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Triple-phase MDCT of liver: Scan protocol modification to obtain optimal vascular and lesional contrast

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Abstract

Context: With advances in 16-slice multidetector computed tomography (MDCT), the entire liver can be scanned in 4–6 s and a single breath-hold dual-phase scan can be performed in 12–16 s. Consequently, optimizing the scan window has become critical. **Aim:** The purpose of our study was to optimize scan delays using bolus-tracking techniques for triple-phase CT of the liver. **Settings and Design:** Fifty patients with liver lesions were randomly divided into two groups with 25 patients each. The patients were subjected to triple-phase MDCT of liver with two different scan protocols. **Materials and Methods:** They were administered 1.5 mL/kg of 300 mg/mL of iohexol at a rate of 3.0 mL/s with a pressure injector. Using bolus-tracking program, scans were commenced at 4, 19, and 44 s and 8, 23, and 48 s for the first, second, and third phases, respectively. The mean CT values [Hounsfield unit (HU)] were measured in the aorta, hepatic artery, portal vein, hepatic vein, liver parenchyma, and lesion using circular region of interest cursor ranging in size from 5 to 20 mm in diameter on all phases. **Statistical Analysis Used:** Statistical analysis was carried out using paired Student's *t*-test. **Results:** In hepatic arterial phase, hepatic artery has shown better enhancement in Group B (8 s) ($P = 0.0498$) compared with Group A (4 s). In portal venous phase, there were no significant differences in contrast enhancement index (CEI) values at any of the six measured regions between the groups. In the hepatic venous phase, liver parenchyma has shown nearly significant ($P = 0.0664$) higher CEI values in Group B (48 s) when compared with Group A (44 s). **Conclusion:** A scan delay of 8 s, after trigger threshold (100 HU) is reached in the lower thoracic aorta, is optimal for the early arterial phase imaging, this phase being most helpful for assessment of hepatic arterial tree (CT angiography). The liver parenchyma showed maximum enhancement at 48 s scan delay.

Key words: Bolus-tracking technique; hepatic angiography; scan delay

Introduction

With advances in helical computerized tomography (CT) with greater anatomic coverage, more rapid scanning times have revolutionized hepatic imaging. The entire liver can be evaluated in a single breath-hold without respiratory mis-registration. Hepatic circulation has two major components: Arterial and portal venous. A rapidly injected contrast bolus can opacify the liver in two stages: an initial hepatic arterial phase followed by a portal venous phase. Consequently, optimizing the scan window has become critical.[1]

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The mini-bolus and automated techniques have inherent drawbacks including limited availability, added cost of the automated-technique software, and increase in table time needed for review of mini-bolus images to calculate the time delay thereby decreasing patient throughput. Because of the reasons mentioned above, studies have been carried out using fixed timing delays for a variety of examinations, including hepatic imaging.[2]

A bolus-tracking technique has become widely available for the optimization of scan timing in individual patients to compensate for the variability of circulation time between patients.[2-4] The purpose of our study was to optimize scan delays for hepatic arterial and portal venous phases for bolus-tracking techniques in multidetector computed tomography (MDCT) of the liver.

Materials and Methods

This study was designed as an analytical study. The study was carried out at Department of Radiodiagnosis of a tertiary care hospital from June 2010 to August 2012. The study was approved by the institutional ethics committee. A total of 50 patients who were detected to have liver lesions on ultrasound and referred for CT scan were randomly divided into two groups with 25 patients each by simple randomization method. Patients with known history of allergy to contrast media and deranged renal function were excluded from the study. Exclusion criteria also included patients with simple cysts of liver, lesions less than 1 cm or more than 10 cm in size and known cases of portal vein thrombosis.

Patients were subjected to triple-phase MDCT of liver after obtaining relevant history and informed consent. Two different scan protocols were applied to these patients. All scans were performed on Somatom Siemens Sensation 16-slice MDCT scanner with 16 × 1.5 detector configuration for un-enhanced phase and hepatic venous phase, while 16 × 0.75 configuration for arterial and portal venous phases. The complete gantry rotation time was 0.5 s with table speed/gantry rotation set at 12mm. Primary slice thickness was 5 mm with reconstruction interval of 2 mm.

All patients were administered 1.5 mL/kg of 300 mg/mL non-ionic iodinated contrast medium (iohexol) at a rate of 3.0 mL/s using a pressure injector with 20-G catheter.[5-10] Bolus-tracking program was used to start the scan after contrast injection.[4] The premonitory scan was taken, and "region of interest" (ROI) cursor was placed in the aorta just above the dome of right hemi-diaphragm. The trigger was set at 100 Hounsfield unit (HU) values.

Patients were randomly divided into two groups so that scans were commenced at 4, +15 (19th s), and + 25 (44th s) s in the first group and 8, +15 (23rd s), and + 25 (48th s) s in the second group, for the first, second, and third phases, respectively. The acquisition times were 5, 9, 9, and 16 s for unenhanced, arterial, portal, and hepatic venous phases, respectively. The unenhanced, arterial, and portal venous phases were acquired by scanning the liver, while in the hepatic venous phases whole abdomen from dome of diaphragm up to pelvis was included in the field of view.

Quantitative image analysis

The mean CT values in HU were measured in the aorta, hepatic artery, portal vein, hepatic vein, liver parenchyma, and lesion of all the patients on the CT console monitor using circular ROI cursor ranging in size from 5 to 20 mm in diameter on unenhanced, first, second, and third phase images.[11] CT values in the aorta was measured just above the level of diaphragmatic dome. For the portal veins, measurements were taken in the proximal veins in two areas (in right and left proximal portal vein branches) and then averaged. In the liver, measurements were taken in three areas (right anterior segment, right posterior segment, and left lobe of liver) and then averaged. For hepatic artery, measurements were taken at the porta.[11] For the hepatic veins, measurements were taken in three areas (right, middle, and left hepatic veins) and then averaged. CT attenuation values of focal liver lesions were also taken in all the phases excluding the adjacent normal liver parenchyma. Blood vessels and bile ducts were excluded from all measurement areas. Quantitative degrees of contrast enhancement were expressed as contrast enhancement indices (CEIs) which were calculated by subtracting CT values on unenhanced images from that on contrast-enhanced images. Lesion to liver contrast was similarly assessed by subtracting CT value of liver from that of lesion.

Statistical analysis

The age and sex distribution of both the groups was compared with Chi-square test and Fisher's exact test, respectively. Paired Student's *t*-test was used to carry out comparisons of various quantitative values (CEI) in two groups. The level of significance was kept at 5% (P value < 0.05).

Results

In this study of 50 patients with liver lesions, there were 37 (74%) males and 13 (26%) females with near-equal distribution in both groups [Table 1]. The age-wise distribution of patients in both the groups has been near similar; however, most patients were in 51–75 years age bracket [Table 2].

As expected, higher CEI values were measured in abdominal aorta and hepatic artery compared to other regions during the first phase (arterial) scan. Interestingly, hepatic artery has shown better enhancement in Group B (P = 0.0498) compared to Group A. Other regions did not show any

differences between the groups in CEI values during the first phase [Table 3a].

In the second phase (portal venous), it was noted that the CEI values of aorta and hepatic artery were decreased and that of portal vein and hepatic vein were increased compared to the first phase in both the protocol groups. However, there were no significant differences in CEI values at any of the six measured regions between the groups [Table 3b].

Table 1: Sex-wise distribution of patients between two scan protocol groups

	Group A (4 s)	Group B (8 s)
Sex		
Male	19 (76%)	18 (72%)
Female	6 (24%)	7 (28%)
Total	25	25

Fisher's exact test: Level of significance (*P*): 1.000^{NS}. NS: Not significant

Table 2: Age-wise distribution of patients between two scan protocol groups

Age (years)	Group A (4 s)	Group B (8 s)
21-35	3 (12%)	4 (16%)
36-50	7 (28%)	5 (20%)
51-75	14 (56%)	15 (60%)
76 and above	1 (4%)	1 (4%)
Total	25	25

Chi-square test: Level of significance *P*: 0.916^{NS}. Degree of freedom: 0.511, 3. NS: Not significant

Table 3a: Comparison of CEIs between two scan protocol groups in first phase of the scan (mean±SD in HU)

Anatomic structure	First phase scan delay		P
	Group A (4 s)	Group B (8 s)	
Abdominal aorta	217±44.63	221±59.37	0.7869^{NS}
Hepatic artery	181±45.82	207±43.65	0.0498*
Portal vein	33±33.92	40±41.48	0.4747^{NS}
Hepatic vein	8±13.80	11±14.65	0.5490^{NS}
Liver parenchyma	7±6.70	9±8.82	0.2279^{NS}
Lesion	35±30.08	24±20.61	0.1335^{NS}

CEIs: Contrast enhancement indices; SD: Standard deviation; HU: Hounsfield unit; NS: Not significant. *Significant

Table 3b: Comparison of CEIs between two scan protocol groups in second phase of the scan (mean±SD in HU)

Anatomic structure	Second phase scan delay		*P*
	Group A (19 s)	Group B (23 s)	
Abdominal aorta	134±48.35	136±33.24	0.8367^{NS}
Hepatic artery	120±43.74	123±31.53	0.7612^{NS}
Portal vein	93±27.25	99±26.29	0.3883^{NS}
Hepatic vein	59±31.67	58±36.94	0.8631^{NS}
Liver parenchyma	29±13.33	34±13.37	0.1230^{NS}
Lesion	35±20.18	34±23.47	0.8997^{NS}

CEIs: Contrast enhancement indices; SD: Standard deviation; HU: Hounsfield unit; NS: Not significant

In the third (hepatic venous) phase, the CEI values of hepatic vein and liver parenchyma were found to be higher compared to previous phases, and the values recorded in arteries and portal vein were found to be lower that of the previous phases. Liver parenchyma has shown nearly significant higher CEI values in Group B ($P = 0.0664$). The CEI values of the lesion also were significantly higher in Group B ($P = 0.0236$) during the third phase [Table 3c]. However, it was noted that the overall CEI values recorded in third phase were comparatively lesser than that of the second phase for the lesion area [Table 3b and c]. The overall analyses of CEI values of lesions for both the groups showed better washout results in Group A compared with Group B [Figure 1].

When the reported lesions are compared between both the protocol groups, there were predilections of hepatocellular carcinoma (HCC) cases in Group A and hemangioma in Group B [Table 4].

Discussion

The aim of triple-phase MDCT of liver is to obtain optimal lesion to liver contrast for correct characterization of the lesion. It is stated that the greater the differences in CT attenuation between the normal liver and tumor, the greater the tumor conspicuity.[9] The value of multiple-phase dynamic CT in detecting small hepatomas was first reported

Table 3c: Comparison of CEIs between two scan protocol groups in third phase of the scan (mean±SD in HU)

Anatomic structure	Third phase scan delay		*P*
	Group A (44 s)	Group B (48 s)	
Abdominal aorta	96±33.39	100±26.26	0.6365^{NS}
Hepatic artery	86±32.52	87±26.67	0.9556^{NS}
Portal vein	79±15.34	84±17.27	0.2273^{NS}
Hepatic vein	76±22.32	82±20.90	0.3838^{NS}
Liver parenchyma	34±7.87	40±8.49	0.0664*
Lesion	20±13.27	31±20.42	0.0236*

CEIs: Contrast enhancement indices; SD: Standard deviation; HU: Hounsfield unit; NS: Not significant. *Significant

Table 4: Lesion-wise distribution of patients between two scan protocol groups

Lesion	Group A (4 s)	Group B (8 s)
Hepatocellular carcinoma	9 (36%)	5 (20%)
Abscess	3 (12%)	1 (4%)
Hemangioma	4 (16%)	7 (28%)
Granuloma	1 (4%)	0
Metastasis	6 (24%)	8 (32%)
Cholangiocarcinoma	1 (4%)	2 (8%)
Hydatid cyst	0	2 (8%)
FNH	1 (4%)	0
Total	25	25

FNH: Focal nodular hyperplasia

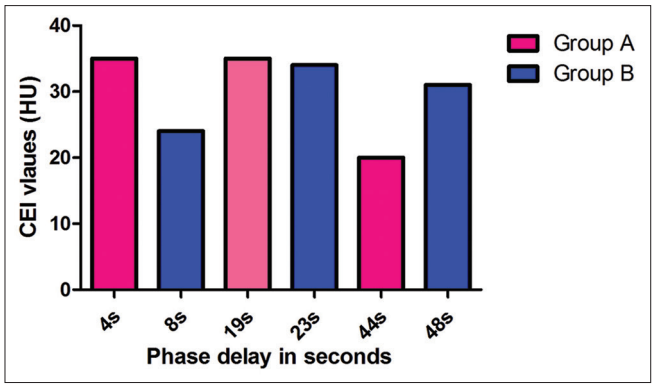

Figure 1: Graphical representation of analyses of CEI values of lesions in group A vs group B

by Ohashi *et al*. who performed dynamic incremental CT using a biphasic protocol, imaging 28 s after contrast administration for early-phase images and 100 s after contrast administration for delayed phase.[12] A further study by Foley *et al*. showed that with initial timing of scanning beginning at the time of aortic arrival of the contrast bolus, three clear separate circulatory phases can be defined by triple-pass hepatic CT technique using the multirow detector scanner. The first pass is termed the "hepatic arterial phase" and the second pass the "portal venous inflow phase" or the "late arterial phase." The third pass began 60 s after the beginning of the contrast injection. During this third pass, hepatic veins are enhanced, termed the "hepatic venous phase".[1] Most metastases to the liver are hypovascular and consequently are best detected during the portal venous phase. Hypervascular primary malignancies (e.g., hepatocellular carcinomas) and certain metastases (e.g., pancreatic islet cell carcinomas, carcinoids, melanomas, pheochromocytomas, choriocarcinomas, and sarcomas) have a proportionately greater hepatic arterial blood supply and, as a result, enhance earlier than does the remainder of the liver.[13] Consequently, these lesions may be visible only on hepatic arterial phase images.[14,15]

In our study, we have compared the outcome of *scan delay difference* of 4 s in each of the three phases to define an optimum scan delay for MDCT of liver.[16,17] We used initial scan delay of 4 s after achieving the trigger threshold of 100 HU. CEI values from six anatomical regions of the liver were compared for two separate scan initiation time which were four s apart during *hepatic arterial phase* (4 s *vs* 8 s), *portal venous inflow phase* (19 s *vs* 23 s), and *hepatic venous phase* (44 s *vs* 48 s).

In this study, during *hepatic arterial phase* [Table 3a], higher CEI values were noted in aorta (217 ± 44.63 HU *vs* 221 ± 59.37 HU) and in hepatic artery (181 ± 45.82 HU *vs* 207 ± 43.65 HU) compared to other three regions (portal vein, hepatic vein, and liver parenchyma), in both the protocol groups, as expected being the earliest phase after the trigger. Interestingly, the hepatic artery CEI values were significantly higher ($P = 0.0498$) when the scan initiation was delayed till 8 s from the trigger rather than 4 s, which suggested better contrast build up in hepatic artery in the second protocol group. In many circumstances, the optimal vascular enhancement is essential, for example, for assessment of anatomical variants of hepatic artery and portal veins in liver transplant donor and recipients.[18,19] Preoperative visualization of anomalous hepatic arterial branches is important in patients who are candidates for hepatic resection and cryoablation or arterial chemoembolization.[20]

During the *portal venous phase* of this study [Table 3b], it was observed that contrast washout has been started in aorta and hepatic artery and build-up of the contrast occurred in portal veins and hepatic veins. Highest CEI values for portal vein regions (93 ± 27.25 HU for protocol 1 group *vs* 99 ± 26.29 HU for protocol 2 group) were recorded in this phase. However, none of the regions measured showed any significant difference between the two protocol groups despite the 4 s delay of scan initiation time (19 s in protocol 1 group *vs* 23 s in protocol 2 group) in the second group.

The recorded CEI values in *hepatic venous phase* [Table 3c] of this study (44 s in protocol 1 group *vs* 48 s in protocol 2 group) had shown beginning of washout of contrast from portal veins apart from continued washout from aorta and hepatic artery as recorded in previous phase. The CEI values of hepatic venous regions and liver parenchyma had shown higher contrast enhancement compared to previous phases in both protocol groups. The liver parenchyma recorded nearly significant ($P = 0.0664$) higher value in protocol 2 group than the other protocol group (34 ± 7.87 HU for protocol 1 group *vs* 40 ± 8.49 HU for protocol 2 group). Therefore, the second protocol (48 s scan delay) is better suited for optimal visualization of liver parenchyma and hepatic veins.

In this study, CEI values of lesions [Figure 1] during the three phases have shown different enhancement responses. The first group has shown a faster build-up of contrast in the first phase (arterial) and then followed by significant washout ($P = 0.0236$) in the third phase (hepatic venous). The second protocol group showed a slower build-up of contrast initially, but once the enhancement was achieved, it was sustained during the third phase also. To interpret this result further, the authors have looked into the distribution of various lesions in both the groups [Table 4]. It is observed that the first group has more number of hype vascular lesions such as HCC,[1] whereas the second group had more number of hemangiomas thus resulting in higher washout in the first group.

Strengths and limitations of the study

The study was designed and performed at ideal radiological settings of a tertiary care hospital. The values were computed by the software, therefore mitigated chances

of observer biases. The sample size was relatively small ($N = 25$) in each group. Therefore, the statistical value of the results is limited. We used non-ionic iodinated contrast of 300 mg/dL conc. at 1.5 mL/kg at a rate of 3 mL/s. Previous studies have emphasized on the use of higher dose (2 mL/kg and above) and rate (4 mL/s and above) for better separation of various phases in multiphasic hepatic imaging.[5,6]

Summary and conclusion

The following conclusions can be drawn from this study:

1. Using the bolus-tracking method, scan delays need to be optimized for portal venous and hepatic venous phases.
2. A scan delay of 8 s, after trigger threshold (100 HU) is reached in the lower thoracic aorta, is optimal for the early arterial phase imaging. This phase is most helpful for assessment of hepatic arterial tree (CT angiography).
3. The liver parenchyma showed a maximum enhancement at 48 s scan delay. This phase is optimal for assessment of hypovascular lesions like metastases from primary in the lung or colon.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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