Portal Venous-Phase CT of the Liver in Patients without Chronic Liver Damage: Does Portal-Inflow Tracking Improve Enhancement and Image Quality?

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Received June 7, 2013; revised July 7, 2013; accepted July 15, 2013

ABSTRACT

Purpose: This study was undertaken to determine if portal-inflow bolus tracking outperforms aortic bolus tracking with respect to the image quality of contrast-enhanced portal venous-phase CT of the liver in patients without chronic liver damage. Materials and Methods: Contrast-enhanced CT of the liver was performed in 132 consecutive patients without chronic liver damage. Patients were prospectively assigned to three protocols: Protocol A—a portal venous-phase scan delay of 6 seconds after superior mesenteric venous (SMV) enhancement increased by 70 HU or 14 seconds after SMV enhancement was visually confirmed, and Protocols B and C—40 and 50 seconds, respectively, after abdominal aortic enhancement increased by 100 HU. Enhancement (ΔHU) of abdominal aorta, portal trunk, and liver parenchyma and diagnostic acceptability were assessed. Results: ΔHU of aorta was higher for protocol A than for protocols B and C (P < 0.05), whereas ΔHU of portal trunk was higher for protocol B than for protocols A and C (P < 0.05). ΔHUs of liver were similar in three protocols. No difference was found between diagnostic acceptabilities of three protocols. Conclusion: Portal-inflow bolus tracking did not outperform aortic tracking in terms of optimization of portal venous-phase CT in patients without chronic liver damage.

Keywords: CT; Liver; Contrast Enhancement; Bolus Tracking

1. Introduction

Usefulness of contrast-enhanced CT for the diagnosis of hepatic diseases is widely recognized and the technique is employed at many centers. Furthermore, temporally resolved multi-phasic CT scanning after the intravenous bolus injection of contrast material is a crucial for the detection and characterization of focal hepatic lesions [1-5]. In particular, the acquisition of optimal portal venous-phase images is essential for the diagnosis of hyper- or hypovascular liver metastases [3-5].

Several researchers have described methods of optimizing scan delays after contrast injection, in particular, for the hepatic arterial-dominant phase imaging, with the use of bolus-tracking [6], test-bolus imaging [7], and fixed injection duration [8] techniques. Bolus-tracking is widely employed in many centers to optimize scan protocols of contrast-enhanced CT of the liver, including the acquisition of hepatic arterial-dominant phase images and subsequently of portal venous-phase images.

Portal venous-phase images play an important role in the detection of malignant hepatic tumors by maximizing the tumor-to-liver contrast, and in the characterization of focal hepatic lesions by demonstrating washout of malignant hepatic tumors [9] or the peripheral paddling of cavernous hemangiomas [2,10]. Nowadays, because the total scan time for the entire liver has reduced to as little as 2 seconds, we wondered whether a dedicated technique could allow scanning of the whole liver and capture the most intense enhancement of liver parenchyma during the portal venous phase. The purpose of this study was to determine if portal-inflow tracking outperforms the widely employed aortic bolus tracking for the optimization of contrast-enhanced portal venous-phase CT of the liver in patients without chronic liver damage. A literature search failed to unearth any reports on this topic.

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2. Materials and Methods

2.1. Patients

This HIPAA-compliant study had institutional review board approval and all patients provided written informed consent. During a recent 5-month period, 176 consecutive patients with a known malignancy and without known chronic liver disease due to viral, alcoholic, autoimmune, or cryptogenic hepatitis underwent abdominopelvic contrast-enhanced CT for a preoperative work-up or a post-therapeutic survey. Of these, 44 patients were excluded because of; prior abdominal surgery that could significantly alter the portal venous blood flow dynamics (n = 38), diffuse fatty liver (n = 2), and numerous liver metastases (n = 4). The remaining 132 patients (88 men and 44 women; age range, 19 - 91 years; mean age, 62.1 years) constituted the study population. The primary malignancies in these 132 patients were; rectal (n = 35), gastric (n = 29), colon (n = 28), breast (n = 10), uterine cervical (n = 5), endometrial (n = 3), esophageal (n = 3), ovarian (n = 3), prostate (n = 2), pancreatic (n = 2), renal cell (n = 1), bile duct (n = 1), appendiceal (n = 1), pulmonary (n = 1), urinary bladder (n = 1) or testicular (n = 1) carcinoma, or gastrointestinal stromal tumor of the stomach (n = 2), malignant lymphoma of the cervical lymph nodes (n = 2), uterine leiomyosarcoma (n = 1), and Paget's disease of the scrotum (n = 1).

2.2. Contrast Material Injection and Scan Protocols

A 16-detector CT scanner (Lightspeed 16; GE Healthcare, Milwaukee, WI) with a fixed tube voltage of 120 kVp and an automatic tube current modulation program (3D mA Modulation; GE Healthcare) was used. Other CT parameters were as follows: collimation, 1.25 mm; detector configuration, 16 detectors with a 1.25-mm section thickness (16 × 1.25 mm); table feed, 27.5 mm per rotation; pitch, 1.37; cranio-caudal scan range, 45 - 50 cm; 32-cm field of view; 0.5-second gantry rotation time; and scan acquisition time, 8.8 - 9.7 seconds. All transverse CT images were reconstructed at section thickness of 5 mm by using a standard reconstruction algorithm.

After the acquisition of unenhanced images, a bolus-tracking program (Smart Prep; GE Medical Systems) was used to determine the optimal time to initiate diagnostic portal venous-phase scanning following the administration of contrast medium. All patients were administered non-ionic iodinated contrast material containing 300 mg of iodine per milliliter warmed to body temperature at a dose of 2 mL per kilograms injected intravenously over 30 seconds using a commercially available power injector through a 21-gauge plastic catheter, which was typically placed in either an antecubital vein or a radial vein. The fractional dose was 20 mg iodine/kg/sec.

2.3. Quantitative Image Analysis

A radiologist (H. W.) with 5 years of post-training experience at interpreting body CT images measured mean CT numbers and determined standard deviations in the abdominal aorta, portal vein trunk, and liver on a commercially available DICOM viewer. Measurements were performed on unenhanced and portal venous-phase axial images. CT numbers of livers were averaged. CT numbers of livers were measured in the left lateral, right anterior, and right posterior segments devoid of blood vessels, bile ducts, focal hepatic lesions, calcifications, and artifacts, and the numbers obtained were averaged. Quantitative degrees of contrast enhancement are expressed as CT numbers increases from unenhanced to contrast-enhanced axial images (ΔHU).

2.4. Qualitative Image Analysis

Two radiologists (H. Kondo and S. G.) with 13 and 10 years of post-training experience of interpreting body CT images, respectively, who were unaware of patient clinical information and CT imaging parameters prospectively and independently reviewed CT images. Each radiologist first graded images alone, and subsequently, consensus grades were reached by discussion.
The radiologists independently graded portal venous-phase CT images separately for diagnostic acceptability using a five-point scale (grade 1 = unacceptable, grade 2 = suboptimal, grade 3 = acceptable, grade 4 = good, grade 5 = excellent). A grade was awarded to each patient after reviewing all images. Grade 5 was given when the image quality (soft tissue contrast, sharpness of tissue interfaces, lesion conspicuity, and paucity of image degradation caused by streaking noise or beam-hardening artifacts) was deemed superb; grade 3 when image quality was fair and did not hamper image interpretation; and grade 1 when image quality was considerably poor enough to hampered image interpretation. Grades 4 and 2 were defined as being intermediate between grades 5 and 3 and grades 1 and 3, respectively.

2.5. Statistical Analysis

Statistical analyses were performed using commercially available software (SPSS, version 17; SPSS, Chicago, Ill). For quantitative measurements, one-way analysis of variances (ANOVA) was performed to compare background factors (patient age and body weight) and mean ΔHUs of the abdominal aorta, portal trunk, and liver between the three protocols. When a statistically significant intergroup difference was found by ANOVA, pairwise comparisons were performed using the Mann-Whitney test with Bonferroni correction, and a stricter p value criterion of <0.017 was considered significant. The Kruskal-Wallis test was used to compare qualitative grades. When a significant difference was found between the three protocols, pairwise comparisons were performed using the Mann-Whitney test with Bonferroni correction, and again a stricter p value criterion <0.017 was considered significant.

3. Results

3.1. Patient Background Factors

The protocol A, B, and C groups consisted of 46, 43, and 43 patients, respectively. No significant difference was found between any two groups in terms of age or body weight (Table 1). Medians times from initiations of contrast injections to initiations of diagnostic scans were 47, 56, and 67 seconds for the three protocols, respectively (Figure 1).

3.2. Quantitative Image Analysis

Means values and the 1 SDs of the ΔHUs of the abdominal aortas, portal veins, and livers for the three protocols are summarized in Table 2, and medians and ΔHU variabilities are summarized in Figure 2. The mean ΔHU of the abdominal aorta was higher for protocol A than for protocols B and C (P < 0.05), and the mean ΔHU of the

<table>
<thead>
<tr>
<th>Table 1. Patient age and body weight in the three protocols.</th>
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<tr>
<td>Protocol A (n = 46)</td>
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<td>Age (y)</td>
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<tr>
<td>Body weight (kg)</td>
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No significant difference in age (P = 0.77) and body weight (P = 0.15) was found between any two protocols.

<table>
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<tr>
<th>Table 2. Contrast enhancement of the abdominal aorta, portal vein, and liver in the three protocols.</th>
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<tr>
<td>Protocol A (n = 46)</td>
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<tr>
<td>Abdominal Aorta</td>
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<tr>
<td>Portal vein</td>
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<tr>
<td>Liver</td>
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Note: Numbers are mean ΔHU ± 1SD. *Value was significantly greater than those in protocols B and C (P < 0.05). **Value was significantly greater than those in protocols A and C (P < 0.05).

Figure 1. Box plot showing time in seconds from initiation of intravenous contrast injection to initiation of portal venous diagnostic scan. Median values were 47, 56, and 67 seconds for protocols A, B, and C, respectively. Boundary of boxes closest to zero indicates 25th percentile, line within boxes indicates median, and boundary of boxes farthest from zero indicates 75th percentile. Error bars indicate smallest and largest values within 1.5 box lengths of 25th and 75th percentiles. Outliers are represented as individual points.

Figure 2. Box plot showing increased contrast enhancement in HU from unenhanced to portal venous-phase images for abdominal aorta, portal vein trunk, and liver. Note same definitions of symbols as those in Figure 1.
portal trunk was higher for protocol B than for protocols A and C ($P < 0.05$). On the other hand, the mean liver ΔHUs in the three groups were comparable.

### 3.3. Qualitative Image Analysis

The mean grades for diagnostic acceptability were $4.30 \pm 0.70$, $3.93 \pm 0.73$, and $4.19 \pm 3.88$ for protocols A, B, and C, respectively (Figures 3 and 4). No difference was found between the three protocols.

### 4. Discussion

The median time from initiating contrast injection to initiating a diagnostic scan with SMV tracking (protocol A) was 47 seconds, and this was rather shorter than 56 and 67 seconds required for aortic tracking (protocols A and B, respectively). Furthermore, the variability of these durations was greater with SMV tracking. The greater variability observed when employing SMV tracking was expected, because these durations were strongly affected by circulation time variations of the portal venous system and systemic circulation. Although we set the delay time from bolus detection in the SMV to maximize hepatic contrast enhancement based on the results of our preliminary study, the actual time from initiation of contrast injection to portal venous-phase diagnostic scan was shortest for protocol A. However, had we even extended the delay time with SMV tracking by for example nine seconds, so that median of the duration was the same as that of protocol B, liver enhancement might have been similar to that observed in the present study.

Despite the difference of no less than 20 seconds in median times from initiation of contrast injection to scan start between SMV and aortic tracking methods, no intergroup difference in hepatic enhancement was observed, which suggested that durations of peak hepatic enhancement in the portal venous phase was sustained fairly long. Therefore, in contrast to scan timing optimization for the hepatic arterial-dominant phase, the scan time window for the portal venous phase was rather wide, and hence strict scan timing optimization might not be necessary for portal venous-phase imaging.

Livers were enhanced on average by 54 - 58 HU during the portal venous phase for all three protocols and no significant difference was observed. HU increases of livers in the present study are consistent with those of a previous study [11], in which it was shown that maximum hepatic enhancement in the portal venous phase was linearly correlated with the iodine dosage (mg/kg of body weight). In this previous study, an iodine dose of 520 mg/kg yielded a hepatic enhancement by 50 HU [11].

In the present study, the standard deviations of hepatic enhancement for all three protocols lay in the range 8.8 - 9.3 HU, and no difference was found between the protocols. Furthermore, qualitative image qualities (based on diagnostic acceptability) were similar for the three protocols. These observations also concur well with those of the previous study [11], in which maximum hepatic enhancement was found to be strongly correlated with iodine dosage (mg/kg) as long as portal venous-phase images were obtained during the fairly long, peak liver enhancement.

When we undertook this study, we also sought to determine whether portal venous tracking allows variabilities in the timing of contrast material portal inflow to be corrected and allows stably capture of maximum hepatic enhancement using a rapid CT scanner that enables a whole liver scan to be conducted within seconds. However, SMV tracking was not found to produce stronger hepatic enhancement despite the somewhat more complex procedure required as compared with aortic tracking.

In the present study, enhancement of the portal vein was significantly greater for aortic tracking with a 40-second scan delay (protocol B). One possible explanation
for the significant difference in portal venous enhancement observed despite no difference in hepatic enhancement in the portal venous phase is that in the protocol B the scan timing was most consistent with the timing of the portal inflow of dense contrast material and the timing was somewhat premature for the hepatic parenchymal imaging, although no differences in hepatic enhancement were found.

This study has some limitations that warrant consideration. First, this study was conducted on a limited cohort at a single institution. Second, the technical difficulty of portal venous bolus tracking in the presence of respiratory motion probably caused the wide variability of scan timing observed when SMV tracking was used. Third, we did not evaluate the diagnostic performance for livers with diseases such as tumors, fatty liver, or cirrhosis. Furthermore, in patients with cirrhosis accompanied by portal hypertension, time to the portal inflow of contrast material may well be variably delayed and portal venous enhancement reduced, which may affect the feasibility of portal venous bolus tracking.

5. Conclusion

Intense hepatic enhancement during the portal venous phase was robustly achieved using aortic bolus tracking in patients without chronic liver disease. Our results showed that portal-inflow bolus tracking was ineffective for increasing hepatic enhancement, reducing enhancement variability or improving image quality.

REFERENCES


