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# Detection of Endoleaks Following Thoracic and Abdominal Aortic Endovascular Aortic Repair—: A Comparison of Standard and Dynamic 4D-Computed Tomography Angiography

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**Abstract**

**Purpose:** Endoleaks are a common complication after endovascular aortic repair (EVAR) and thoracic endovascular aortic repair (TEVAR). The detection and correct classification of endoleaks is essential for the further treatment of affected patients. However, standard computed tomography angiography (CTA) provides no hemodynamic information on endoleaks, which can result in misclassification in complex cases. The aim of this study was to compare standard CTA (sCTA) with dynamic, dual-energy CTA (dCTA) for detection and classification of endoleaks following EVAR or TEVAR. **Materials and Methods:** This retrospective evaluation compared 69 sCTA diagnostic examinations performed on 50 different patients with 89 dCTA diagnostic examinations performed on 69 different patients. **Results**: In total, 15.9% of sCTA examinations and 49.4% of dCTA examinations led to the detection of endoleaks. With sCTA, 20.0% of patients were diagnosed with endoleaks, while with dCTA, 37.7% of patients were diagnosed with endoleaks. With sCTA, mainly Type I endoleaks were detected, whereas, with dCTA, the types of detected endoleaks were more evenly distributed. In comparison with the literature, the frequencies of endoleak types detected with dCTA better reflect the natural distribution than the frequencies detected with standard CTA. **Conclusion:** Based on the retrospective comparative evaluation, dCTA could pose a valuable supplementary diagnostic tool resulting in a more accurate and realistic detection and classification of suspected endoleaks.

**Keywords**

endovascular aneurysm repair, computed tomographic angiography, endoleak, hemodynamics, 4-dimensional dynamic CTA

## Introduction

Endovascular aortic repair (EVAR) is a well-established method for the treatment of abdominal aortic aneurysm and even became first-line therapy in a subset of patients meeting certain criteria and suffering from intact abdominal aortic aneurysms.[1] Especially, an assumed lower perioperative morbidity and lesser blood loss during intervention are the main benefits of the procedure.[2] Consequently, it is more widely used in clinical routine in recent years.[3,4] However, despite ongoing technical and procedural advancements, EVAR still does have a high potential of complications including both, systemic (eg, ischemia) and endograft related (eg, stent migration) complications.[2,5]

Also thoracic endovascular aortic repair (TEVAR) has emerged as a potential alternative to emergency open surgical repair for acute aortic syndromes, mostly for the descending aorta.[6] TEVAR of the ascending aorta poses a challenge, mainly because of the curvature of the aortic arch, proximal fixation close to the aortic valve and coronary ostia, distal fixation that may impinge on the innominate artery,

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considerable hemodynamic forces, and risk of cardiac and aortic injury and retrograde aortic dissection. Some of the major complications of this procedure include perforation of the left ventricle, injury and dissection of the aortic root, and occlusion of the coronary arteries.[7]

A device-related complication common to both, EVAR and TEVAR, is the peri- and post-procedural occurrence of endoleaks.[2] Endoleaks are persistent blood flows within the aneurysm sac following EVAR or TEVAR. Conceptually the aortic stent-graft excludes the aneurysm from the circulation by providing a conduit for blood to bypass the sac.[8] Following the classification originally introduced by White et al., 5 types of endoleaks can be discriminated.[9]

Type 1 endoleaks occur because of an inadequate seal at the site of the aortic stent-graft attachment. Therefore, blood flow leaks alongside the graft into the aneurysm sac. Prevalence of type 1 endoleaks ranges from about 3% up to 19% in high-risk patients and certain new repair approaches.[9–13]

Type 2 endoleaks occur in ~25% of EVAR cases because of a retrograde flow through branch vessels that continue to fill the aneurysm sac.[14] In contrast to type 1 endoleaks, endoleaks of type 2 can usually resolve spontaneously over time. Sidloff et al. reported a spontaneous resolution of 35.4% of type 2 endoleaks over a range of 3 months to 4 years.[15] Type 3 endoleaks follow a mechanical failure of the aortic stent-graft, such as fractures, holes or defects on the graft fabric, or junctional separation of the modular components. In a recent multicenter study, they were reported in 2.1% of 965 patients.[16] Type 4 endoleaks are rare (0.3%)[17] and occur when blood leaks across the graft due to its porosity, which typically resolves within a few days of graft placement.[8] Overall, the absence of perioperative endoleaks just after stent deployment defines the technical success of EVAR or TEVAR.[14] In a recent meta-analysis, endoleaks of any type were observed in 16.4% of the patients after TEVAR in the ascending aorta and in 18.0% of patients after TEVAR in the descending aorta.[14]

As endoleaks cause a high systemic blood pressure within the aneurysm sac, they can ultimately even lead to aortic rupture and, consequently, often need to be addressed in an additional intervention.[18] Within the EUROSTAR registry, the cumulative risk for rupture after aortic repair was 1% with types 1 and 3 endoleaks representing significant risk factors.[11] Therefore, the detection and classification of endoleaks are mandatory.

Computed tomography angiography (CTA) is the standard diagnostic procedure as a valuable noninvasive tool for follow-up and endoleak detection[19,20] but usually provides no hemodynamic information on endoleaks. Dynamic (dual-energy) CTA may improve the diagnostic performance in the evaluation of endoleaks.[8,21] In 2012, Sommer et al. already showed the high diagnostic performance of dynamic scan protocol comprising 12 phases and radiation dose levels not exceeding those of a standard triphasic CT at that time.[22] By simplifying the dynamic dual-energy CT multiphasic scan protocol to 5 low dose scans with a time resolution of 1.4 seconds, the radiation dose could be reduced to a dose level of a standard dual phase CTA protocol.[8]

Above-stated advancements in dynamic CTA technique are consequently arguing the major concern of this diagnostic tool, namely high dose burdens. Hereby, the focus shifts to tapping the full diagnostic potential of this tools for the accurate detection of endoleaks.

The aim of this study was to compare the detection rate of different types of endoleaks after EVAR using standard CTA versus dynamic CTA and to highlight possible shortcomings or advantages of the compared methods.

## Materials and Methods

This study is a retrospective comparative evaluation of standard and dynamic CTA diagnostic examinations, which were performed between March 21, 2015 and March 21, 2018. The basic characteristics of the 2 study populations can be found in Table 1. This study has been performed out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by local ethics committee (No.: 837.512.16; 10380).

Patient records were retrospectively reviewed by an experienced radiologist for the presence of an endoleak or the type of endoleak. In addition, a second experienced radiologist confirmed the diagnoses via consensus read.

Endoleaks were identified as contrast opacification of the aneurysm sac outside the graft. Type 1 endoleaks were classified on CTA on the basis of the location of the endoleak in contiguity with the proximal attachment site, as well as the early filling of the endoleak sac. Endoleaks were classified as type 2 endoleaks if the endoleak sac could not be seen communicating with the distal or proximal attachment site or if there was delayed enhancement of the endoleak sac. If an endoleak was associated with the junctional separation of 2 stent-graft sections, it was defined type 3 endoleak.

### *Standard Computed Tomography Angiography*

Standard CTA (sCTA) utilizing helical technique and retrospective gating was performed with a 320 row CT (0.5 mm detector collimation and 350 milliseconds gantry rotation time; Aquilion ONE, Toshiba Medical Systems [now: Canon Medical Systems Corporation], Otawara, Japan) as recently described.[23] CT angiography with the Aquilion ONE scanner was performed with a tube voltage of 100 or 120 kVp, a rotation time of 275 milliseconds, and adaptive tube current that depended on sex and BMI. For sCTA, a nonionic contrast agent (350 mg of iodine) was injected into an antecubital vein of the right arm. The amount and flow of

**Table 1.** Basic Characteristics of the Study Population.

| Variable | Standard CTA | Dynamic CTA |
|---|---|---|
| Number **of examinations** | 69 | 89 |
| Number **of patients** | 50 | 69 |
| Number **of male patients** | 44 (88.0%) | 59 (85.5%) |
| Average **age of patients in years (mean ± standard deviation)** | 69.8 ± 11.2 | 72.1 ± 10.2 |
| Reason **for CTA diagnostics** | | |
| **EVAR** | 42 (60.9%) | 56 (62.9%) |
| **TEVAR** | 26 (37.7%) | 28 (31.5%) |
| Aneurysma **spurium** | 0 | 1 (1.1%) |
| Bentall **procedure** | 0 | 1 (1.1%) |
| Hemangioma | 0 | 1 (1.1%) |
| Tubular **prosthesis** | 1 (1.4%) | 0 |
| Unknown | 0 | 2 (2.2%) |

Abbreviations: CTA, computed tomography angiography; EVAR, endovascular aortic repair; TEVAR, thoracic endovascular aortic repair.

contrast agent was adjusted to body weight, ranging between 60 and 80 mL with a flow rate of 4 mL/s.[24] The sCTA was performed by bolus tracking in an arterial phase. The dose-length product was noted.

### *Dynamic Computed Tomography Angiography*

A third-generation dual-source CT scanner (SOMATOM Force, Siemens Healthcare, Forchheim, Germany) with a detector width of 5.4 cm was used for dual-energy dynamic CTA (dCTA). With this CT scanner, dynamic CTA was performed in a dual-energy acquisition with tube voltages set to 90/Sn150 kVp, a rotation time of 250 milliseconds, and adaptive tube current.

The delay after bolus tracking in the pulmonary artery was 3 seconds. This was followed by 5 bidirectional radiation dose optimized scans with a temporal resolution of 1.4 seconds. The total temporal observation period was thus 14 seconds. The field of view of 360 mm on the longitudinal axis. The dose-length product was noted.

In Figure 1, an example of dynamic CTA with a type 3a endoleak is visualized.

Images were calculated by addition of the original low-tube-voltage and high-tube-voltage images with a 0.6 weighting ratio. Four-dimensional datasets were generated by means of SyngoVia workstation (VA30, Siemens Healthcare, Forchheim, Germany). For dCTA, a nonionic contrast agent (350 mg of iodine) was injected into an antecubital vein of the right arm. The amount and flow of contrast agent was adjusted to body weight, ranging between 60 and 70 mL with a flow rate of 5 mL/s.[24]

### *Statistics*

Statistical analyses were performed with IBM SPSS (version 23; International Business Machines Corp., Armonk, NY, USA). For descriptive statistics, mean values and standard deviations were calculated. Pearson's chi-squared test was applied to sets of unpaired categorical data to evaluate the likelihood that any observed difference between the sets was due to chance. A p-value $\leq$0.05 was considered statistically significant. In addition, Pearson's contingency coefficient was calculated to provide an easier to interpret measurement of the strength of the association.

## Results

Numbers and types of endoleaks, which were detected with the 2 different CTA approaches, are summarized in Table 2.

### *Standard CTA*

In total, 69 sCTA diagnostic examinations were performed on 50 different patients. The majority of patients were male (88.0%). The patients were on average 69.8 ± 11.2 years old when the examination took place. Six patients were screened twice, 5 patients were screened 3 times, and 1 patient was screened 4 times.

The reasons for performing sCTA diagnostics were routine checks following EVAR (60.9%), TEVAR (37.7%) and the placement of a tubular prosthesis (1.4%). Radiation exposure in the sCTA in the arterial phase was 475.7 ± 72.4 dose-length product (mGy × cm). With sCTA, 11 endoleaks were detected in total. In relation to the number of performed diagnostic examinations, 15.9% of sCTA examinations led to the detection of endoleaks. In regard to examined patients, in 10 out of 50 patients (20.0%) endoleaks were diagnosed.

Eight (72.7%) of the detected endoleaks were classified type 1, and 3 (27.3%) were classified type 2, respectively.

### *Dynamic CTA*

In total, 89 dCTA diagnostic examinations were performed on 69 different patients. The majority of patients were male

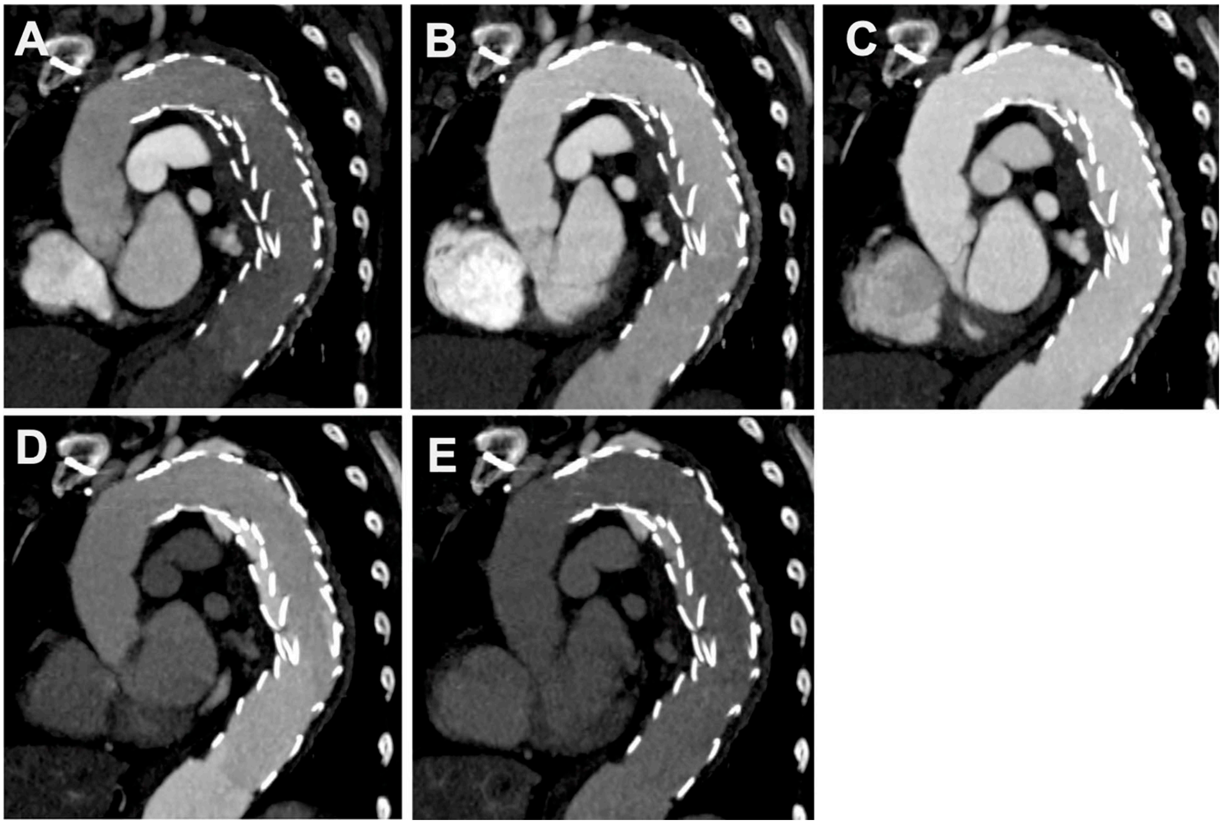


**Figure 1.** Angulated and time-resolved reconstruction of dynamic computed tomography angiography (CTA) after implantation of 2 overlapping TEVAR-stents. (A) First scan in the early phase with low contrast in the ascending aorta: No contrast agent between both stent grafts. (B) 1.4 seconds after the first scan—early arterial phase with increasing contrast throughout the aorta: Contrast agent between both stent grafts in the lower overlapping zone. (C) 4.2 seconds after the first scan—arterial phase with homogeneous contrast throughout the aorta: Contrast agent between both stent grafts in the upper overlapping zone. (D) 7.0 seconds after the first scan—Contrast agent propagation between both stent grafts into the aneurysma sac. (E) 12.6 seconds after the first scan—Contrast agent persists in the aneurysm sac and residually in the overlapping zone. There is no more contrast agent in the aorta. The endoleak was classified type 3a.

**Table 2.** Detailed Descriptive Summary of Detected Endoleaks and Endoleak Classification Within the Compared Methods.

| Variable | Standard CTA | Dynamic CTA |
|---|---|---|
| Total **number of detected endoleaks** | 11 | 44 |
| Percentage **of detected endoleaks relative to the number of diagnostic examinations** | 15.9% | 49.4% |
| Number **of patients with endoleaks** | 10 (20.0%) | 26 (37.7%) |
| **Types of endoleaks** | | |
| Type **1 (no further specification)** | 0 | 1 (2.3%) |
| Type **1a (proximal)** | 6 (54.5%) | 13 (29.5%) |
| Type **1b (distal)** | 2 (18.2%) | 6 (13.6%) |
| Type **2 (no further specification)** | 1 (9.1%) | 11 (25.0%) |
| Type **2a (single vessel)** | 2 (18.2%) | 3 (6.8%) |
| Type **2b (2 vessels or more)** | 0 | 5 (11.4%) |
| Type **3a (junctional separation of the modular components)** | 0 | 4 (9.1%) |
| Endoleak **(no further specification)** | 0 | 1 (2.3%) |
| Seam **aneurysm (after Bentall procedure)** | 0 | 1 |

Abbreviation: CTA, computed tomography angiography.

**Table 3.** Summary of Detected Endoleaks in Dependence of the CTA-Approach and the Surgical Technique.

| | **Standard CTA** | | **Dynamic CTA** | |
|---|---|---|---|---|
| **Endoleak type**<br>**n = number of examinations** | EVAR<br>n=42 | TEVAR<br>n=26 | EVAR<br>n=56 | TEVAR<br>n=28 |
| Type **1** | | | | 1 (3.6%) |
| Type **1a** | 1 (2.4%) | 5 (19.2%) | 6 (10.7%) | 7 (25%) |
| Type **1b** | 1 (2.4%) | 1 (3.8%) | 4 (7.1%) | 2 (7.1%) |
| Type **2** | | | 10 (17.9%) | 1 (3.6%) |
| Type **2a** | 2 (4.8%) | | 3 (5.4%) | |
| Type **2b** | | 1 | 5 (8.9%) | |
| Type **3a** | | | | 4 (14.3%) |
| Endoleak, **unspecified** | | | | 1 (3.6%) |
| Total **number of endoleaks** | 4 (9.5%) | 7 | 28 (50.0%) | 16 (57.1%) |

Abbreviations: CTA, computed tomography angiography; EVAR, endovascular aortic repair; TEVAR, thoracic endovascular aortic repair.

(85.5%). The patients were on average 72.1 ± 10.2 years old when the examination took place. Nine patients were screened twice, 4 patients were screened 3 times, and 1 patient was screened 4 times.

The reasons for performing dynamic CTA diagnostics were routine checks following EVAR (62.9%), TEVAR (31.5%), Aneurysma spurium (1 case), Bentall procedure (1 case) and hemangioma (1 case). Radiation exposure in the dynamic CTA in the multiphases was 855.7 ± 54.2 dose-length product (mGy × cm).

With dCTA, a total number of 44 endoleaks was detected. In relation to the number of diagnostic examinations, 49.4% of dynamic CTA examinations led to the detection of endoleaks. In 26 out of 69 patients (37.7%) endoleaks were diagnosed.

Twenty of the 44 detected endoleaks (45.4%) were classified type 1, 19 were classified type 2 (43.2%), and 4 endoleaks were classified type 3 (9.1%).

### *Comparison of Standard CTA With Dynamic CTA*

With dCTA, endoleaks were detected in nearly twice as many patients as compared with sCTA. Considering the number of total CTA examinations, 3 times more endoleaks were detected with dynamic compared with standard CTA.

In addition, with standard CTA mainly type 1 endoleaks were detected, whereas, with dynamic CTA, the types of endoleaks were more evenly distributed (Table 2). There was a statistically significant association between the CTA approach (standard vs dynamic) and the number and types of detected endoleaks (Pearson's contingency coefficient = 0.367; p=0.006).

Furthermore, standard CTA detected a lower number of type 2 endoleaks after EVAR in comparison to dCTA (sCTA n=3 vs dCTA n=19; p=0.002; Table 3). With endoleaks determined by dynamic CTA examinations, a statistically significant correlation of occurrence of endoleaks and performed endovascular procedure (EVAR/TEVAR) could be shown (Pearson's contingency coefficient = 0.568; p=0.003). Following EVAR, type 2 endoleaks predominated, while following TEVAR, type 1 endoleaks were more prevalent. This association was not found with the standard CTA approach (p=0.319).

## Discussion

Standard CTA has been supposed the gold standard for the assessment and detection of possible endoleaks following EVAR and TEVAR.[2,8] However, besides its clear benefits like presenting a noninvasive diagnostic tool and broad availability, it comes with several shortcomings regarding evaluation of complex and dynamic hemodynamic situations.[22,8] A key remaining issue has been to understand the reliability of dynamic endoleak volume and direction measurements. This information is needed to interpret changes in endoleak flow over time and also raises the question whether complex scenarios—especially after EVAR—could be insufficiently evaluated by means of sCTA.

Within the sCTA group a considerably lower number of endoleaks were detected in total. As the study groups did not differ regarding their risk for the occurrence of an endoleak, this may suggest an underestimation of endoleaks by sCTA. This could be based on the additional 4-dimensional dynamic information of dynamic CTA, for example, enabling a better differentiation between blood flow and eccentric calcifications. Standard CTA generates data based on a one-time (monophasic) examination protocol that leads to a snapshot of the patient in form of a helical dataset, whereas up to 12 helical (low dose) datasets are generated by the dynamic approach. Within the study protocol, 5 bidirectional cycles were performed and thus generated 4-dimensional datasets over a scan length of 36 cm, and therefore, could visualize dynamic blood flow with a high temporal resolution of 1.4 seconds. The total temporal observation period was thus 14 seconds.

After administration of a contrast agent, endoleak identification with computed tomography is generally based on detecting a perigraft flow of contrast agent out of the stent-graft and into the aneurysm. Besides a precise determination of the location of the endoleak and the classification whether it involves the proximal end of the stent-graft (type 1) or other collateral vessels (type 2), also the specification of the flow direction is of great importance. However, the direction of flow within the aneurysmal sac and/or in collateral vessels is sometimes difficult to detect with conventional CT imaging.[8] For example, opacification of a lumbar artery can reflect both a type 2 endoleak (retrograde flow) and a type 1 endoleak combined with an anterograde flow into a lumbar artery.[8] This observation could explain the high percentage of type 1 endoleaks determined with standard CTA in this study, which was not found with dynamic CTA.

When compared with the literature, following EVAR type 2 endoleaks occurred at frequencies 22%[25] and 24.5%.[26] Following TEVAR, type 2 endoleaks occurred at frequencies between 1%[27,28] and 7%,[13] and type 1 endoleaks occurred at frequencies between 2%[27] and 8%.[13] Therefore, the low frequencies of type 2 endoleaks as detected with the sCTA approach might not reflect real-world situations. As especially type 2 endoleaks are associated with continued sac expansion,[13] the early identification and correct classification of this kind of complication are of utmost importance.[29]

The data at hand suggest a better detection as well as more accurate classification of endoleaks following EVAR and TEVAR by dynamic CTA in comparison to standard CTA. In line with literature, dynamic approaches could pose a promising and noninvasive supplement for the detection and sufficient evaluation of endoleaks resolving the issues of sCTA.[22,30] Technological advances also have dramatically reduced dynamic CTA radiation dose, making serial dynamic CTA clinically feasible for longitudinal EVAR or TEVAR follow-up.[31]

On the contrary, dynamic CTA is unlikely to completely replace standard CT as it currently is not possible to evaluate aortic and thoracic aorta with 1 scan due to the limited region of interest. Following the suggestion by Sommer et al. it may could be part of a routine follow-up protocol for patients undergoing EVAR.[22] Current developments regarding dual-energy or dual-source techniques for improving the contrast of utilized contrast agent or photon-count technique for additional dynamic information could further improve dynamic CTA protocols.[30]

The study at hand does come with several limitations. Besides a single-center design and a small study population no direct comparison to other dynamic procedures, for example, contrast enhanced ultrasound or digital subtraction angiography were performed. Due to ethical considerations regarding X-ray exposure, patients did not undergo both, dynamic and standard CTA. For future studies, the same patients could be compared with both methods in a prospective long-term study approach to increase direct comparability.

## Conclusion

Endoleaks represent a severe complication after endovascular treatment of the aorta. Based on this retrospective comparative evaluation, dynamic CTA with time-resolved information regarding blood flow could lead to a more accurate diagnosis and characterization of suspected endoleaks. Dynamic CTA might pose a valuable supplementation within the follow-up diagnostics of patients undergoing EVAR and TEVAR.

### Authors' Note

The data from this study have not been presented or published elsewhere. Each author approved the current version of the manuscript.

### Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Stephan Waldeck and Marc A. Brockmann received lecture fees from Siemens Healthineers and Canon Medical Corporation. The other authors declare no conflict of interest.

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