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Dynamic Volumetric Computed Tomography Angiography Is a Preferred Method for Unclassified Endoleaks by Conventional Computed Tomography Angiography After Endovascular Aortic Repair

Kai Hou, MD;* Ting Zhu, MD, PhD;* Wei Zhang, PhD; Mengsu Zeng, MD, PhD; Daqiao Guo, MD, PhD; Weiguo Fu, MD, PhD; Yi Si, MD, PhD

Background—The aim of this study was to assess the feasibility and safety of dynamic volumetric computed tomography angiography (DV-CTA) for endoleaks detected but not classified by conventional CTA in patients after endovascular aortic repair.

Methods and Results—From January 2016 to October 2017, 24 patients with endoleaks with aneurysm sac enlargement detected but not classified by conventional CTA were randomly assigned to the conventional CTA group and the DV-CTA group for further evaluation. The amount of contrast agent, radiation dosage, and changes in creatinine during the operation were compared between the 2 groups. Reintervention was performed according to the endoleak classification followed by the 6- and 12-month follow-up. The accuracy of classifying endoleaks by DV-CTA was comparable to that by digital subtraction angiography. Additionally, the total amount of contrast agent and the radiation dosage in the DV-CTA group during the operation were diminished by 14.0% (P=0.007) and 12.1% (P=0.004), respectively, compared with those in the conventional CTA group. No contrast-induced nephropathy was observed. All endoleaks were treated instantly after identification. No endoleaks were found in any of the patients during follow-up.

Conclusions—DV-CTA could replace digital subtraction angiography as an alternative method for the classification of endoleaks that cannot be differentiated by conventional CTA. Additionally, the amount of contrast agent and the total radiation dosage were substantially reduced, which improved safety among operators and patients. (*J Am Heart Assoc.* 2019;8:e012011. DOI: 10.1161/JAHA.119.012011.)

Key Words: computed tomography angiography • endoleak • endovascular aortic repair • stent grafts

Endovascular aortic repair (EVAR) has become the primary treatment for abdominal aortic aneurysm.[1,2] However, endograft-related complications, such as endoleaks, stent-graft migration, or rupture, are highly related to EVAR and result in continuous aneurysm sac enlargement or false lumens, eventually leading to aortic rupture. Thus, persistent endoleaks may indicate EVAR failure and require further reintervention.[3,4] As a result, the correct classification of endoleaks is clinically conducive to establish the proper reintervention strategy. Currently, conventional computed tomography angiography (C-CTA) is considered the standard method for detecting endoleaks. Nevertheless, the C-CTA only acquires the static images instead of the dynamic blood flow. Presently, the criterion standard for detecting the source vessels of the endoleak is digital subtraction angiography (DSA).[5] However, the main disadvantage of DSA is that it requires a large amount of contrast agent and radiation dose because of the angiography series during the entire procedure. Furthermore, the identification of endoleaks by DSA depends on the operator's experience.

Thus, a convenient and safe imaging approach to differentiate the source vessels associated with endoleaks is desirable. Dynamic volumetric computed tomography angiography (DV-CTA) has been previously used for endoleak detection because of its striking features such as a broad scanning length in the z-axis and sequential scanning with time-resolved imaging.[6,7] There are a few studies that have evaluated the feasibility of DV-CTA in identifying endoleak types. The purpose of our study was to illustrate the use of

DV-CTA imaging technology to classify endoleaks that were difficult to differentiate by C-CTA, to evaluate its fidelity and diagnostic performance, and to compare the amount of contrast agent and radiation dosage used with that of C-CTA.

Materials and Methods

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Study Design and Patients

This prospective study was approved by the institutional review board, and all patients gave written informed consent after being made aware of the risks and benefits of C-CTA, DV-CTA, and DSA.

At our institution, consecutive patients treated with EVAR were referred for C-CTA as a post-therapeutic follow-up between January 2016 and October 2017 followed by endoleak classification. We performed a randomized controlled study to identify the types of endoleaks and reintervention. The inclusion criteria included endoleaks that were difficult to classify, as well as an aneurysm sac enlargement of at least 5 mm/6 mo. The exclusion criteria were as follows: identified endoleak type and endoleaks without aneurysmal enlargement regardless of whether the classification was known (close surveillance would be recommended). The recruited patients were randomized into the C-CTA group and the DV-CTA group based on a 1:1 randomization scheme using the open-source randomization

software (https://www.randomizer.org/, ResearchRandomizer, Social Psychology NetWork). In the C-CTA group, intraoperative DSA was used to determine the classification of the endoleaks. In the DV-CTA group, endoleaks were first classified using a 320-row detector scanner for DV-CTA. Two days later, the culprit vessels associated with the endoleaks were confirmed by intraoperative DSA. Once the culprit vessels associated with the endoleaks and the type of endoleaks were identified, the treatment was executed immediately as mentioned below.

DV-CTA Protocol

All examinations were performed using a Toshiba 320-row detector CT volume scanner (Aquilion ONE, Toshiba Medical Systems) with a *z*-axis of 16 cm per volume scan. Patients were placed in the supine position on the CT table to scan the region of the endoleak, which was previously determined by conventional CTA. The examination table remained stationary during the entire scanning process. To reduce the radiation dosage, we chose CT scanning with a low tube voltage and the adaptive iterative dose reduction 3D method. All parameters were set as listed in Table 1. First, we performed a test with a low-dose bolus (10 mL of contrast agent at 4 mL/s) to record the duration required for the contrast agent to reach the top of the stent-graft, which is known as the preset delay time. Then, a high-concentration iodine contrast agent (iodine, 370 mg I/mL) was injected through the peripheral vein with a high-pressure syringe. The total amount of contrast agent was injected at 0.8 mL/kg

Table 1. Parameters of Dynamic Volumetric CTA

Parameter	Value
Acquisition	12–16 phases
Tube voltage, kVp	80
Tube current, mAs	120
Rotation time, s	0.5
Scan time, s	0.5
Resolution time, s	2
Total scan time, s	24–32
Collimation, mm	320×0.5
DLP, mGy·cm	539.5 (505.0–566.4)
Scan range, cm	16
Slice thickness, mm	0.5
Increment, mm	0.25
Contrast material volume, mL	62.5 (55–74)
Flow rate, mL/s	4

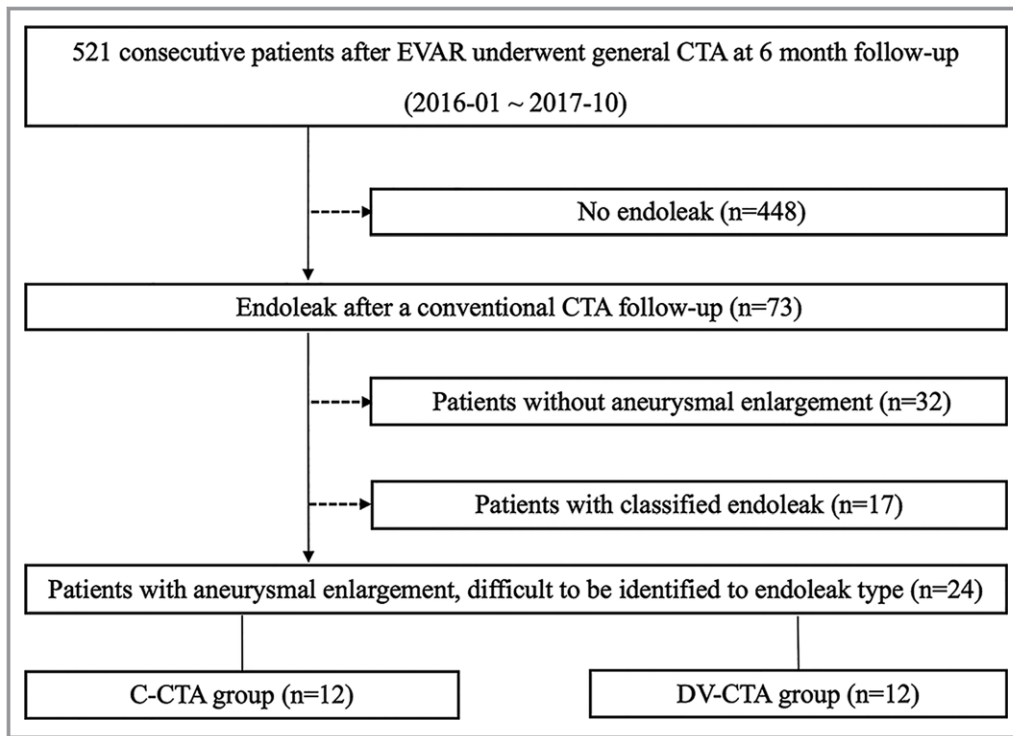CTA indicates computed tomography angiography; DLP, dose-length product.

Figure 1. Flow chart of inclusion and exclusion criteria. C-CTA indicates conventional computed tomography angiography; DV-CTA, dynamic volumetric computed tomography angiography; EVAR, endovascular aortic repair.

body weight (flow rate, 4.0 mL/s). Finally, 25 mL of saline was injected at the same flow rate. The dynamic acquisition sequence was triggered 2 s before the preset delay time. The complete DV-CTA series consisted of a 0.5-s tube exposure with a temporal resolution of 2 s, containing $\approx$12 to 16 intermittent scan phases. As a result, the total scan time was nearly 24 to 32 s. The dose-length product was noted on the machine.

DSA and Treatment for Endoleaks

All patients were hydrated before the intervention procedure. For endoleaks in the C-CTA group, the culprit vessels associated with the endoleaks were confirmed by multiple intraoperative DSA. For endoleaks in the DV-CTA group, the blood vessels identified by the DV-CTA were directly super-selected during intraoperative angiography to confirm the consistency between the 2 methods. A type I endoleak was repaired by balloon remodeling or a cuff. Complete emboliza-tion of the culprit vessels was performed for type II endoleaks. Stent-graft relining was preferred when a type III endoleak was identified.

Contrast use and radiation dosage for each procedure, including the DV-CTA and the subsequent intervention, were recorded. In the DV-CTA group, all the measurements included the sum of all the procedures. In contrast, the measurements in the C-CTA group comprised the sum of the procedures without the DV-CTA.

Image Postprocessing and Analysis

All volume data packets obtained by dynamic scanning were transmitted to the Toshiba postprocessing workstation (Vitrea Workstation, Cannon Medical Systems) to achieve final

Table 2. Patient Characteristics

Characteristics	C-CTA (n=12)	DV-CTA (n=12)	P Value
Age, y	63.92±9.16	71.41±9.62	0.75*
Sex (M/F)	10/2	9/3	1.000[†]
BMI, kg/m^2	23.7±2.7	24.4±3.7	0.34*
Diabetes mellitus	4	3	1.000[†]
Previous stroke	0	0	NA
Renal insufficiency	0	1	1.000[†]
Coronary artery disease	2	1	1.000[†]
Smoking history	4	5	1.000[†]
COPD	0	1	1.000[†]

BMI indicates body mass index; C-CTA, conventional computed tomography angiography; COPD, chronic obstructive pulmonary disease; DV-CTA, dynamic volumetric computed tomography angiography.
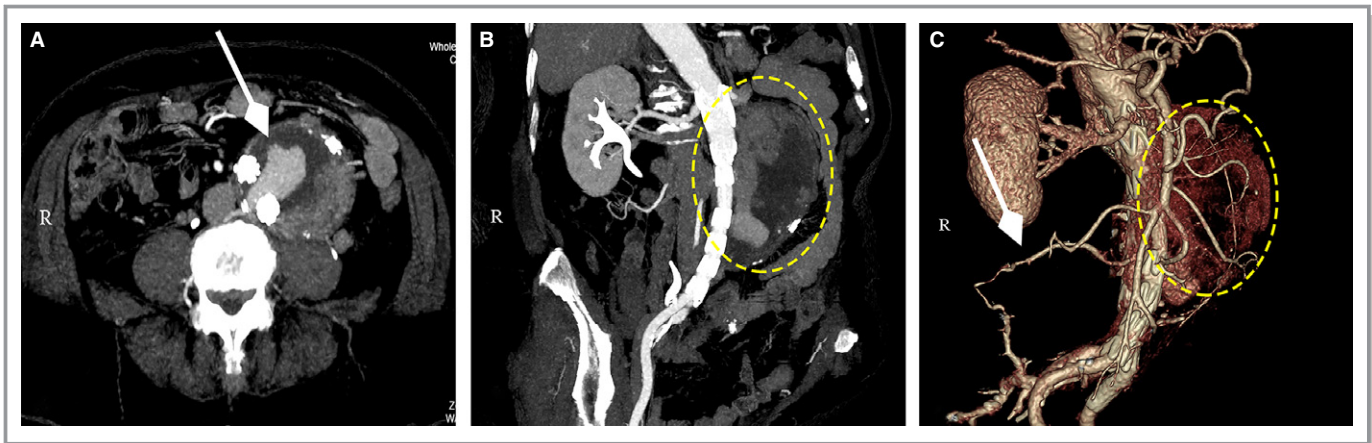*t test.
[†]Fisher exact test.

Figure 2. Endoleak detected by conventional CTA in a 72-year-old man after EVAR at the 6-month follow-up was not differentiated between type I/III and type II endoleaks. **A,** Cross-sectional image indicates the obvious endoleak (arrow) in the aneurysm after EVAR. **B,** Multiplanar reconstruction image of a coronal section shows a large amount of endoleak (circle) with being incapable of classifying the endoleak type. **C,** The 3D image shows the endoleaks (circle) and the suspicious vessels supplying the endoleaks (arrow). CTA indicates computed tomography angiography; EVAR, endovascular aortic repair.

images and videos using maximum density projection, multiplanar reconstruction, and volume rendering technique reconstruction under identical conditions. The images and videos were analyzed by 2 senior radiologists who were blinded to the clinical data and the results of conventional CTA. For DSA images, the classification of the endoleaks was confirmed by 2 experienced vascular surgeons who were blinded to the results of conventional CTA and DV-CTA. If the results were controversial, the data were re-evaluated by the third chief vascular surgeon.

Statistical Analysis

The continuous variables are shown as the mean±SD or median (interquartile range), and the categorical variables are described as N (%). The continuous variables were analyzed using the *t* test or Wilcoxon rank-sum test, and the categorical variables were analyzed using the χ^2 test or Fisher exact test. All tests were 2-sided. All analyses were performed using statistical software (SPSS 19.0; SPSS, Chicago, IL), and $P \leq 0.05$ indicated a statistically significant difference.
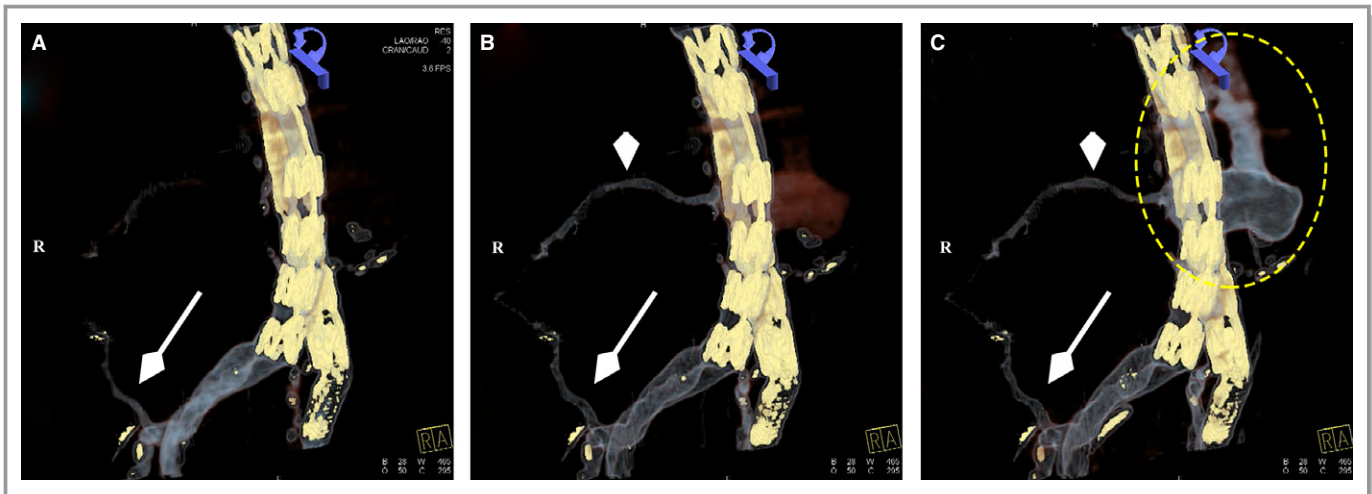
Figure 3. The culprit vessel was evaluated by DV-CTA to confirm the type II endoleak. **A,** A 3D image at 22 s shows the branch of the right hypogastric artery (arrow) but not the endoleak. **B,** A 3D image at 28 s shows the ILA (arrowhead) connected with a branch of the right hypogastric artery (arrow) with no sign of endoleak. Therefore, a type I endoleak was excluded. **C,** A 3D image at 40 s shows the endoleaks (circle) supplied by the ILA (arrowhead), thus indicating a type II endoleak. The arrow indicates the right hypogastric artery. DV-CTA indicates dynamic volumetric computed tomography angiography; ILA, iliolumbar artery.

Results

Basic Characteristics of the 2 Groups

Between January 2016 and October 2017, a total of 521 consecutive patients were recruited after EVAR in the vascular surgery department. Seventy-three patients were found to have endoleaks after 6 or 12 months of conventional CTA follow-up. Thirty-two of those patients did not show aneurysmal enlargement and were excluded; however, close surveillance was recommended. Another 17 patients with classified endoleaks were also excluded. The remaining 24 patients with aneurysmal enlargements in whom the endoleak type was difficult to identify were randomly divided into the conventional CTA group and the DV-CTA group (Figure 1). Patient characteristics are provided in Table 2. There were no significant differences between the C-CTA group and DV-CTA group.

Classification of Endoleak Confirmed by DV-CTA and DSA

The source vessels associated with the endoleaks were found in the conventional CTA group using a DSA protocol published previously.[5]

In the DV-CTA group, the endoleaks of 12 patients were all classified, although their culprit vessels could not be identified by conventional CTA. Figure 2 shows that the endoleak was not confirmed by conventional CTA. However, Figure 3 shows that the endoleak could be identified as a type II via DV-CTA. Video S1 suggests that the dynamic film of DV-CTA could indicate the type II endoleak in this case. During the reintervention procedure for this case, the diagnostic catheter was directly superselected into the culprit vessel characterized via DV-CTA, and the type II endoleak was confirmed followed by embolization (Figure 4). Table 3 displays all final DSA angiography results, which were consistent with those of DV-CTA, suggesting that the accuracy of DV-CTA in detecting the culprit vessels associated with the endoleaks was 100% (Table 3).

Comparison of Parameters During the Reintervention

An average of 6 angiograms were performed to confirm the culprit vessels associated with the endoleaks in the C-CTA group. However, only a single angiogram was needed in the DV-CTA group. Compared with those in the C-CTA group, the contrast use and radiation dosage for identifying endoleaks in the DV-CTA group were remarkably reduced by 20.5% ($P<0.001$) and 13.7% ($P<0.002$), respectively. Likewise, the amount of contrast agent and radiation dosage in the DV-CTA group during the entire intervention procedure (including identifying and treating the endoleaks) were decreased by 53.7% ($P<0.001$) and 61.5% ($P<0.001$), respectively. However, the contrast use and the radiation dosage in the 2 groups during the treatment procedure were comparable. When including the contrast agent and radiation dosage used in the DV-CTA procedure, the total contrast use and radiation dosage during hospitalization were still diminished by 14.0% ($P=0.007$) and 12.1% ($P=0.004$), respectively (Table 4).

Postoperative Effect and Follow-Up of the 2 Groups

Endoleaks were not found in either group after the operation. No recurrence of endoleaks was identified in any of the
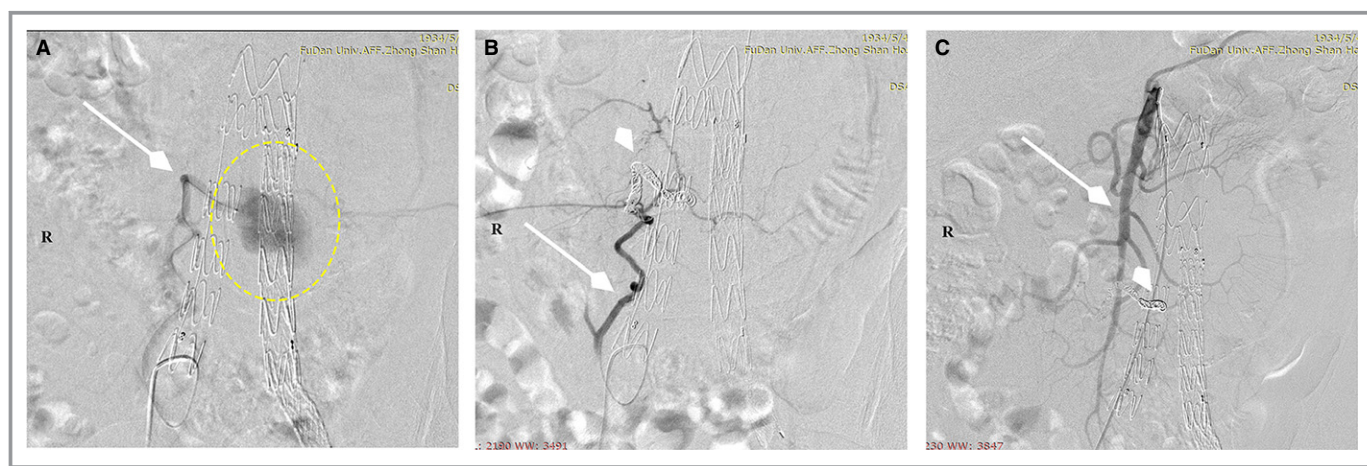
Figure 4. Reintervention for the type II endoleak identified by the DV-CTA. **A**, The endoleak (circle) was confirmed by the angiogram in the ILA (arrow). **B**, The endoleak disappeared after the embolization coil (arrowhead) was placed in the ILA (arrow). **C**, The endoleak was not visualized even when the angiogram was in the superior mesenteric artery (arrow). The arrowhead indicates the embolization coil. DV-CTA indicates dynamic volumetric computed tomography angiography; ILA, iliolumbar artery.

patients during the 3- and 6-month follow-ups (Figure 5). There was no contrast nephropathy in either group during hospitalization. In addition, the change in serum creatinine in the DV-CTA group was not significantly different compared with that in the conventional CTA group at 48 hours after the operation (*P*>0.05).

Discussion

Our results suggested that the excellent accuracy of DV-CTA in classifying endoleaks after EVAR was 100%, which greatly assisted clinicians in identification of the blood vessels associated with the endoleaks during reintervention. In addition, identification of the endoleak vessels by preoperative DV-CTA significantly reduced the radiation dosage within the operation, effectively reducing the risk to clinicians and patients. Moreover, the strategy could reduce the use of contrast agents and the damage to kidney function. Therefore, to our knowledge, this is the first study to investigate the feasibility and safety of endoleak classification after EVAR using DV-CTA compared with conventional CTA.

C- CTA, the current standard method for post-EVAR follow-up,[8] can only provide static images, which cannot show the direction of blood flow in the endoleaks, especially the direction of a large amount of blood leakage outside the stent-graft. Moreover, C- CTA can miss low-flow endoleaks emerging in the late arterial period.[7] Lehmkuhl et al indicated that the 2 scan phases in the C-CTA, 3 and 6, with 12 and 27 s after the bolus-tracking threshold, respectively, were the most appropriate scan phases for the identification of endoleaks. Additionally, David indicated that endoleaks could be found using C-CTA with 90.5% sensitivity and 100% specificity.[9] However, these scan phases are not sufficient to characterize endoleaks for clinical reasons. Recently, DV-CTA has shown promise in demonstrating the type and source of the endoleaks discussed in previous reports.[6] Therefore, some authors have suggested DV-CTA as a routine follow-up examination for the detection of endoleaks.[6,7] According to our results, C–CTA is sufficient for the detection of endoleaks, while DV-CTA is a promising adjuvant strategy for endoleaks that are difficult to classify.

In our study, the Toshiba 320-row detector CT dynamic imaging technique was used to evaluate the classification of the endoleaks preoperatively. The detection tube can cover the required observation area of the stent-graft according to the results of C–CTA. Additionally, our data showed that the present protocol can accurately capture the entire process of contrast agent flow to identify the culprit vessels associated with endoleaks. With regard to the postprocessing strategy, we mainly used cine imaging with a 1.5-s interval to observe the development process of the contrast agent in an

aneurysm with the optimal angle in the 3-dimension space and eventually classify the endoleaks according to the characteristics of the position and density change of the contrast agent.

The incidence of endoleak after EVAR is generally reported to be 20% to 30%.[5,10] Currently, type IV endoleaks are rare because of improved stent materials, which are considered to be self-limiting or seal spontaneously. Conversely, type II endoleaks are relatively common, occurring in 10% to 25% of patients after EVAR and warrant embolization of the culprit vessels if aneurysmal enlargement is observed.[11] In addition, type I and type III endoleaks are considered to have high risk because of persistently increased sac pressure and are treated by reintervention such as balloon remodeling, cuff implantation, or relining.[12,13] Therefore, it is essential to

Table 3. Diagnosis of Endoleaks by Different Methods

	Follow-Up Time (mo)	EL by C-CTA	EL by DV-CTA	EL by DSA
C-CTA				
1	12	I or II	No	II
2	6	I or II	No	I
3	12	II or III	No	II
4	6	I or III	No	I
5	12	I or II	No	I
6	6	I, II, or III	No	II
7	12	II or III	No	III
8	6	II or III	No	II
9	6	II or III	No	I
10	12	I or II	No	II
11	6	I, II, or III	No	I
12	12	II or III	No	II
DV-CTA				
1	6	I, II, or III	II	II
2	6	I or II	I	I
3	12	II or III	II	II
4	6	II or III	II	II
5	6	I or II	I	I
6	12	I or II	II	II
7	12	II or III	II	II
8	6	II or III	III	III
9	6	I or II	I	I
10	12	I, II, or III	II	II
11	12	II or III	I	I
12	6	I or II	II	II

C–CTA indicates conventional computed tomography angiography; DSA, digital subtraction angiography; DV-CTA, dynamic volumetric computed tomography angiography; EL, endoleak.

Table 4. Parameters Comparison During the Reintervention

Results	C-CTA (n=12)	DV-CTA (n=12)	Variation Percentage* (%)	P Value[†]
Contrast				
Contrast use for IOE, mL	97.5 (90–110)[‡]	62.5 (55–74)[§]+15 (10–20)[‡]	20.5	<0.001
Contrast use for intervention, mL	60 (57.5–62.5)[‖]+97.5 (90–110)[‡]	58 (47.5–77.5)[‖]+15 (10–20)[‡]	53.7	<0.001
Total amount of contrast use, mL	157.5 (147.5–172.5)	135.5 (110–150)	14.0	0.007
Exposure				
Radiation dosage for IOE, mGy	671.7 (624.1–719.5)[‡]	539.5 (505.0–566.4)[§]+40.2 (38.6–45.8)[‡]	13.7	0.002
Radiation dosage for intervention, mGy	419.4 (342.0–576.1)[‖]+671.7 (624.1–719.5)[‡]	379.4 (309.8–508.7)[‖]+40.2 (38.6–45.8)[‡]	61.5	<0.001
Total radiation dosage, mGy	1091.1 (966.1–1295.6)	959.1 (831.6–1059.2)	12.1	0.004

C-CTA indicates conventional computed tomography angiography; DV-CTA, dynamic volumetric computed tomography angiography; IOE, identification of endoleak.

*Value ((C-CTA)−Value (DV-CTA))/Value (C-CTA)×100%.

[†]Wilcoxon rank sum test.

[‡]Value in the IOE during the procedure of digital subtraction angiography (DSA).

[§]Value in the procedure of DV-CTA.

[‖]Value in the treatment during the procedure of DSA.

identify endoleaks to determine further treatment strategies. In terms of our data, 32.9% (24/73) of the endoleaks were persistently aggressive and difficult to identify according to the endoleak type. Some researchers have found that it is difficult to distinguish type I/III endoleaks from type II endoleaks using C-CTA.[6,7] The current criterion standard for classifying endoleaks is DSA, which merely captures the endoleak blood in 2-dimension space. Nevertheless, DV-CTA could precisely distinguish type I/III and type II endoleaks, as demonstrated by our study and other studies in the literature,[6,14] mainly because of the characteristics of the DV-CTA in its dynamic image capturing in 3-dimension space. Thus, DV-CTA could be an initiative technique with wide application for classifying endoleaks.

A safety analysis of DV-CTA plus DSA has not been reported; thus, we quantified the contrast use and radiation dosage during the procedure. Our results showed that the contrast use and radiation dosage in the 2 groups were comparable during the treatment procedure after the culprit vessel was identified. As a matter of fact, the difference consisted of the procedure of identification of the endoleak. To confirm the endoleak type, multiple angiograms were
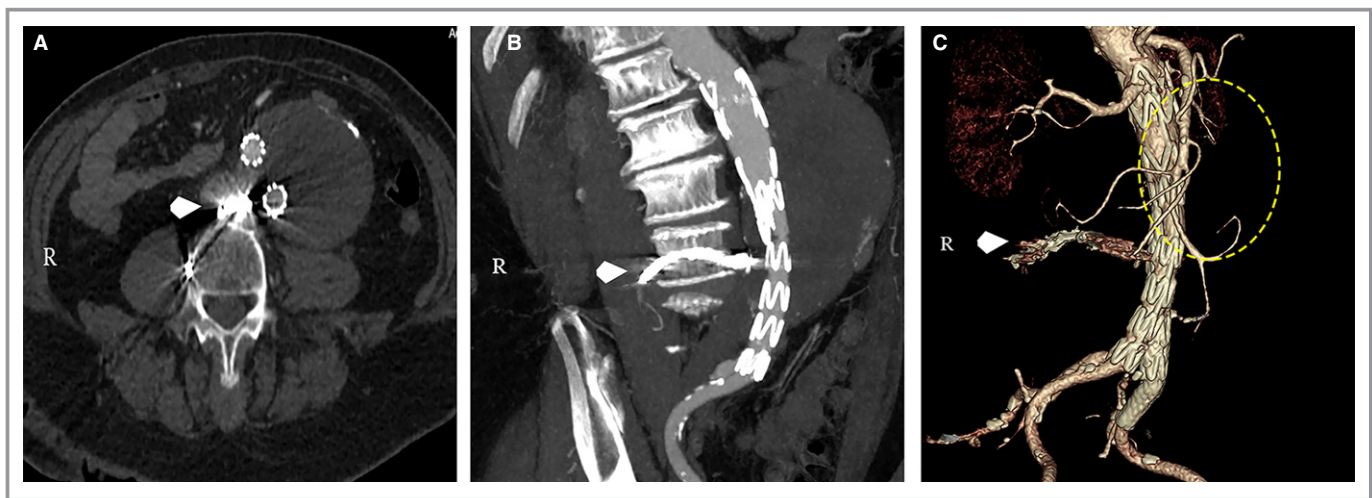

Figure 5. No endoleak was detected by the conventional CTA at the 6-month follow-up after reintervention. **A** and **B**, Cross-section and multiplanar reconstruction images both indicate no endoleak in the aneurysm and embolization coil in the ILA (arrowhead). **C**, The 3D image shows an embolization coil in the ILA (arrowhead) and no endoleak outside of the stent-graft (circle). CTA indicates computed tomography angiography; ILA, iliolumbar artery.

performed in the C-CTA group, while fewer angiograms were performed in the DV-CTA group because of identification of the culprit vessels. Therefore, much less contrast use and radiation exposure were recorded in the DV-CTA group (Table 4). A couple of studies have provided relatively reliable estimates of cancer risk for moderate-to-high radiation doses.[15–17] Thus, our new DV-CTA protocol could further decrease cancer risks for clinicians accordingly. Additionally, it is worth mentioning that patients in the C-CTA group underwent diagnosis and treatment of endoleaks in 1 single procedure, resulting in much more contrast use and radiation exposure in a short time (Table 4), which put patients at risk for radiation injury and contrast-induced nephropathy.[18,19] In contrast, the identification and treatment of endoleaks were separated into 2 procedures with a 48-hour interval time in the DV-CTA group, which gave patients adequate time for hydration and lessened the risk of contrast-induced nephropathy and radiation injury (Table 4).

This study has some limitations. First, the number of patients recruited in this study was limited; thus, the results of the statistical analysis may be biased. We will continue to collect patients who meet the inclusion criteria and confirm the benefit of DV-CTA compared with conventional CTA. Second, DV-CTA is still restricted by its scan length and comparatively high radiation dosage. For patients with longer stent systems, it would be difficult to complete the analysis of the whole stent with the fixing table within 1 scan. In the future, scanning of a long stent can be completed by improving the machine design, and the radiation dosage can be minimized by optimizing the scanning procedure. Third, considering the patient's radiation dosage, the 1.5-s interval of the acquired images was insufficient to accurately capture a live image of the endoleaks; thus, future improvements in technology or equipment will further increase the resolution time while maintaining a safe dose of radiation. Finally, although the technique can effectively distinguish type I/III endoleaks from type II endoleaks, it is still not helpful for distinguishing type V endoleaks.

In general, DV-CTA can be used as an effective and safe diagnostic technology for endoleaks that are difficult to characterize by C-CTA. Additionally, DV-CTA can distinguish the endoleak vessels through dynamic data collection and postprocessing analysis and consequently reduce the radiation dosage, amount of contrast agent, and influence on the renal function of patients. Future studies with larger patient cohorts are required to further demonstrate the potential benefits of DV-CTA with long-term prospective follow-up.

Disclosures

None.

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SUPPLEMENTAL MATERIAL

Supplemental Video Legend:

Video S1. This video shows that the endoleak was type II and the culprit vessel derived from the iliolumbar artery which was connected to the branch of the right hypogastric artery. Best viewed with Windows Media Player.