Error in the Automatic Bolus Tracking System in Dynamic Computed Tomography: Preliminary Case Results

Myeong Seong Kim
The Korean National Cancer Center
Jiwon Choi
Jeonju University
Dae Cheol Kweon (dckweon@gmail.com)
"Shinhan University" https://orcid.org/0000-0002-0243-5142

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Abstract

Background: Multidetector computed tomography (CT) images of the liver can be obtained rapidly, and parenchymal lesions can be detected using an iodine-containing contrast medium. In such imaging, the time to peak enhancement is important for optimal lesion detection. When using the bolus tracking system (BTS), the CT commences after a threshold Hounsfield unit value is reached. Methods: In current BTS, contrast medium is injected into blood vessels at a high speed using an automated injector; however, it may cause movement in the vessel in which the region of interest (ROI) is set, so that the timing of the scan is affected, leading to indeterminate artery and portal phase in angiography or liver dynamic examination. We therefore aimed to identify the cause of failure of CT due to an error in BTS and to suggest an appropriate preventive method. Results: Subjects underwent BTS-CT angiography and abdominal examinations in two university hospitals using a 64-detector CT scanner. An automatic BTS was used to time the start of the scanning when the injected contrast medium reached the threshold level in the ROI. Errors in bolus tracking were divided into patient-related and machine-related errors. Among 2,000 patients who underwent BTS-CT, error was observed in 15 cases, in which the bolus tracking timing was shifted as a result of movement of the patient or respiratory changes due to the rapid injection of contrast medium, which led to CT failure. Conclusions: To reduce CT-BTS failures, the patient's position and the change in the position of the blood vessels due to the patient's breathing pattern should be carefully considered, and the ROI should be set to a sufficiently small area in the blood vessel.

Introduction

Due to recent advances in computed tomography (CT) techniques, multidetector CT (MDCT) images of the liver can now be acquired within 20 seconds, using two or more steps [1]. To distinguish lesions in the parenchyma of soft organs or to identify blood vessel morphology by CT scanning, contrast medium containing iodine is used. When using contrast media, the time until the peak enhancement at the target organs is reached is very important for setting the optimal contrast to noise ratio (CNR) and increasing theaccuracy of lesion detection. In other words, it is important to be able to distinguish between the arterial phase and the venous phase of the contrast agent when using rapid MDCT scanning [2].

The timing-bolus method, in which a small amount of contrast medium (10 mL) is injected during the pre-scan (pre-CT scan concurrent with the peak enhancement time), has the advantage of determining the individual time-delay in advance. The use of different amounts of contrast medium (100–200 mL) can cause a variation in peak enhancement times, which can lead to errors when contrast medium has been used previously [3]. In contrast, the bolus tracking system (BTS) starts the CT scan in real time after an arbitrary time when a threshold value, generally 100 Hounsfield units (HU), determined by the contrast media is reached [4]. Some studies have demonstrated that the automated BTS can better tailor the time delay for diagnosis of liver and pancreas lesions, and thus improves the CNR and characterization of liver parenchyma lesions, or vessel angiography [5–6].

Currently, contrast medium is injected into blood vessels at high speed by means of an automatic injector in BTS. The patient may move due to irregular deep breathing or due to a surprise-reaction to the rapid injection of the contrast agent. This may result in movement of the vessel in which the region of interest (ROI) has been set, making it difficult to register when the contrast agent entered the body. In the event of such an error, the CT examination fails to attain the intended goal (indeterminate artery and portal phase in CT angiography or dynamic examination of the liver). Similar problems can also be caused by other factors, including patient anxiety and additional radiation exposure during re-examination. However, few studies have investigated methods for preventing and coping with errors in CT scans that use a BTS.

Therefore, the purpose of this study was to analyze the causes of errors in BTS-CT scans to determine an appropriate way to reduce such failure, and ultimately, to increase the diagnostic value of CT images.

Subjects And Methods

Patient Population

The CT images that were analyzed in this study were obtained from subjects attending two university hospitals in a metropolitan area, between January 2, 2017, and February 28, 2017. From the pool of 2,000 cases, those containing errors (n = 15) were detected and analyzed. The BTS error cases were divided according to the cause of the error in contrast injection during CT examinations.

Contrast Injection and Scanning Protocols

This study was approved by the relevant institutional review board (KHNMC IRB 042) and the need to obtain informed patient consent was waived due to the retrospective nature of the study. All subjects were administered contrast media, and a 64-detector CT scanner was used (Philips Brilliance, Philips Medical Systems, Best, The Netherlands). The contrast medium (30 mL) was injected into the right antecubital fossa using an Ultravist® 300 (GE Healthcare, Princeton, NJ, USA) and an 18-gauge cannula. Contrast injection was performed using an auto-injector (Autoenhance A–50, Nemoto Kyorindo, Tokyo, Japan). The patients were breathing comfortably during the injection of the contrast agent.

BTS was employed, with an ROI placed in the abdominal descending aorta by the radiological technologists. The flow of the contrast medium was initiated 10 s after injection of the contrast medium in all patients. Additionally, the timing of CT data acquisition (i.e., the delay from the start of infusion to the CT scan) was determined by the time point at which the mean ROI reached a preset threshold of 100 HU. The tube voltage applied for monitoring until the trigger point to commence scanning was 120 kVp, the tube current was 50 mA, the exposure time was 500 ms, and the convolution kernel was B. The mean CT dose index volume (CTDIvol) and dose length product (DLP) during contrast injection monitoring were 0.08 mGy and 4.2 mGy·cm.

Results

Eleven of the 15 cases showing error during BTS-CT were male and 4 were female. Thirteen cases involved errors in liver CT examinations and 2 involved cases of error in CT angiography. The contrast agent injection rate, via an auto injector, was 3.5 mL/s for liver dynamic tests and 4.2 mL/s for CT angiography examinations. Table 1 summarizes the results of all of the BTS-CT examinations showing error during the study period. In 4 of the 15 cases, the CT scan was performed before the contrast medium reached the site of interest. In the 11 remaining cases, the scan was delayed, occurring after the CT contrast signal was observed. In these BTS-CT scans, 14 cases involved radiographer error, rather than automatic scanning based on contrast agent threshold, and one case involved extravasation.

The case of extravasation is depicted in Figure 1; this involved a patient who was admitted for abdominal CT examination. A circular ROI covering approximately two-thirds of the abdominal aortic diameter was placed below the level of the renal vessels. Serial scans were acquired at this level following the injection of contrast medium. A real-time plot of HU versus time revealed a gradual increase in enhancement that reached a maximum HU value of 100, 31 s after which the plot showed a falling trend, failing to reach the desired HU of 100.

Figure 2 shows that the ROI was positioned on the aorta at 25–27 s after injection of the contrast agent; there was then a sudden signal decrease, followed by an increase in the HU, on the patient monitoring graph, caused by movement.

Figures 3–8 showed that the ROI position was shifted due to patient movement, thus, the trigger HU value changed during the signal monitoring of the contrast medium, leading to early or late timed CT scans.

Figure 9 represents a 73-year-old male patient who underwent contrast injection for 48 s during an abdominal CT scan.

Figure 10 displays the timing of CT scans after contrast injection as a scatter plot of the BTS-CT data.

Discussion

This study analyzed cases of BTS-CT that failed due to errors in the injection of contrast medium. In this study, we show that errors in BTS-CT involved inappropriate timing due to the user's erroneous ROI setting or changes in the position of the blood vessels due to the patient's movement during the CT scan when using rapid injection of contrast medium.

BTS is an indispensable technique used to monitor contrast enhancement of the image visually. Several factors influence the quality of CT images during dynamic CT scans. In this study, interference of the signal from the ROI due to respiration movement was confirmed. It is possible to reduce the test fail rate by setting the ROI size to a size smaller than that of the vessel cross-section in an effort to reduce the risk of image distortion due to respiratory motion

Several studies have reported that the patient's breathing interferes with signal monitoring during BTS-CT scans. In particular, in abdominal or cardiac CT scans, breathing imbalance causes the abdominal artery to move, leading to failure of CT scans [7–8], 3DCT using abdominal volumetry [9], PET imaging, and radiotherapy. It has been reported that a respiration synaptic gating technique can be used to correct the motion caused by respiration during PET imaging and radiotherapy [10–12].

In patients with multiple hepatocellular carcinoma, dynamic CT scans using the BTS technique are essential, but their accuracy can be jeopardized by the patient's respiratory movement. Therefore, in order to improve the accuracy of the test, it is necessary to avoid shallow or rapid breathing during BTS-CT. Spiral CT of the abdominal and hepatic biliary system can experience errors due to the respiratory motion of the hepatic artery. Existing data of movement during the BTS technique show that there is marked movement in the anterioroposterior (AP) direction and little movement in the lateral direction.

Occasionally, abdominal aortic ROI measurements in a calcified aorta failed due to respiratory motion. Because of the inability to maintain controlled respiration during the CT scan, movement in the AP as well as the lateral direction occurred, resulting in suboptimal BTS for abdominal CT scans. Respiratory correction, using shallow respiration or multiple breaths has been reported to improve ROI omission [13–14].

The ROI movements that were recorded in abdominal CT scans are displayed in Table 4. Taking this movement into account, the user should ensure that the center of the ROI is set to a size that is sufficiently smaller than the cross-sectional area of the vessel, taking the movement of the patient's blood vessel into consideration. CT scans that use a BTS involve injection of fluid into the human body at a rate that is significantly faster than is used in other techniques (3.0–7.0 mL/s). Very rapid injection of a contrast agent often causes a startle movement in the patient, moving the set ROI from the vessel, which then leads to failure of the CT scan. Therefore, the radiology technologist should provide the patient with a preliminary explanation before injecting the contrast agent, such as "do not be surprised when the contrast agent is injected into the blood vessel rapidly; if you experience any pain, please communicate that immediately."

Conclusion

To reduce CT-BTS failures, it is necessary to consider the patient's position and the change in the position of the blood vessels due to the patient's breathing pattern, and to set the ROI to an appropriately small area within the blood vessel. Additionally, the procedure should be adequately explained to the patient before starting the scan to prepare the patient for the rapid injection of the contrast medium.

Declarations

Ethics approval and consent to participate: All procedures performed in studies involving human participants were in accordance with the ethical standards of the IRB (approval number KHNMC IRB 2012–042 Kyung Hee University Hospital at Gangdong Ethics Committee) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Consent for publication: Not applicable

Availability of data and material: Not applicable

Competing interests: The authors declare that they have no conflicts of interest

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Tables

Table 1. Parameters of bolus tracking system for CT

Manufacturer	Tube voltage (kV)	Tube current (mA)	Exposure time (ms)	Convolution kernel
Philips	120	30	500	B

Table 2. Radiation dose of CTDIvol and DLP

Manufacturer	CTDIvol (mGy)	DLP (mGy·cm)
Philips	0.08	4.2

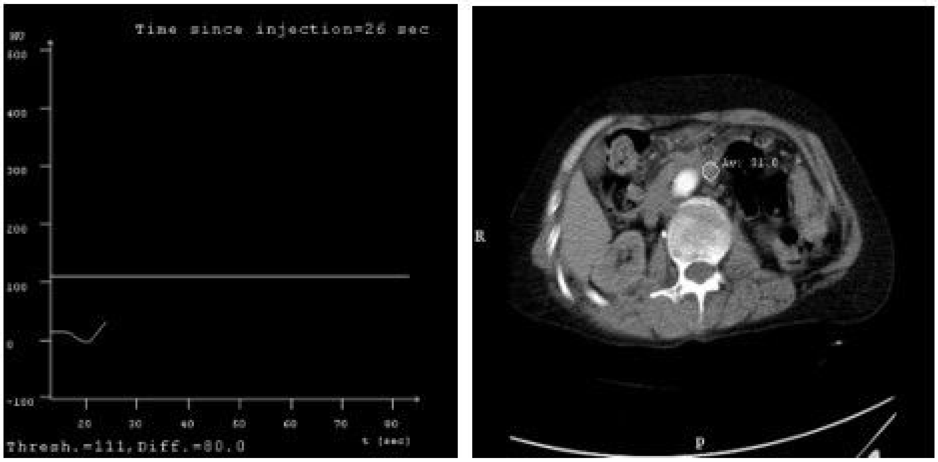
Table 3. Summary of the cases of human error in the bolus tracking system for MDCT in setting the ROI of the abdominal descending aorta

Patient	Protocol	Gender	Age (year)	Delay between injection and scan (sec)	Enhancement of threshold at point of scan (HU)	Operation	Results
1	Liver	F	45	26	31	Manual	
2	Hepatobiliary	F	50	34	159	Manual	
3	Abdominal	M	73	48	4		Extravasation and Fail
4	Abdominal	M	66	29	124	Manual	
5	Liver	M	67	25	-9	Manual	
6	Liver	M	54	28	13	Manual	
7	Liver	M	56	25	73	Manual	
8	Hepatobiliary	F	55	30	40	Manual	
9	Liver	M	56	26	51	Manual	
10	Hepatobiliary	F	74	19	8	Manual	
11	Liver	M	71	57	42	Manual	
12	Liver	M	46	23	49	Manual	
13	Hepatobiliary	F	50	24	53	Manual	
14	Liver	M	62	25	109	Manual	
15	Liver	M	46	23	19	Manual	

Table 4. Summary of movements in the abdominal organ

Protocol	**Movement (mm)**	**Organ**
Abdomen [Lin YH][15]	0.02 – 40.75	Abdominal artery
Abdomen [Brander ED][16]	13	Liver
Abdomen [Hallman JL][17]	9.7 (motion) 3-18 (SI direction)	Liver
Abdomen [Tai A][18]	7.9 ± 3.2	Liver
Abdomen [Kubas A][19]	19.7 ± 8.3 (CC) 4.5 ± 2.3 (lateral) 8.9 ± 6.5 (AP)	Liver tumor
Abdomen [Brock][20]	8.5 (SI) 10 (LR)	Liver

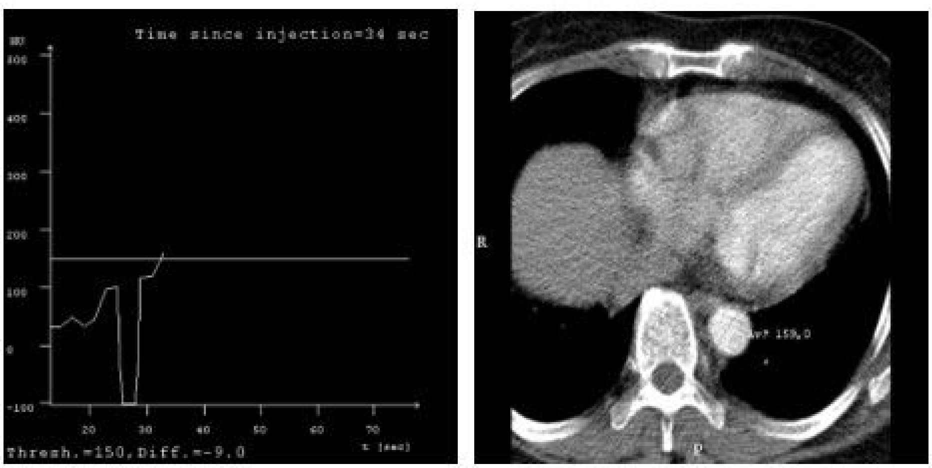
Figures



a b

Figure 1

Automatic bolus system display during 31 s after contrast media injection in a patient undergoing multidetector computed tomography of the abdomen. Plot of time versus Hounsfield units (HU) at the region of interest (ROI) (a) and a non-enhanced image of the abdominal aorta, demonstrating the ROI (b).



a b

Figure 2

Automatic bolus system display during contrast media injection in a female patient undergoing multidetector computed tomography. Plot of time versus Hounsfield units (HU) at the region of interest (ROI) (a) and a non-enhanced image of abdominal aorta, demonstrating the ROI, near the abdominal descending aorta (b).

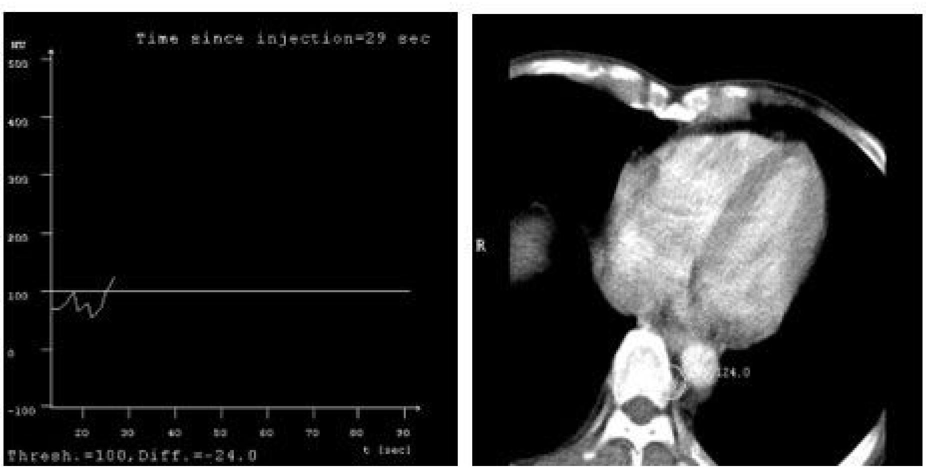


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Figure 3

Automatic bolus system display during contrast media injection in a 66-year-old male patient undergoing multidetector computed tomography of the abdomen. Plot of time versus Hounsfield unit (HU) at the region of interest (ROI) (a) and a non-enhanced image of the abdominal aorta, demonstrating the ROI (b).

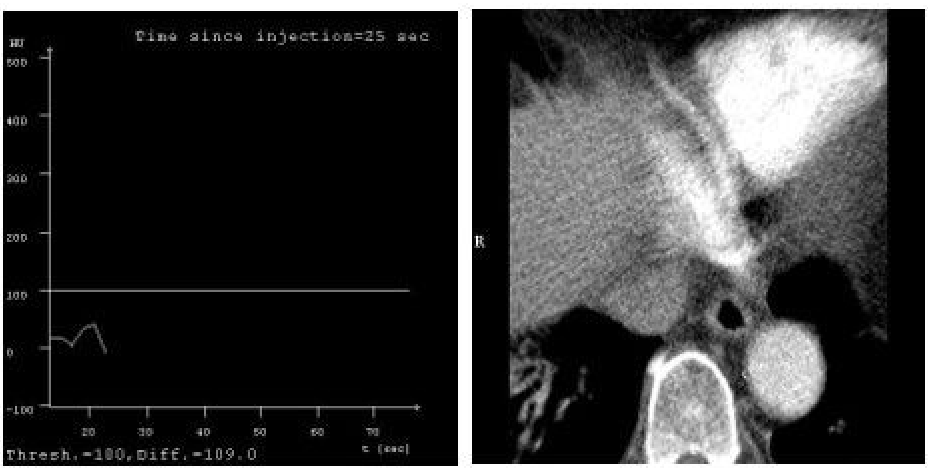

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Figure 4

Automatic bolus system display during contrast media injection in a 66-year-old male patient undergoing multidetector computed tomography of the abdomen in which the region of interest (ROI) in the aorta moved. Plot of time versus Hounsfield unit (HU) at the region of interest (ROI) (a) and a non-enhanced image of the abdominal aorta, demonstrating the ROI (b).

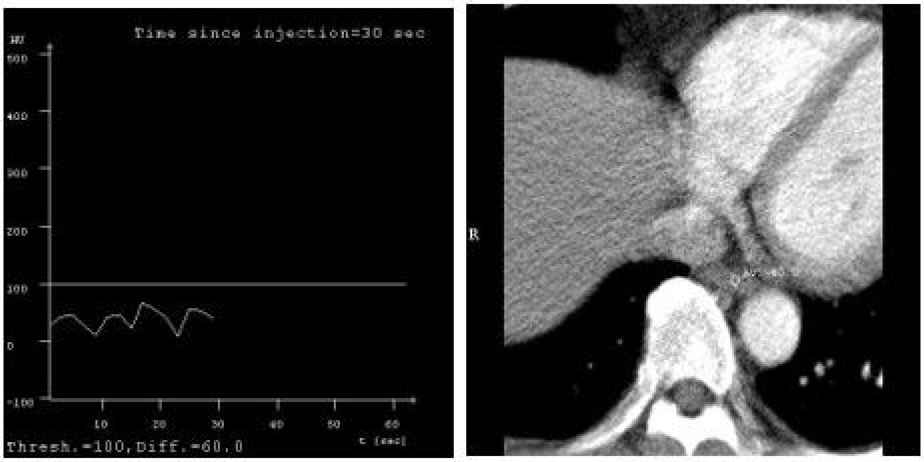

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Figure 5

Automatic bolus system display during 30 s of contrast media injection. Plot of time versus Hounsfield unit (HU) at the region of interest (ROI) (a) and a non-enhanced image of the descending aorta demonstrating the movement of the ROI set in the esophageal area.

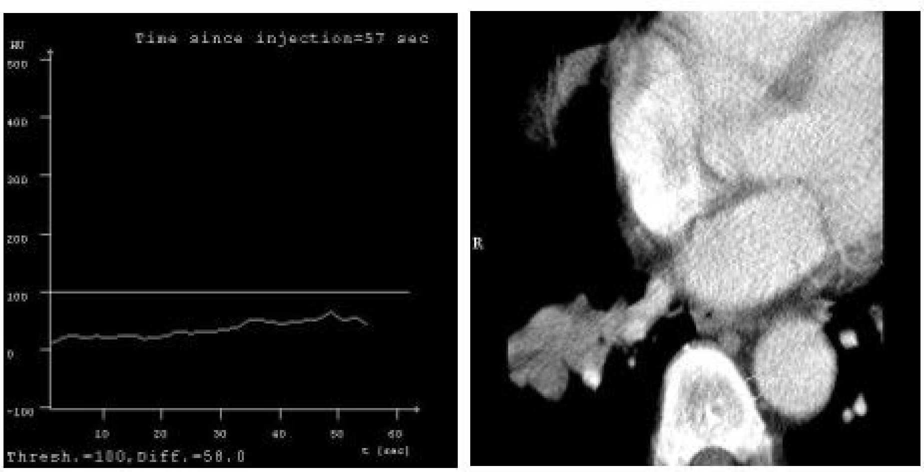

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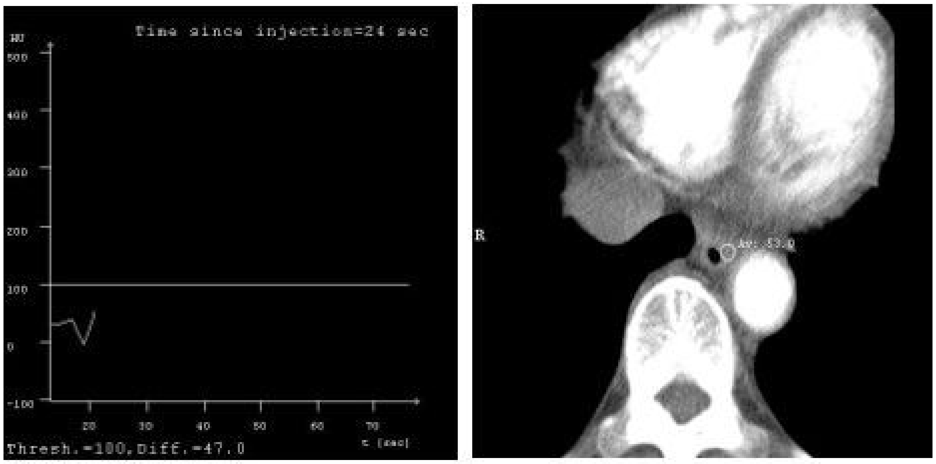
Figure 6

Automatic bolus system display during 57 s of contrast media injection. Plot of time versus Hounsfield unit (HU) at the region of interest (ROI) (a) and a non-enhanced image demonstrating the ROI set in the thoracic spine (b).



a b

Figure 7

Automatic bolus system display during 24 s of contrast media injection. Plot of time versus Hounsfield unit (HU) at the region of interest (ROI) (a) and a non-enhanced image of the ROI set in the esophageal area (b).

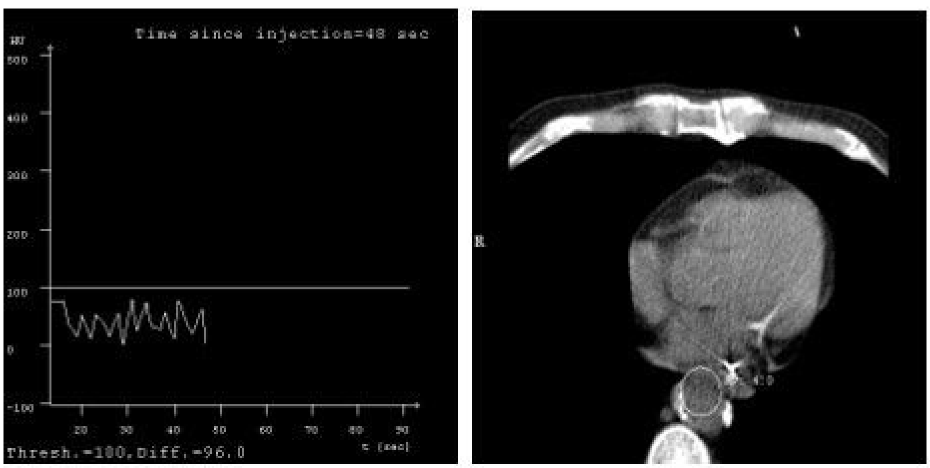


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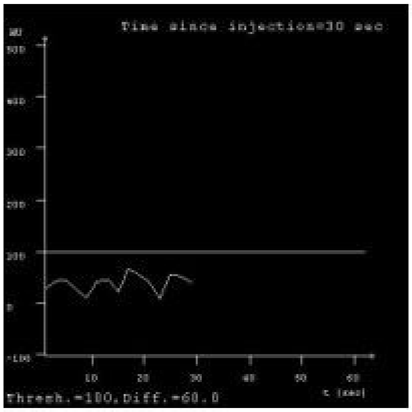
Figure 8

Automatic bolus system display during contrast media injection in a 73-year-old patient undergoing multiple detector computed tomography of the abdomen for colon cancer. Plot of time versus Hounsfield unit (HU) at the region of interest (ROI) (a). Non-enhanced image of the abdomen (b). Contrast media injection flow speed was 2.0 mL/s; administration of 80 mL of contrast media volume resulted in extravasation.



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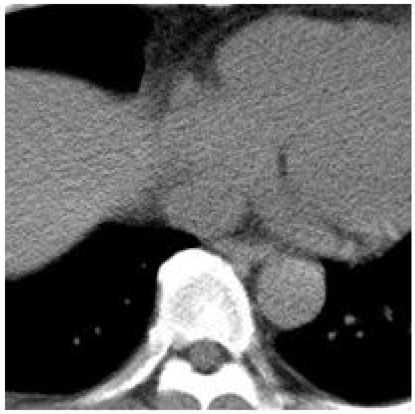

b

c

Figure 9

Automatic bolus system display during 30 s of contrast media injection. Plot of time versus Hounsfield unit (HU) at the region of interest (ROI) (a) and non-enhanced images of the descending aorta (b and c) showing the ROI set in the esophageal area (c).

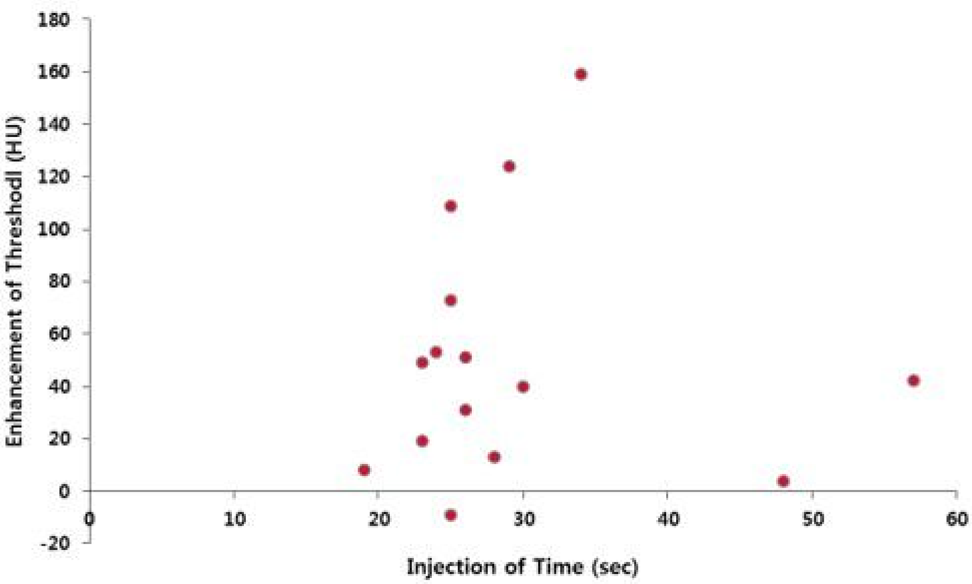

Figure 10

Plot of the threshold enhancement against the injection time of the automatic bolus system in multidetector computed tomography scanning.