Carbon dioxide cone-beam computed tomography for the technical assessment of endovascular aortic intervention

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ABSTRACT

Cone-beam computed tomography (CBCT) is widely used for the technical assessment of standard and complex endovascular aortic interventions. Use of iodinated contrast in CBCT imaging might provide useful additional information; however, this also increases the procedural contrast dose, which may cause renal function deterioration, and the radiation exposure. We describe the technique and feasibility of carbon-dioxide (CO_2)-enhanced CBCT for the technical assessment of standard and complex endovascular aortic repair. In our experience CO_2-CBCT had no related adverse events and provided satisfactory imaging quality to assess endograft integrity, vessels patency, and was safely performed in case of severe chronic renal insufficiency. (J Vasc Surg Cases Innov Tech 2024;10:101580.)

Keywords: Abdominal; Aortic aneurysm; Carbon dioxide; Cone-beam computed tomography; Endovascular aneurysm repair; Renal insufficiency

Endovascular aortic repair has progressively evolved from standard endovascular aortic repair (EVAR) to fenestrated-branched repair (F-BEVAR) for the treatment of disease involving the renal-mesenteric arteries. Both standard and complex EVAR can be performed with high rates of technical success and durability; however, the risk for reinterventions still represents the major drawback of endovascular interventions.[1-3] In particular, early reinterventions or complications may be caused by technical defects that are not immediately recognized during the index procedure,[4-6] and their intraoperative identification and correction can prevent clinical complications and secondary interventions during follow-up.[4,7-10]

Several imaging techniques are available for the technical assessment of EVAR and F-BEVAR, such as completion angiography, cone-beam computed tomography (CBCT), or intravascular ultrasound.[7,9,11] CBCT can provide valuable information regarding the conformation of the endograft components and identify significant structural defects such as kink, compression, or disconnection.[4,7,8] Contrast-enhanced CBCT can provide additional information on patency of the endograft components, target vessels, and the presence of endoleaks. However, the use of iodinated contrast agents during CBCT increases the overall procedural contrast dose and may cause adverse events, especially in patients with baseline impaired renal function or allergies. Moreover, compared with contrast-free CBCT, contrast-enhanced CBCT determines an additional radiation exposure.

Carbon dioxide (CO_2) had emerged as a contrast dye alternative. Being physiologically present within the human body, it appears to be safer than iodinated dye, with no reported risk of allergic reaction and lack of nephrotoxicity.[12,13] The use of CO_2 for conventional angiography[14] has been broadly investigated; however, its role in CBCT imaging is unknown. The aim of this report is to describe the feasibility, safety, and image quality of CO_2-enhanced CBCT for the technical assessment of standard and complex endovascular aortic repair.

TECHNIQUE

We started using CO_2-CBCT in selected patients at risk for contrast-induced nephrotoxicity, but the technique can be applied to virtually all patients. Patients' consent was obtained. Main contraindications to intravascular CO_2 administration are severe chronic obstructive pulmonary disease, pulmonary hypertension, and right to left cardiopulmonary shunt. Also, CO_2 should not be injected in the thoracic aorta, to avoid the risk of cerebral air embolism.

The endovascular aortic procedure is performed in a hybrid operating room equipped with a ArtisPheno angiographer (Siemens) under general anesthesia. Intraoperative angiographies are usually performed using an Angiodroid CO_2 injector (Angiodroid Spa). After completion of the endovascular procedure in a standard way, a 6 Fr 55-cm long sheath is advanced from a femoral access

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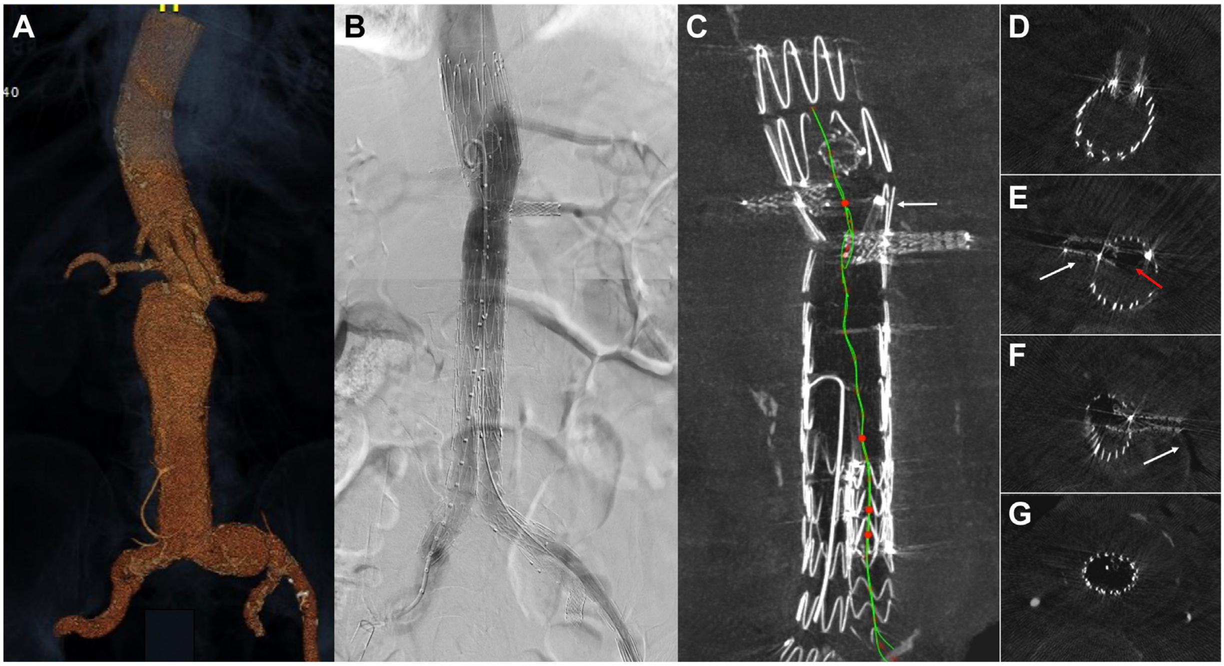

Fig 1. **A**, Three-dimensional reconstruction of the preoperative computed tomography angiography (*CTA*) of a juxtarenal aortic aneurysm. Note the presence of a celiac-mesenteric trunk. **B,** Completion angiogram with carbon dioxide (*CO_2*), after fenestrated endovascular repair (*FEVAR*). **C,** Multiplanar reconstruction (*MPR*) reconstruction of the CO_2-cone-beam computed tomography (*CBCT*), showing integrity and patency of all the endograft components. The 6Fr sheath was positioned with the tip at the level of the pararenal aorta (*arrow*). **D,** Axial view of the CO_2-CBCT, detailing the celiac-mesenteric trunk. **E,** Axial view of the CO_2-CBCT, detailing the right renal artery (*white arrow*). Note the contrast layering on the anterior aspect of the aorta (*red arrow*). **F,** Axial view of the CO_2-CBCT, detailing the left renal artery. Note the contrast layering on the anterior aspect of the aorta. **G,** Axial view of the CO_2-CBCT, detailing the complete sac exclusion without evidence of endoleaks.

and positioned at the desired level. The tip of the sheath should be placed slightly (2-3 cm) above the major region of interest: above the celiac trunk for the visualization of the visceral-renal arteries (Fig 1), above the renal arteries for the visualization of renal arteries and infrarenal aorta (Fig 2), or in the infrarenal abdominal aorta for the visualization of the distal aorta and iliac axis (Fig 3). The angiographer is then set up for the acquisition of a contrast-free CBCT (using Siemens Pheno "4sDR Surgery P" protocol). The CO_2 injector is flushed and armed for an injection of 100 ml of CO_2 at 700 ± 50 mmHg using the preset aortic protocol (Fig 4). There is virtually no limit to the total CO_2 dose during a single procedure, but a minimum of 2 minutes time is required between consecutive injections, in order to avoid excessive CO_2 accumulation. CBCT acquisition and CO_2 injection are started simultaneously; this allows for the synchronization of the rotation of the angiographer with the CO_2 injection and diffusion, because both acquisition and CO_2 diffusion are characterized by a similar time delay from the input signal (approximately 2 seconds). The dose area product for each CO_2-enhanced CBCT is typically around 2000 uGy*m.[2]

This technique was adopted in nine patients undergoing standard EVAR (n = 5), EVAR with iliac branch device (n = 1), and FEVAR (n = 3) (Video 1, online only). On CBCT images, CO_2 appears as a dark (black) area filling the arterial lumen (Fig 5). Summary of CO_2-CBCT findings are reported in Table I. There were no related adverse events, and image quality was satisfactory in all cases. No patient received an intraoperative revision based on CO_2-CBCT. No technical defects or endoleaks occurred after a median 6 months of imaging follow-up by CT angiography or contrast-enhanced ultrasound.

DISCUSSION

CBCT is commonly used for the technical assessment of standard and complex EVAR and has been demonstrated to reduce early complications and secondary interventions[4,7,8,15] after aortic endovascular interventions. Compared with contrast-free CBCT, contrast-enhanced CBCT provides additional information on patency of the endograft components and target arteries and presence of endoleaks. Although CO_2 use as angiographic contrast media is well-established, its use during CBCT has not been previously described.

In our experience, CO_2-CBCT is feasible and safe, with no reported related adverse events and satisfactory imaging quality from the clinical standpoint. CO_2 carries the advantage of completely avoiding the use of

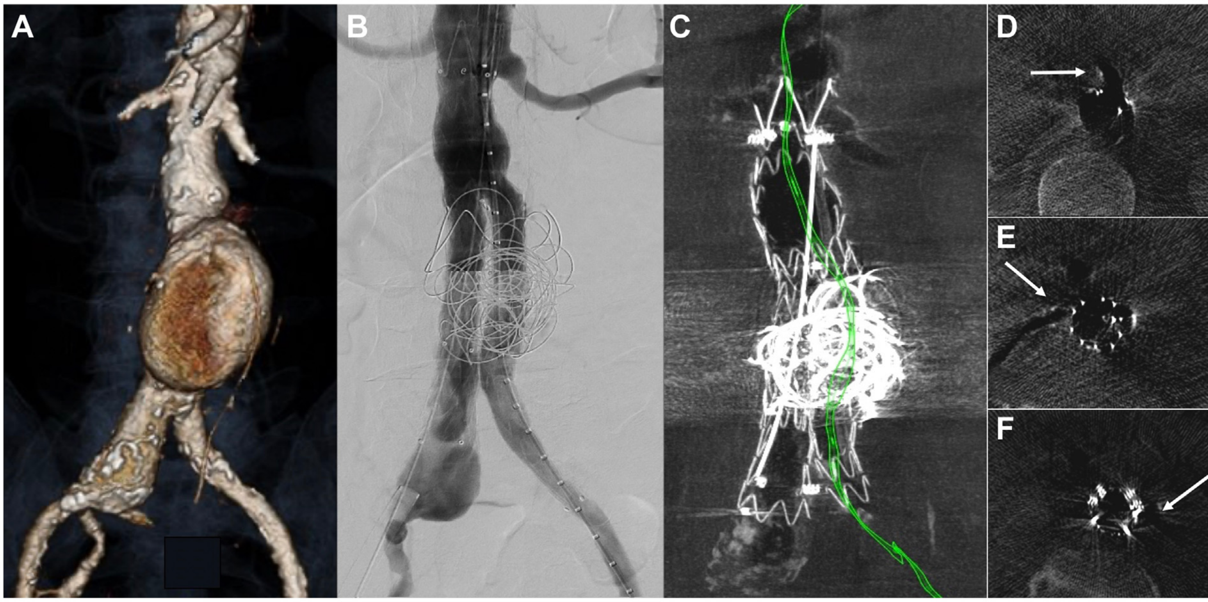

Fig 2. A, Three-dimensional reconstruction of the preoperative computed tomography angiography (*CTA*) of an infrarenal aortic aneurysm. **B,** Completion angiogram with carbon dioxide (*CO_2*), after endovascular aortic repair (*EVAR*) with endoanchors and aneurysm sac embolization. **C,** Multiplanar reconstruction (*MPR*) of the CO_2-cone-beam computed tomography (*CBCT*), showing integrity and patency of all the endograft components. The 6Fr sheath was positioned with the tip at the level of the pararenal aorta. **D,** Axial view of the CO_2-CBCT, detailing the superior mesenteric artery (*arrow*). **E,** Axial view of the CO_2-CBCT, detailing the origin of the right renal artery (*arrow*). **F,** Axial view of the CO_2-CBCT, detailing the proximal landing zone at the level of the endoanchors. The *arrow* indicates the left renal artery.

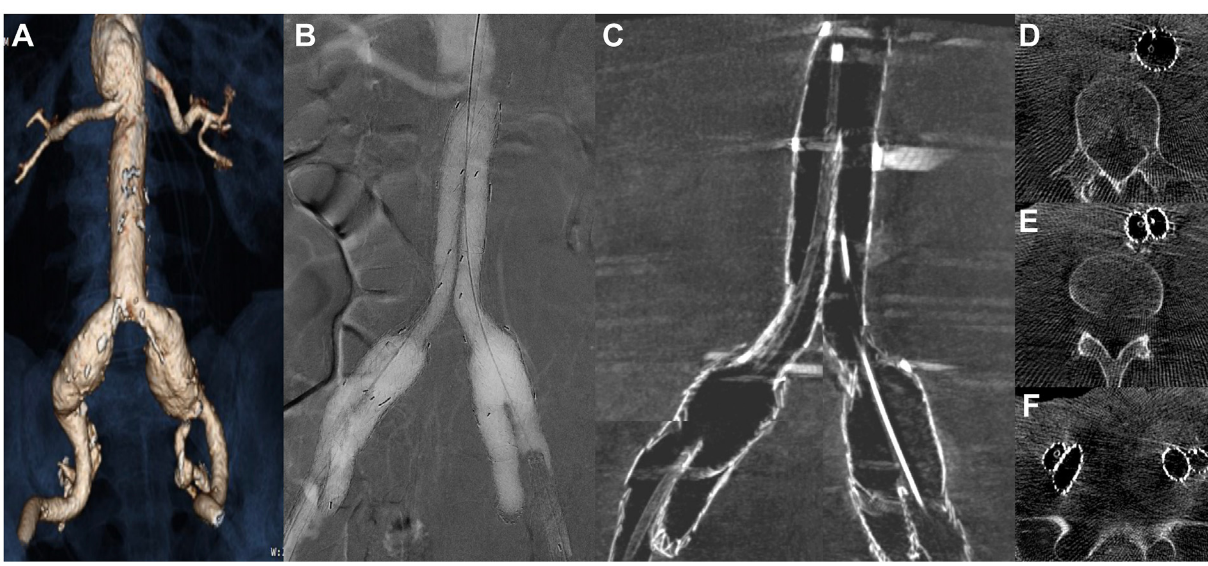

Fig 3. A, Three-dimensional reconstruction of the preoperative computed tomography angiography (*CTA*) of a bilateral common iliac aneurysm. **B,** Completion angiogram with carbon dioxide (CO_2), after endovascular aortic repair (*EVAR*) with bilateral iliac branch device. **C**. Multiplanar reconstruction (*MPR*) of the CO_2-cone-beam computed tomography (*CBCT*), showing integrity and patency of all the endograft components. The 6Fr sheath was positioned with the tip at the level of the infrarenal aorta. **D,** Axial view of the CO_2-CBCT at the level of the aortic main body. **E,** Axial view of the CO_2-CBCT at the level of the aortic bifurcation. **F,** Axial view of the CO_2-CBCT, detailing the bilateral iliac bifurcation, with adequate CO_2 filling of the external and hypogastric branch components.

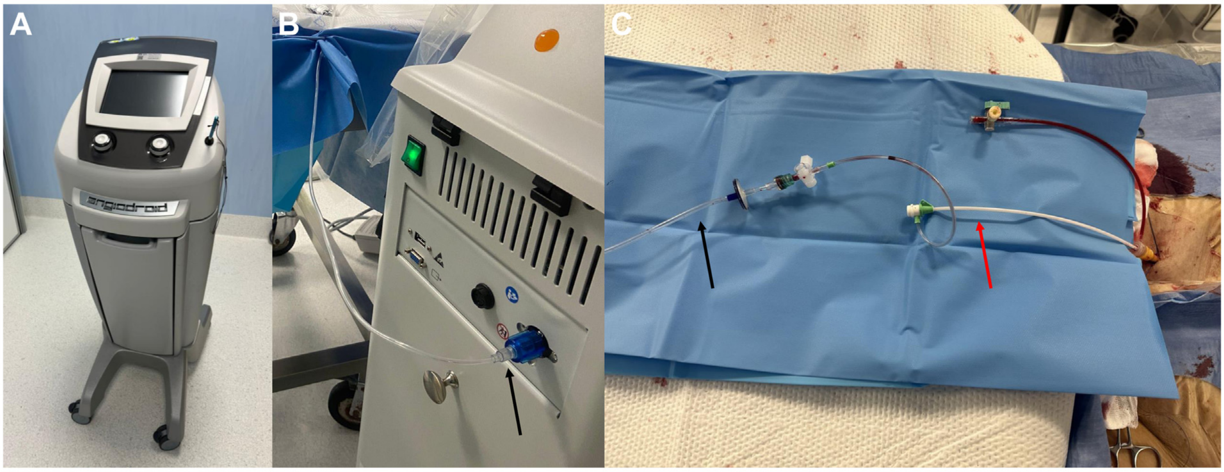

Fig 4. **A**, The automated carbon dioxide (*CO_2*) injector (Angiodroid) is a portable device incorporated with a touch screen for injection setting. **B,** The CO_2 circuit of the injector is connected to the injections sheath through a dedicated tube (*black arrow*). **C,** Image of the operating table setting for the cone-beam computed tomography (*CBCT*) acquisition. The CO_2 connection tube (*black arrow*) is directly connected with the 6Fr 55-cm long sheath used for the injection (*red arrow*).

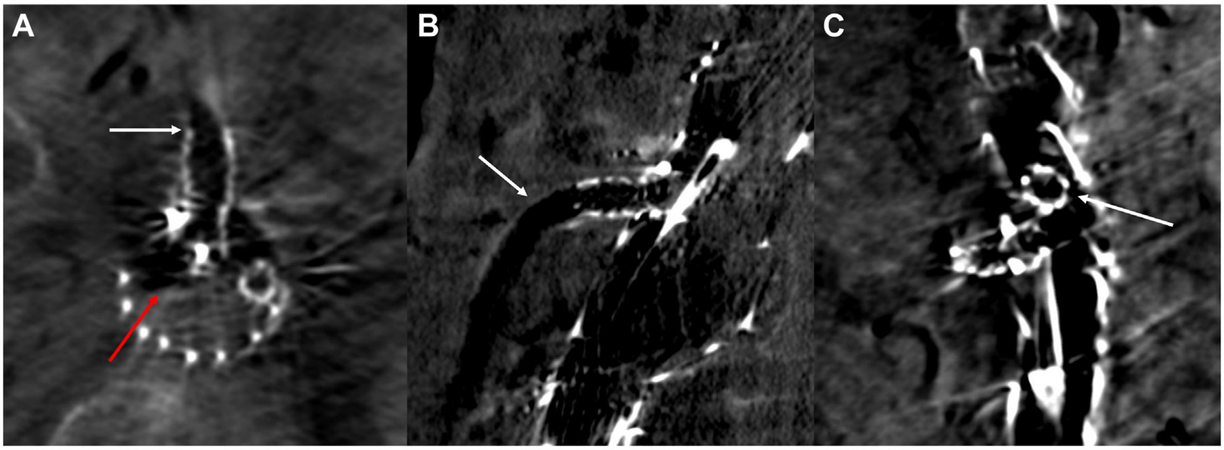

Fig 5. Carbon dioxide (*CO_2*)-cone-beam computed tomography (CBCT) three-dimensional multiplanar reconstruction (*MPR*) of the superior mesenteric artery after fenestrated endovascular repair (*FEVAR*). **A,** Axial view, showing the filling of the superior mesenteric artery (*SMA*) (*white arrow*) and the contrast layering in the anterior part of the aortic lumen (*red arrow*). **B,** Sagittal view, showing the patency of the SMA. **C,** Coronal view, showing adequate bridging stent conformation at the level of the fenestration (*arrow*).

nephrotoxic agents and can be safely performed also in cases with severe chronic renal insufficiency at risk for dialysis. Also, adequate images can be obtained using contrast-free CBCT software protocol acquisition, with a significant reduction of radiation exposure, that in our setting is approximately 2000 $uGym^2$ for CO_2-CBCT and 4000 $uGym^2$ for iodinated contrast-CBCT.

To obtain useful images, it is important to standardize the modality and site of CO_2 injection. The main issue is related to the extremely high solubility and diffusivity of CO_2 gas, that acts as a contrast agent by displacing intra-arterial blood. The gas injection through a diagnostic catheter or a small-size sheath (6 Fr), increases the flow resistance within the CO_2 circuit, which permits a sufficient delay for tomography acquisition. Compared with iodinated contrast CBCT, the CO_2-enhanced region is more restricted and usually does not cover the entire abdominal aorta from the visceral to the hypogastric arteries. For this reason, the injection sheath should be carefully positioned according to the aortic region to be investigated: above the celiac trunk for F-BEVAR, above the renal arteries for standard EVAR, and at the level of the renals for iliac branch devices.

The quality of the images was generally good, with adequate visualization of large, medium, and small arteries. In large arteries (aorta), CO_2 may not completely

Table. Summary of the seven patients undergoing carbon dioxide (*CO_2*) cone-beam computed tomography (*CBCT*) for the technical assessment of endovascular aortic repair (*EVAR*)

Patient ID	Sex	Age	Type of endovascular repair	Procedural iodinated contrast volume, ml	Procedural CO_2 volume, ml	CBCT technical success	CBCT site of CO_2 injection	CBCT DAP/total procedural DAP, uGym^2	Notes
1	M	77	EVAR + left iliac branch device	10	400	Yes	Infrarenal	2048/7051	Good visualization of infrarenal aorta and hypogastric arteries. No visualization of renal arteries because of infrarenal CO_2 injection.
2	M	84	EVAR + endoanchors	0	300	Yes	Suprarenal	2209/8902	Adequate visualization of SMA and renal arteries. Type II endoleak fed by lumbar arteries.
3	M	80	EVAR	0	300	Yes	Suprarenal	2041/7990	Adequate visualization of renal arteries and SMA. CO_2 layering at the level of the pararenal aorta.
4	M	81	EVAR	0	300	Yes	Infrarenal	2101/7539	Adequate visualization of infrarenal aorta and iliac arteries. No visualization of renal arteries because of infrarenal CO_2 injection
5	M	79	FEVAR	20	400	Yes	Pararenal	2148/20434	Good visualization of renal arteries. Adequate enhancement of infrarenal aorta and iliac arteries.
6	F	71	EVAR	0	200	Yes	Infrarenal	2039/6853	Adequate enhancement of infrarenal aorta and iliac arteries. No visualization of renal arteries because of infrarenal CO_2 injection.
7	M	74	EVAR	0	300	Yes	Infrarenal	2056/6961	Good visualization of infrarenal aorta and iliac arteries. Type II endoleak fed by lumbar arteries. No visualization of renal arteries because of infrarenal CO_2 injection.
8	M	72	EVAR	0	300	Yes	Suprarenal	2056/7002	Adequate visualization of renal arteries.
9	M	75	FEVAR	40	400	Yes	Pararenal	2094/14083	Adequate visualization of renal arteries and SMA. CO_2 layering at the level of the pararenal aorta.

DAP, Dose-area product; *FEVAR*, fenestrated endovascular aneurysm repair; *SMA*, superior mesenteric artery.

displace blood, creating a CO_2 "layering" with a posterior lack of filling on axial images, especially in the cranial region. Aortic side branches with a posterior orientation (ie, hypogastric arteries) may not always be adequately assessed, owing to the CO_2 antigravitational migration. Also, it is not unusual to observe gas bubbles within the aneurysm, which may derive either from endoleaks or air "trapping" in case CO_2 is used for angiographies during the intervention. However, it may difficult to establish the exact cause of gas visualization within the aneurysm sac and to clearly determine the type of endoleak, which might remain indeterminate, as it has been described also with standard contrast-CBCT or CT angiography.[10,16] Therefore, this information should be completed by the evaluation for any structural defect on CBCT, and comparison with the final completion angiogram.[10] Further studies are necessary to establish the sensitivity of CO_2-CBCT in the assessment of endoleaks and vessels' patency, compared with other imaging modalities.

CONCLUSION

This initial experience on CO_2-CBCT demonstrates its feasibility, safety, and satisfactory quality of the images, offering a viable alternative to traditional contrast CBCT based on iodinated contrast, with reduction of the overall radiation dose. CO_2-CBCT can be safely performed in patients with renal impairment at risk for dialysis or allergies and may be considered also in other patients to reduce the overall contrast dose. Further studies are needed to optimize the technique and investigate its clinical significance.

AUTHOR CONTRIBUTIONS

Conception and design: MA, FG, MP, FS
Analysis and interpretation: MA, FS
Data collection: MB, SM
Writing the article: MA, FS
Critical revision of the article: MA, MB, SM, FG, MP, FS
Final approval of the article: MA, MB, SM, FG, MP, FS
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DISCLOSURES

None.

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