Showa Univ J Med Sci 30(1), 107～112, March 2018

Original

Evaluation of Deep Venous Thrombosis Using Dual-energy CT

Keita YAMANA, Yoshimitsu OHGIYA, Yuki TASHIRO,
Hanako KURODA, Kosuke TOYOFUKU and Takehiko GOKAN*

Abstract : Deep vein thrombosis (DVT) was evaluated using virtual monochromatic imaging (VMI) with dual-energy analysis. We used data from 29 patients who were imaged at Showa University Hospital using the pulmonary embolism (PE)/DVT protocol and evaluated based on the diagnostic utility of VMI with dual-energy analysis. By VMI, we compared the computed tomography (CT) values of the femoral veins on both sides and the surrounding muscle tissues at 40 keV and conventional imaging ; two radiologists performed the visual evaluation in three stages. We also evaluated the CT values of thrombi for cases with DVT. We conducted a retrospective cohort study on 29 patients (18 males and 11 females) with a mean age of 66.8 (range : 31–86) years. DVT was confirmed in four of the subjects (13.7%). Visual evaluation confirmed a significant difference between the CT values at 40 keV and with conventional imaging (2.76 vs. 1.81 ; $P < 0.05$). CT values in the femoral vein were 274.67 (range : 186.35–63.31) Hounsfield units (HU) at 40 keV and 109.46 (range : 74.54–155.66) HU with conventional imaging ($P < 0.05$). Contrast-to-noise ratios (CNRs) [(femoral vein CT value–adductor muscle CT value)/adductor muscle standard deviation (SD)] were 11.77 (range : 3.93–26.33) HU at 40 keV and 9.87 (range : 1.28–27.56) HU with conventional imaging ($P < 0.05$). The thrombus/femoral vein ratio (CT value) was 0.34 at 40 keV and 0.59 with conventional imaging, while the CNR was 17.52 at 40 keV and 4.32 with conventional imaging ; both differences were significant. Low-voltage contrast CT is beneficial for enhancing images of veins and it may also be very useful for detecting DVT.

Key words : dual-energy computed tomography, monochromatic imaging, deep vein thrombosis

Introduction

Dual-energy CT (DE-CT) uses two different tube voltages and is able to prepare virtual monochromatic X-ray images at arbitrary energies. Various clinical advantages are expected to emerge because of this technology, including reduced artifacts with high-energy imaging, less contrast agent required for low-energy imaging, and reduced exposure to radiation. However, it is known to increase SD and artifacts by lowering energy.

Department of Radiology, Showa University School of Medicine, 1-5-8 Hatanodai, Shinagawa-ku, Tokyo 142-8666, Japan.
* To whom corresponding should be addressed.

DE-CT is currently used for bone mineral density quantification and bone removal using simple X-ray imaging, and many studies have been conducted since it was first reported in 1977[1]. Initially, two scans were required to obtain data, then in 1988, a new clinical device allowed for single-scan imaging; however, the technology was not widely adopted because of several limitations that were difficult to overcome including long imaging times, noise due to poorly regulated scattered radiation in low tube-voltage imaging, deviation in the position, and beam hardening artifacts. In 2006, Siemens launched a CT device that produced images using two X-ray tubes, leading to a newfound focus on DE-CT imaging. Subsequently, this technology was advanced with each manufacturer's unique characteristics and is now sufficient for clinical use.

Recently, Siemens began to equip single-source CT devices with a new technology called "twin-beam dual energy," which allowed routine dual-energy tests for the first time. These devices obtain image data without any temporal or spatial error by simultaneously scanning with two different types of energies (high and low). The resultant two types of data allow for extraction of contrast agent components; differentiation of tissues such as bones, blood vessels, and calcification; and dual-energy imaging that visualizes information such as the compositional analysis of kidney stones, enabling routine tests with high resolution and low radiation exposure.

Pulmonary embolism (PE) that develops in the lower extremities is a well-known sequela of deep venous thrombosis (DVT) that can be fatal[2, 3]. The mortality rate of untreated PE is 30%; however, if it is treated, the mortality rate decreases to 5%–8%[4, 5]. Symptoms of DVT are diverse, making diagnosis difficult based on clinical findings only[6]. Thus, an evaluation based on imaging would be useful in making a definitive diagnosis[7, 8]. To obtain good images of the veins, appropriate scanning parameters and timing of the imaging are important, but can be challenging to achieve, and additional imaging is required for evaluating the presence of DVT in 3.1%–15.2% of cases[7, 10–13].

DE-CT virtual monochromatic imaging (VMI) has a high CT value for iodine during low-voltage imaging; accordingly, if an iodine contrast agent is used, the blood vessels will show a high concentration of iodine, which improves visualization. In addition, because the CT value does not increase with thrombi, it creates a good contrast between strongly stained veins and a thrombus, making a diagnosis of DVT easier. Therefore, this study examined whether DE-CT VMI low-voltage imaging could be useful in diagnosing DVT, in comparison with conventional imaging.

Materials and methods

We used data of 29 patients who were imaged using the PE/DVT protocol at Showa University Hospital. The study period was April 1, 2017 to July 30, 2017. We compared CT values of the femoral veins on both sides and the surrounding muscle tissues at 40 keV with the values obtained using conventional imaging, and calculated contrast-to-noise ratios (CNR) using the following equation: $CNR = (VV - AD) / N$, where VV and AD are CT values of the femoral veins and adductor muscles, respectively, and N is the SD of the adductor muscles. The region of interest (ROI) for the adductor muscle group was set at a diameter of ≥ 1 cm, while that for

Table 1. Comparison of visual evaluations, CT values, and CNRs between imaging 40 keV and conventional imaging. All values are means.
At 40 keV, femoral vein CT values were higher than those obtained by conventional imaging, CNRs were high, and visual evaluations were improved (P < 0.05).

		40 keV	Conventional image	
Visual evaluation	Radiologist A	2.97	1.86	P < 0.05
	Radiologist B	2.55	1.76	P < 0.05
	Total score of two radiologists	2.76	1.81	P < 0.05
	Femoral vein CT value (HU)	274.67	85.77	P < 0.05
	Adductor muscle CT value (HU)	107.05	60.98	P < 0.05
	Adductor muscle SD value	11.7	6.48	P < 0.05
	CNR		4.1	P < 0.05

the femoral veins was set at a diameter one-half or more of the diameter of the femoral veins. In addition, we calculated the ratio of CT values with the thrombus and the femoral vein on the opposite side of the thrombus for subjects with DVT. Two radiologists made a visual evaluation according to three stages (3, good; 2, equivocal; and 1, poor).

Diagnosis of DVT was based on complete or partial contrast defects in at least two continuous axial planes[8] at 40 keV (venous phase). To avoid subjective bias in the radiologists' evaluation, evaluation was done after diagnosing DVT according to the method described above.

Calculations and statistical analysis

We used the Wilcoxon rank-sum test to compare visual evaluations by two radiologists at 40 keV and conventional imaging. We also used paired *t*-tests to compare femoral vein CT values, adductor muscle CT values, CNRs, and thrombus CT values.

Statistical calculation was performed using JSTAT 2012 and Microsoft Excel 2016. We considered $P < 0.05$ to be statistically significant.

Results

We conducted a retrospective cohort study with 29 patients (18 males and 11 females), with a mean age of 66.8 (range: 31–86) years. DVT was confirmed in four subjects (13.7%). The images did not show any strong artifacts by movement or clear indication of a lack of contrast agent due to leakage. We calculated the mean of the visual evaluations, noise evaluations, and total scores of radiologists A and B (Table 1), and found a significant difference in visual evaluations between those taken at 40 keV and by conventional imaging (2.76 vs. 1.81).

Mean CT values in the femoral veins were 274.67 (range: 186.35–63.31) Hounsfield units (HU) at 40 keV and 109.46 (range: 74.54–155.66) HU with conventional imaging ($P < 0.05$). Mean CT values of the adductor muscles were 107.05 (range: 63.31–146.09) HU at 40 keV and 67.12 (range: 39.69–91.59) HU by conventional imaging ($P < 0.05$), while mean adductor muscle SD values were 15.45 (range: 9.26–28.1) HU at 40 keV and 4.69 (range: 2.81–8.54) HU by

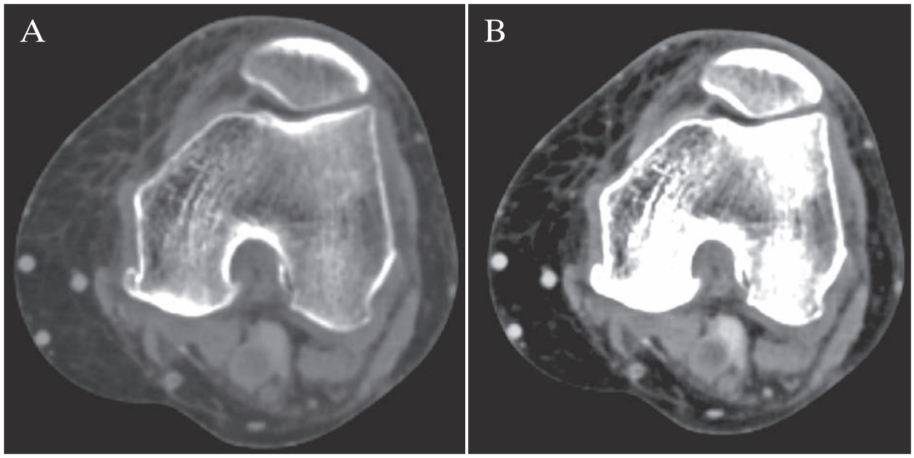

Fig. 1.
A : Conventional imaging. CT value in the femoral vein was low (100.39 HU), and the contrast with surrounding tissues was good. It was difficult to evaluate the presence or absence of DVT.
B : 40 keV. CT value in the femoral vein was high (250.98 HU), and the contrast with surrounding tissues was good. It was easy to evaluate the presence or absence of DVT.

conventional imaging ($P < 0.05$).

Mean contrast-to-noise ratios (CNRs) [(femoral vein CT value–adductor muscle CT value) / adductor muscle standard deviation (SD)] were 11.77 (range : 3.93–26.33) HU at 40 keV and 9.87 (range : 1.28–27.56) HU by conventional imaging ($P < 0.05$).

The thrombus / femoral vein ratio (CT value) was 0.34 at 40 keV and 0.59 with conventional imaging, while the CNR was 17.52 at 40 keV and 4.32 with conventional imaging ; both differences were significant.

Discussion

When using CT clinically, tissue contrast generally improves as the tube voltage is reduced, but noise increases. To this end, many studies have demonstrated the advantages of virtual monochromatic X-ray imaging with low energy using DE-CT analysis, such as in evaluations of endoleak following aortic stent placement and pulmonary artery thromboembolism[14–21]. In this study, we used differences in contrast and noise from two different energies—low energy (40 keV) and high energy (conventional imaging)—in DE-CT VMI to perform a within-case comparison, and found significant differences.

With conventional imaging, the CNR decreased significantly ; however, contrast between the femoral vein and background (we used the adductor muscles as the baseline) varied in each case. Indeed, in one patient the CT value in the femoral vein was lower than that in the adductor muscles (Fig. 1), and in such cases it is difficult to visually diagnose DVT. In addition, CT values of the femoral veins and adductor muscles were close in many cases, rendering them with a low visual evaluation score by conventional imaging. Thus, even in cases where DVT

Table 2. CT and CNR values for four subjects with DVT.
At 40 keV, there was higher contrast between the thrombus and the femoral vein than that obtained by conventional imaging.

	Thrombus CT value (40 keV)	Femoral vein CT value (40 keV)	Thrombus CT value (conventional image)	Femoral vein CT value (conventional image)
Patient A	93.62	226.2	60.07	90.48
Patient B	75.11	250.98	49.99	100.392
Patient C	95.75	343.8	74.88	137.52
Patient D	102.79	289.98	78.14	115.992

	Thrombus / vein (40 keV)	Thrombus / vein (conventional image)	CNR [(Femoral vein-thrombus) / SD) (40 keV]	CNR [(Femoral vein-thrombus) / SD) (conventional image]
Patient A	0.41	0.66	7.97	1.83
Patient B	0.30	0.50	18.42	5.28
Patient C	0.28	0.54	26.79	6.76
Patient D	0.35	0.67	16.94	3.43

evaluation by conventional imaging was difficult, visual evaluation was improved by lowering the energy (40 keV).

In DVT cases, CNRs were improved at 40 keV when visualizing the thrombi (Table 2). In addition, the mean visual evaluation was 3.0 at 40 keV and 1.9 by conventional imaging. Visualization of DVT improves as the surrounding veins are emphasized. During virtual low-voltage imaging, the CT value of the thrombus is high, although not as high as that seen with iodine. Hence, the difference in CT values between the thrombus and contrasted veins is high, and contrast between the thrombus and contrasted vein is high, improving visualization.

Limitations of this study are as follows. First, the number of cases with DVT is small, and a larger scale DVT survey and examinations of the actual improvement in DVT diagnosis are needed. Second, mean scores of visual evaluations by the two radiologists were inconsistent (radiologist A, mean scores of 2.41 and radiologist B, mean scores of 2.16), although both evaluations at 40 keV were better than those by conventional imaging ($P < 0.05$).

Conclusion

Low-voltage contrast CT is useful in enhancing images of veins and could also be useful in detecting DVT.

Conflict of interest disclosure

None of the authors have any conflicts of interests to declare.

References

1) Genant HK, Boyd D. Quantitative bone mineral analysis using dual energy computed tomography. *Invest Radiol*. 1977;**12**:545–551.
2) Laack TA, Goyal DG. Pulmonary embolism: an unsuspected killer. *Emerg Med Clin North Am*. 2004;**22**:961–983.
3) Spencer FA, Gore JM, Lessard D, *et al*. Patient outcomes after deep vein thrombosis and pulmonary embolism: the worcester venous thromboembolism study. *Arch Intern Med*. 2008;**168**:425–430.
4) Goldhaber SZ. Clinical overview of venous thromboembolism. *Vasc Med*. 1998;**3**:35–40.
5) Goldhaber SZ. Pulmonary embolism. *N Engl J Med*. 1998;**339**:93–104.
6) Stein PD, Saltzman HA, Weg JG. Clinical characteristics of patients with acute pulmonary embolism. *Am J Cardiol*. 1991;**68**:1723–1724.
7) Kalva SP, Jagannathan JP, Hahn PF, *et al*. Venous thromboembolism: indirect CT venography during CT pulmonary angiography—should the pelvis be imaged? *Radiology*. 2008;**246**:605–611.
8) Kelly AM, Patel S, Carlos RC, *et al*. Multidetector row CT pulmonary angiography and indirect venography for the diagnosis of venous thromboembolic disease in intensive care unit patients. *Acad Radiol*. 2006;**13**:486–495.
9) Cham MD, Yankelevitz DF, Shaham D, *et al*. Deep venous thrombosis: detection by using indirect CT venography. The Pulmonary Angiography- Indirect CT Venography Cooperative Group. *Radiology*. 2000;**216**:744–751.
10) Yankelevitz DF, Gamsu G, Shah A, *et al*. Optimization of combined CT pulmonary angiography with lower extremity CT venography. *AJR Am J Roentgenol*. 2000;**174**:67–69.
11) Ghaye B, Szapiro D, Willems V, *et al*. Pitfalls in CT venography of lower limbs and abdominal veins. *AJR Am J Roentgenol*. 2002;**178**:1465–1471.
12) Nazaroglu H, Ozmen CA, Akay HO, *et al*. 64-MDCT pulmonary angiography and CT venography in the diagnosis of thromboembolic disease. *AJR Am J Roentgenol*. 2009;**192**:654–661.
13) Cham MD, Yankelevitz DF, Henschke CI. Thromboembolic disease detection at indirect CT venography versus CT pulmonary angiography. *Radiology*. 2005;**234**:591–594.
14) Szucs-Farkas Z, Kurmann L, Strautz T, *et al*. Patient exposure and image quality of low-dose pulmonary computed tomography angiography: comparison of 100- and 80-kVp protocols. *Invest Radiol*. 2008;**43**:871–876.
15) Szucs-Farkas Z, Schaller C, Bensler S, *et al*. Detection of pulmonary emboli with CT angiography at reduced radiation exposure and contrast material volume: comparison of 80 kVp and 120 kVp protocols in a matched cohort. *Invest Radiol*. 2009;**44**:793–799.
16) Kang MJ, Park CM, Lee CH, *et al*. Dual-energy CT: clinical applications in various pulmonary diseases. *Radiographics*. 2010;**30**:685–698.
17) Sangwaiya MJ, Kalra MK, Sharma A, *et al*. Dual-energy computed tomographic pulmonary angiography: a pilot study to assess the effect on image quality and diagnostic confidence. *J Comput Assist Tomogr*. 2010;**34**:46–51.
18) Chandarana H, Godoy MC, Vlahos I, *et al*. Abdominal aorta: evaluation with dual-source dual-energy multidetector CT after endovascular repair of aneurysms—initial observations. *Radiology*. 2008;**249**:692–700.
19) Laks S, Macari M, Chandarana H. Dual-energy computed tomography imaging of the aorta after endovascular repair of abdominal aortic aneurysm. *Semin Ultrasound CT MR*. 2010;**31**:292–300.
20) Numburi UD, Schoenhagen P, Flamm SD, *et al*. Feasibility of dual-energy CT in the arterial phase: imaging after endovascular aortic repair. *AJR Am J Roentgenol*. 2010;**195**:486–493.
21) Stolzmann P, Frauenfelder T, Pfammatter T, *et al*. Endoleaks after endovascular abdominal aortic aneurysm repair: detection with dual-energy dual-source CT. *Radiology*. 2008;**249**:682–691.

［Received December 24, 2017 : Accepted January 11, 2018］