the study population was shown in Fig. 1. Eleven (8%) of the 124 enrolled patients were excluded from the study because of: (a) equipment failure due to the lack of the patients' consensus ($n = 4$); (b) inadequate injection technique ($n = 3$); or (c) body weight (BW) ≥71 kg ($n = 4$). Patients with BW ≥ 71 kg were excluded, because previous study of MDCT aortography with a low tube voltage and low-dose CM indicated that the patients weighing more than 70 kg should be scanned according to the standard [120 kVp of tube voltage CT, 100 mL (300 mg I/mL) of CM] protocol to maintain image quality [5]. So we estimate that the result of that study can also refer to an image noise elevation of hypervascular liver tumor in patients with BW ≥ 71 kg. Finally, fifty-eight patients were assigned to group A and 55 patients to group B. Group A included 32 men and 26 women (age range, 41–85 years; mean, 73 years) and group B included 33 men and 22 women (age range, 37–84 years; mean, 71 years). The mean BW was 53 kg (range, 43–70 kg) in group A and 55 kg (range, 37–70 kg) in group B, which were not significantly different (Mann–Whitney's U test was performed; $P = 0.27$). The mean body mass index, calculated as weight in kilograms divided by height in meters squared, was 21 (range, 17–25) in group A and 22 (range, 17–28) in group B, which were not significantly different (Mann–Whitney's U test was performed; $P = 0.11$).

In addition, the coordinator (H.T.) with ten years of experience in gastrointestinal and hepatobiliary radiology assessed the CT images in both groups for the diagnosis of hypervascular HCC and the evaluation of tumor-to-liver contrast, according to the imaging definition of the American Association for the Study of Liver Diseases guideline [10]. In the diagnosis of HCC with diameters greater than 1 cm, twenty five hypervascular HCCs in ten patients of group A and 18 hypervascular HCCs in 9 patients of group B were confirmed in the dynamic CT of the liver. In the diagnosis of HCCs with diameters smaller than 1 cm, eighteen hypervascular HCCs (mean diameters; 0.72 ± 0.16 cm) in ten patients of group A and 13 hypervascular HCCs (mean diameter; 0.8 ± 0.12 cm) in 8 patients of group B were confirmed in the dynamic CT of the liver.

2.2. Clinical image data acquisition

2.2.1. Measurement of radiation exposure

Since it is not possible to characterize the specific dose given to each patient under our routine clinical conditions, we used the CT dose index (CTDI) and dose length product (DLP) for estimation of radiation exposure based on the manufacturer's phantom data. The CTDIs were measured for both CT protocols by using an adult-sized poly-methyl methacrylate (PMMA) phantom. The phantom was 32 cm in diameter and of at least 14 cm in length for body scanning. The measurements are taken at the center and peripheral within the PMMA phantom. CTDI is a dose index which consists of 2/3 of the $CTDI_{100}$ peripheral dose plus 1/3 of the $CTDI_{100}$ central dose. The $CTDI_{100}$ dose is defined as the integral of the dose profile produced in a single axial scan along a line perpendicular to the imaging plane from −50 mm to +50 mm, divided by the product of the number of slices and the nominal tomographic section thickness. The DLP is computed given the CTDI × (total scan coverage in cm). The system computes CTDI and DLP automatically. For radiation dose assessment, CTDI and DLP were recorded from the dose page of each abdominal CT from the PACS workstation (Synapse® PACS, FUJIFILM Medical Systems) for all CT examinations.

2.3. CT scanning

Patients in group A underwent conventional dynamic CT at 120 kVp with auto mA (noise index, NI = 11.0) with a setting of 0% ASIR and those in group B underwent dynamic CT at 100 kVp with auto mA (NI = 14.0) with a setting of 40% ASIR for the detection and screening of HCC on a 64-channel MDCT system. Four phases (unenhanced, arterial, portal venous and equilibrium phases) imaging was performed for the dynamic CT of the liver. Arterial phase scanning was commenced 20 s after the CT number of the supraceliac abdominal aorta reached at 100 HU. For the portal venous and equilibrium phases, time delays of 30 and 80 s after arterial phase scanning were applied, respectively. The same protocol was used for both groups, as follows: display FOV = 35 cm, reconstruction slice thickness = 5 mm, detector collimation = 0.625 mm, detector pitch = 0.984, gantry rotation period = 0.4 s, and matrix size = 512 × 512 pixels. Kernel regression for image processing and reconstruction was standard.

2.4. Contrast injection protocols

The amount of CM was determined according to the iodine dose and the patient's BW. All Patients in group A received 600 mg I/kg of nonionic CM intravenously [11], and those in group B received 480 mg I/kg. We prepared four kinds of iodine CM for each patient's size to minimize patients' allergic risk. In group A, 1.9 mL/kg CM with an iodine concentration of 320 mg I/mL (ioversol; Optiray® 320) was used for patients with BW ≤ 53 kg; 1.6 mL/kg CM with 370 mg I/mL (iopamidol; Iopamiron® 370) was used for patients with BW = 54–61 kg; and 2 mL/kg CM with 300 mg I/mL (iohexol) was used for patients with BW = 62–70 kg. In group B, 2 mL/kg CM with an iodine concentration of 240 mg I/mL (ioversol; Optiray® 240, Covidien, Tokyo, Japan) was used for patients with BW ≤ 50 kg; 1.5 mL/kg CM with 320 mg I/mL (ioversol; Optiray® 320) was used for patients with BW = 51–66 kg; and 1.3 mL/kg CM with 370 mg I/mL (iopamidol; Iopamiron® 370, Bayer Healthcare, Osaka, Japan) was used for patients with BW = 67–70 kg.

The same protocol was used for both groups, with a fixed CM injection duration of 30 s. For example, a patient in group A (BW = 50 kg) should receive 50 × 600 = 30,000 mg of iodine, so 100 mL of CM (300 mg I/mL) was used, with an injection rate of CM of 100 mL/30 s = about 3.3 mL/s. The injection duration was fixed at 30 s so that sufficient aortic enhancement (approx. 300 HU) was achieved in most patients with an iodine dose of about 500 mg/kg [1]. It has been reported that over 500 mg of iodine per kg of BW is required to achieve high diagnostic quality on liver CT [2,6]. To determine the scanning time for hepatic arterial-phase imaging, the arrival time of contrast medium to the abdominal aorta was measured using an automatic bolus-tracking technique with automated scan-triggering software (SmartPrep®; GE Healthcare, Japan).

2.5. Image analysis

2.5.1. Quantitative image analysis

CT values (HU) were measured by placing region of interest (ROI)s (approx. 2 cm^2) on the hepatic parenchyma (three point ROIs