Human Error in the Automatic Bolus Tracking System of Case Results in CT Scanning

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Abstract - We therefore aimed to identify the cause of failure of CT due to an error in BTS and to suggest an appropriate preventive method. 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. 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.

Key words : Bolus tracking system, Contrast media, Computed tomography, Human error

INTRODUCTION

Due to recent advances in computed tomography (CT) techniques, multi-detector CT (MDCT) images of the liver can now be acquired within 20 seconds, using two or more steps (Oto *et al*. 2005). 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 the accuracy 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 (Ichikawa *et al*. 2006).

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 (Laghi 2007). 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 (Silverman *et al*. 1995). 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 (Mehnert *et al*. 2001; Fukukura *et al*. 2010).

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 re-

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gion 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

1. 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. All procedures performed in studies involving human participants were in accordance with the ethical standards of the IRB and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

2. Contrast Injection and Scanning Protocols

This study was approved by the relevant institutional review board 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^2.

RESULTS

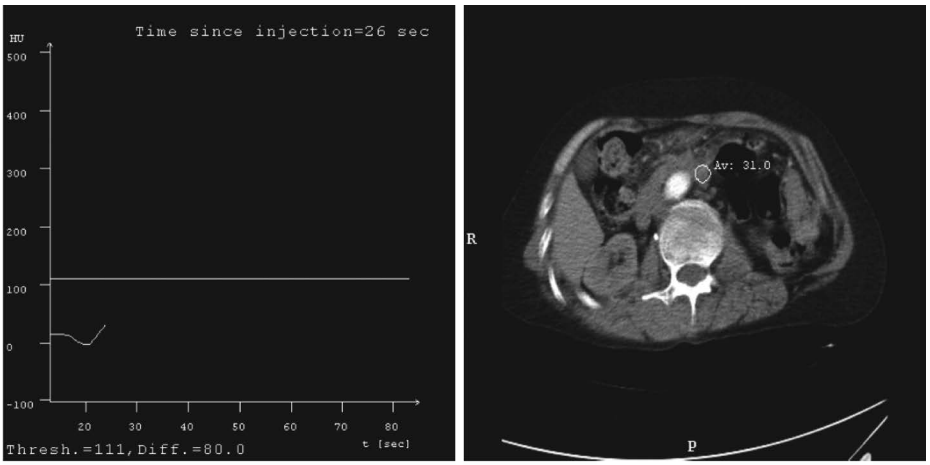
Eleven of the 15 cases showing error during BTS-CT were male and 4 were female. Thirteen cases involved errors in liver CT examinations and 2 involved cases of error in CT angiography. The contrast agent injection rate, via an auto injector, was 3.5 mL · s^{-1} for liver dynamic tests and 4.2 mL · s^{-1} 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 radiological thechnologists error, rather than automatic scanning based on contrast agent threshold, and one case involved extravasation.

The case of extravasation is depicted in Fig. 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.

Manual triggering of the scan was performed at 31 sec (Fig. 1). Fig. 2 showed that ROI was positioned on the aorta at 25~27 sec after injection of the contrast agent, there was a sudden signal decrease followed by an increase in the HU on the patient monitoring graph due to movement. Figs. 3~8 showed ROI position is shifted due to patient movement, thus, the trigger HU value changed during the signal

Table 1. 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	



(a) (b)

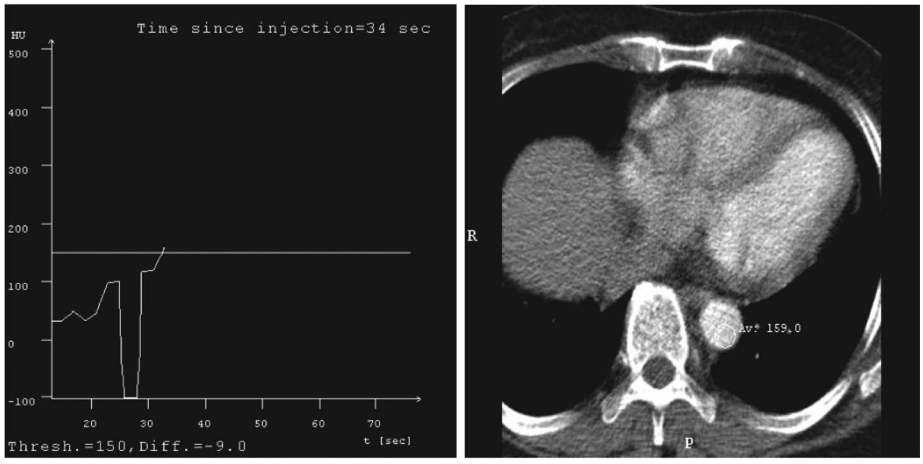
Fig. 1. Automatic bolus system display during 31 seconds of contrast media injection. Patient undergoing MDCT of the abdomen. Plot of time versus Hounsfield unit (HU) at the region of interest (ROI; a) and a non-enhanced image of the abdominal aorta, demonstrating the ROI (b).

monitoring of the contrast medium, leading to early or late timed CT scans. Fig. 9 represents a 73-year-old male patient who underwent contrast injection for 48 seconds during an abdominal CT scan. Fig. 10 displayed the timing of CT scans after contrast injection was shown as a scatter plot of the BTS CT data.

DISCUSSION

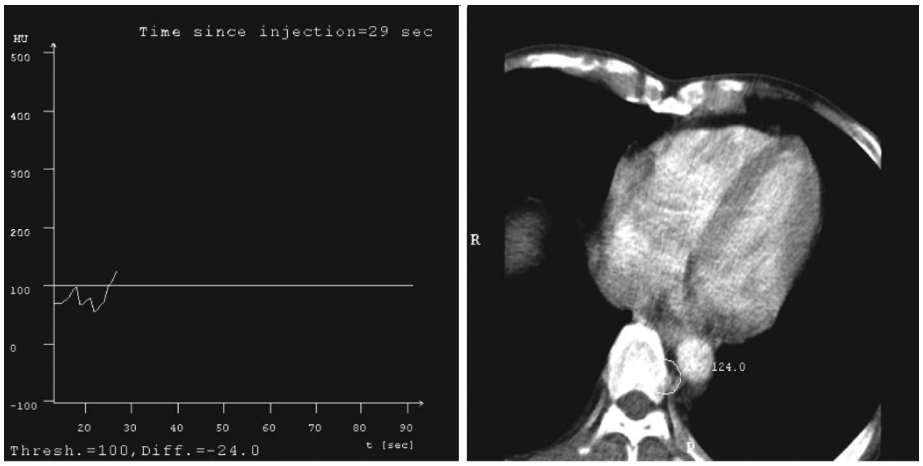
This study analyzed cases of BTS-CT that failed due to errors in the injection of contrast medium. In this study, we show that errors in BTS-CT involved inappropriate timing due to the user's erroneous ROI setting or changes in the position of the blood vessels due to the patient's movement during the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



(a) (b)

Fig. 2. Automatic bolus system display during contrast media injection in a female patient undergoing MDCT. Plot of time versus Hounsfield unit (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).



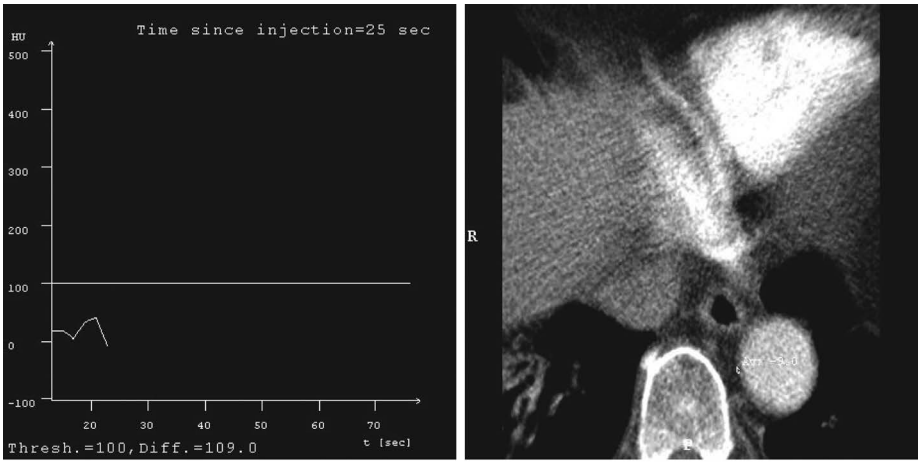
(a) (b)

Fig. 3. Automatic bolus system display during contrast media injection in a 66 year-old male patient undergoing MDCT of the abdomen. Plot of time versus Hounsfield unit (HU) at the region of interest (ROI; a) and a non-enhanced image of abdominal aorta, demonstrating the ROI (b).

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.

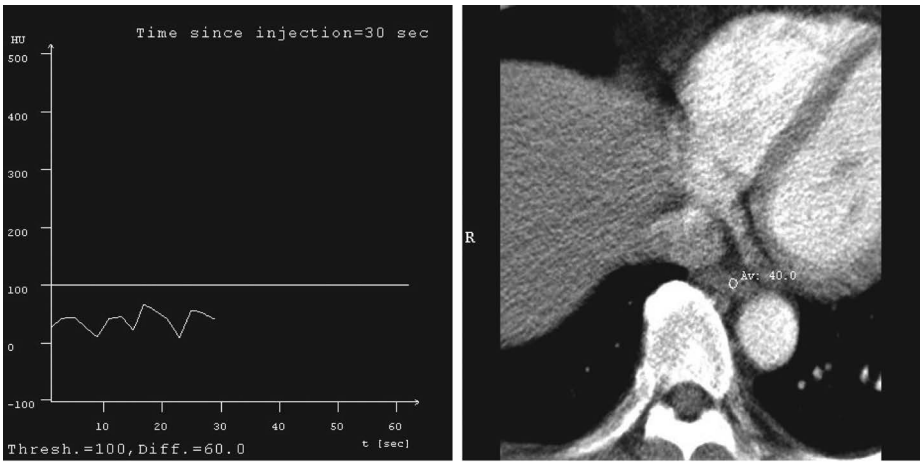
Several studies have reported that the patient's breathing interferes with signal monitoring during BTS-CT scans. In particular, in abdominal or cardiac CT scans, breathing imbalance causes the abdominal artery to move, leading to failure of CT scans (Clifford *et al*. 2002; Takemura *et al*. 2008), 3D CT using abdominal volumetry (Hallman *et al*. 2012), 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 (Beddar *et al*. 2007; Zhang *et al*. 2007; Liu *et al*. 2012).

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 mo-



(a) (b)

Fig. 4. Automatic bolus system display during contrast media injection in a 66 year-old male patient undergoing MDCT of the abdomen in which the ROI in the aorta moves. Plot of time versus Hounsfield unit (HU) at the region of interest (ROI; a) and a non-enhanced image of abdominal aorta (b).



(a) (b)

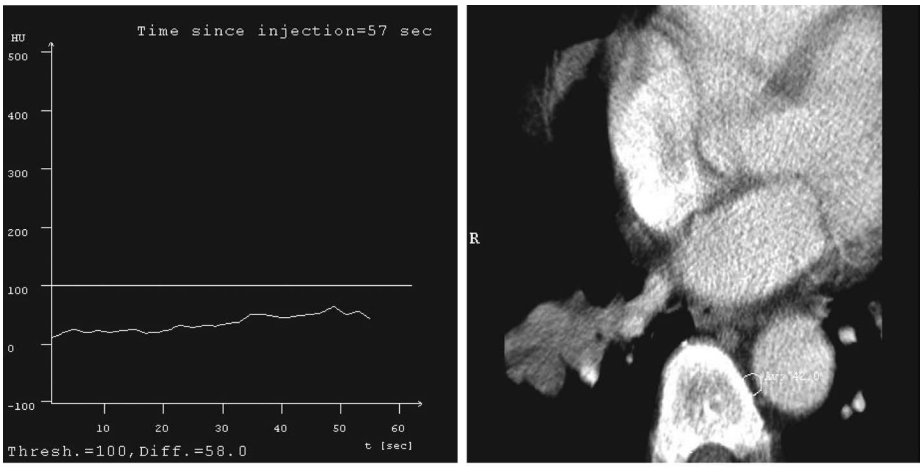
Fig. 5. Automatic bolus system display during 30 seconds of contrast media injection. Plot of time versus Hounsfield unit (HU) at the region of interest (ROI; a) and a non-enhanced image of the descending aorta demonstrating the movement of the ROI setting in the esophageal area.

tion 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 (Sahani *et al*. 2007; Ippolito *et al*. 2008).

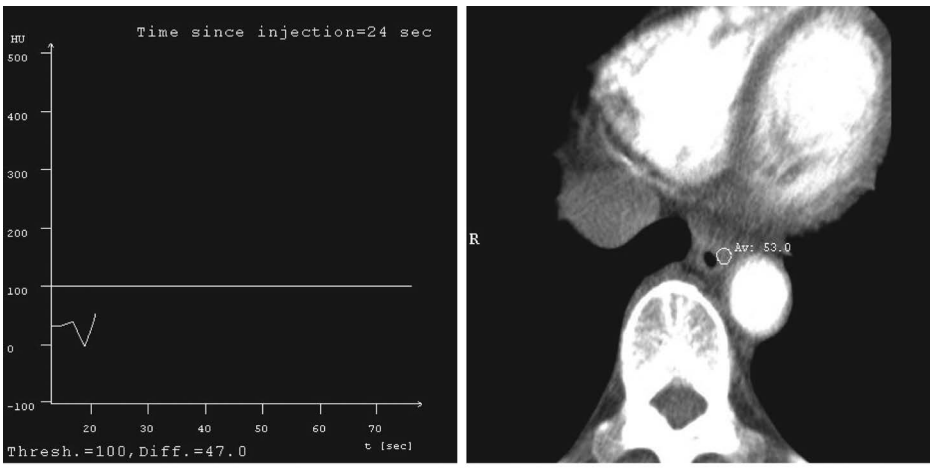
In this study, CTDI dose of BTS-CT was 0.08 mGy and Ishikawa *et al*. (2017) was 1.31∼6.56 mGy when scanned with 10, 20, 30, 50 mA. The dose was measured in this test, and it was also measured as 0.018 mSv at an effective dose at 30 mA using a phantom study (Kweon and Choi 2019). Kim *et al*. (2016) reported 100 kVp, 50 mA and 120 kVp, 30 mA in the BTS-CT angiography phantom examination and recommended dose minimization by scanning. Further BTS-CT research is needed to reduce radiation dose.

The ROI movements that were recorded in abdominal CT



(a) (b)

Fig. 6. Automatic bolus system display during 57 seconds 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 setting in the thoracic spine (b).



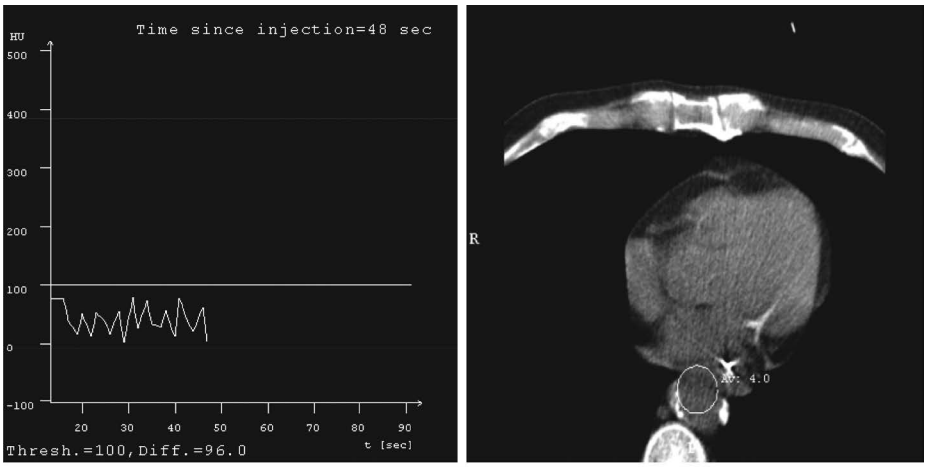
(a) (b)

Fig. 7. Automatic bolus system display during 24 seconds 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 setting in the esophageal area (b).

scans are displayed in Table 2. 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 ($3.0 \sim 7.0\ \mathrm{mL \cdot s^{-1}}$). 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

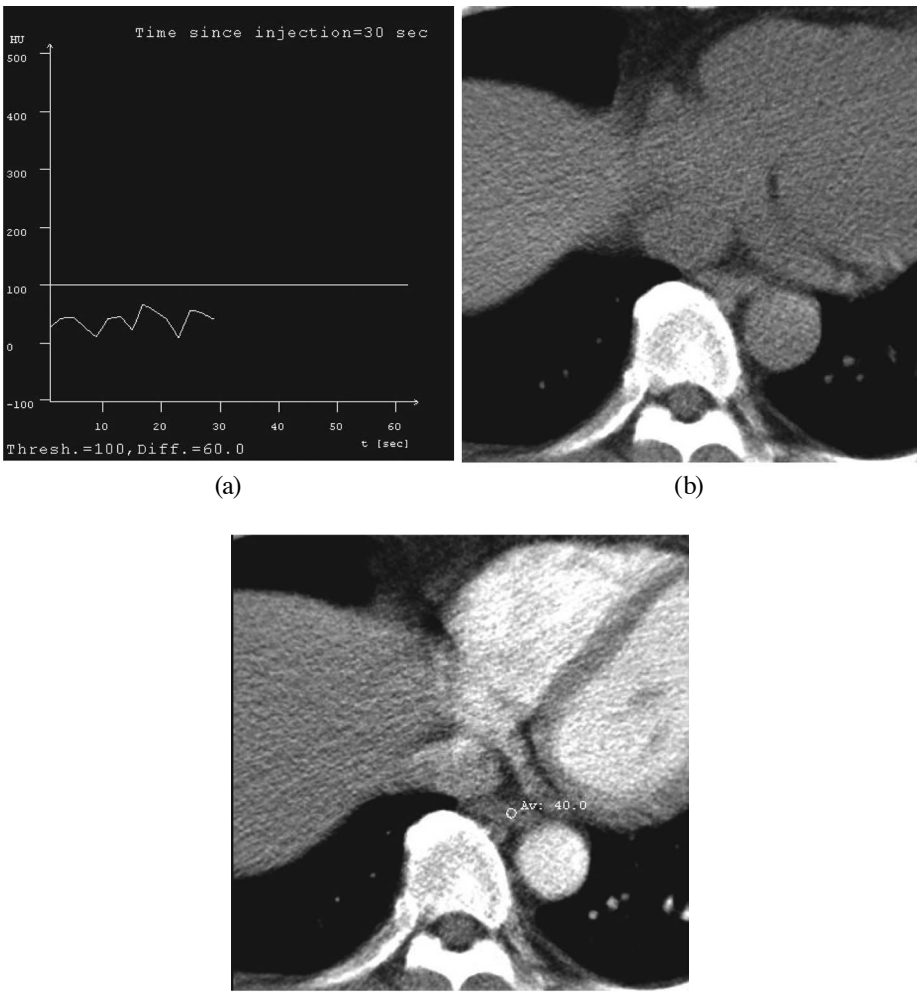
Table 2. Summary of movements in the abdominal organ

Protocol	Movement (mm)	Organ
Abdomen (Lin *et al*. 2014)	0.02∼40.75	Abdominal artery
Abdomen (Brandner *et al*. 2006)	13	Liver
Abdomen (Hallman *et al*. 2012)	9.7 (motion) 3∼18 (SI direction)	Liver
Abdomen (Tai *et al*. 2013)	7.9 ± 3.2	Liver
Abdomen (Kubas *et al*. 2008)	19.7 ± 8.3 (CC) 4.5 ± 2.3 (lateral) 8.9 ± 6.5 (AP)	Liver
Abdomen (Brock *et al*. 2003)	8.5 (SI) 10 (LR)	Liver



(a) (b)

Fig. 8. Automatic bolus system display during contrast media injection in a 73-year-old patient with multiple detector (DM) and colon cancer undergoing MD computed tomography (CT) of the abdomen. 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 $mL \cdot sec^{-1}$ and 80 mL of contrast media volume resulted of extravasation.



(a) (b)

(c)

Fig. 9. Automatic bolus system display during 30 seconds 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 setting in the esophageal area (c).

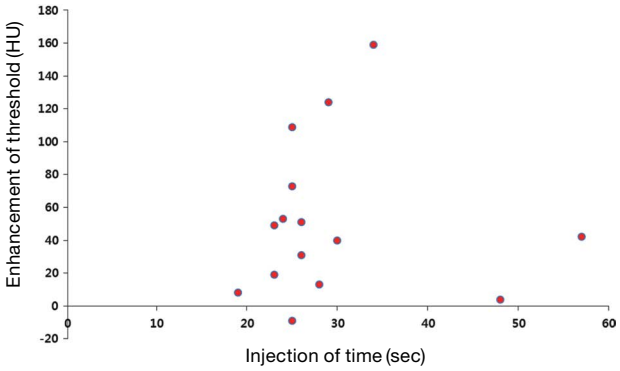


Fig. 10. Plot of the enhancement of the threshold against the injection time of the automatic bolus system in MD CT scanning.

when the contrast agent is injected into the blood vessel rapidly; if you experience any pain, please communicate that immediately."

The limitations of the study need to suggest quantitative values for ROI setting, contrast injection rate, method to reduce scan errors due to patient movement, and reduction. In addition, it is necessary to further study the quantitative human error in BTS-CT examination by comparing the characteristics of CT scanning.

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.

REFERENCES

Beddar AS, Kainz K, Briere TM, Tsunashima Y, Pan T, Prado K, Mohan R, Gillin M and Krishnan S. 2007. Correlation between internal fiducial tumor motion and external marker motion for liver tumors imaged with 4D-CT. *Int. J Radiat. Oncol. Biol. Phys.* **67**:630-638.

Brandner ED, Wu A, Chen H, Heron D, Kalnicki S, Komanduri K, Gerszten K, Burton S, Ahmed I and Shou Z. 2006. Abdominal organ motion measured using 4D CT. *Int. J. Radiat. Oncol. Biol. Phys.* **65**(2):554-560.

Brock KM, Balter JM, Dawson LA, Kessler ML and Meyer CR. 2003. Automated generation of a four-dimensional model of the liver using warping and mutual information. *Med. Phys.* **30**(6):1128-1133.

Clifford MA, Banovac F, Levy E and Cleary K. 2002. Assessment of hepatic motion Secondary to respiration for computer assisted interventions. *Comput. Aided. Surg.* **7**:291-299.

Fukukura Y, Takumi K, Kamiyama T, Shindo T, Higashi R and Nakajo M. 2010. Pancreatic adenocarcinoma: a comparison of automatic bolus tracking and empirical scan delay. *Abdom. Imaging.* **35**:548-555.

Hallman JL, Mori S, Sharp GC, Lu HM, Hong TS and Chen GT. 2012. A four-dimensional computed tomography analysis of multiorgan abdominal motion. *Int. J. Radiat. Oncol. Biol. Phys.* **83**(1):435-441.

Ichikawa T, Erturk SM and Araki T. 2006. Multiphasic contrast-enhanced multidetector-row CT of liver: contrast-enhancement theory and practical scan protocol with a combination of fixed injection ration and patients' body-weight-tailored dose of contrast material. *Eur. J. Radiol.* **58**:165-176.

Ippolito D, Sironi S, Pozzi M, Antolini L, Ratti L, Alberzoni C, Leone EB, Meloni F, Valsecchi MG and Fazio F. 2008. Hepatocellular carcinoma in cirrhotic liver disease: functional computed tomography with perfusion imaging in the assessment of tumor vascularization. *Acad. Radiol.* **15**:919-927.

Ishikawa Y, Urikura A, Yoshida T, Takiguchi K and Nakaya Y. 2017. Radiation dose optimization for the bolus tracking technique in abdominal computed tomography: usefulness of real-time iterative reconstruction for monitoring scan. *Radiol. Phys. Technol.* **10**(2):155-160.

Kim MS, Lee JW, Kim SG and Kweon DC. 2016. Radiation dose and image quality assessment of the bolus timing method for CT angiography. *Iran. J. Radiol.* **14**(2):e31918.

Kubas A, Mornex F, Merle P, d'Hombres A, Lorchel F and Chapet O. 2008. Irradiation of hepatocellular carcinoma: impact of breathing on motions and variations of volume of the tumor, liver and upper abdominal organs. *Cancer Radiother.* **12**(8):768-774.

Kweon DC and Choi JW. 2019. Analysis of radiation dose for the bolus tracking technique using the CTDI phantom of CT Study. *J. Radiat. Ind.* **13**(3):229-234.

Laghi A. 2007. Multidetector CT (64 Slices) of the liver: examination techniques. *Eur. Radiol.* **17**:675-683.

Liu F, Hu Y, Zhang Q, Kincaid R, Goodman KA and Mageras GS. 2012. Evaluation of deformable image registration and a motion model in CT images with limited features. *Phys. Med. Biol.* **57**:2539-2554.

Lin YH, Huang SM, Huang CY, Tu YN, Liu SH and Huang TC. 2014. Quantitative analysis of respiration-related

movement for abdominal artery in multiphase hepatic CT. *PLoS One*. **23**;9(12):e114222.

Mehnert F, Pereira PL, Trubenbach J, Kopp AF and Claussen CD. 2001. Automatic bolus tracking in monophasic spiral CT of the liver: liver-to-lesion conspicuity. *Eur. Radiol*. **11**:580-584.

Oto A, Tamm EP and Szklaruk J. 2005. Multidetector row CT of the liver. *Radiol. Clin. North Am*. **43**:827-848.

Sahani DV, Holalkere NS, Mueller PR and Zhu AX. 2007. Advanced hepatocellular carcinoma: CT perfusion of liver and tumor tissue-initial experience. *Radiology* **243**:736-743.

Silverman PM, Roberts S, Tefft MC, Brown B, Fox SH, Cooper C and Zeman RK. 1995. Helical CT of the liver: clinical application of an automated computer technique, SmartPrep, for obtaining images with optimal contrast enhancement. *Am. J. Roentgenol*. **165**:73-78.

Tai A, Liang Z, Erickson B and Li XA. 2013. Management of respiration-induced motion with 4-dimensional computed tomography (4DCT) for pancreas irradiation. *Int. J. Radiat. Oncol. Biol. Phys*. **86**(5):908-913.

Takemura A, Suzuki M, Sakamoto K, Kitada T, Iida H, Okumura Y and Harauchi H. 2008. Analysis of respiration-related movement of upper abdominal arteries: preliminary measurement for the development of a respiratory motion compensation technique of roadmap navigation. *Radiol. Phys. Technol*. **1**:178-182.

Zhang Q, Pevsner A, Hertanto A, Hu YC, Rosenzweig KE, Ling CC and Mageras GS. 2007. A patient-specific respiratory model of anatomical motion for radiation treatment planning. *Med. Phys*. **34**:4772-4781.

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