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CARDIAC COMPUTED TOMOGRAPHY (TC VILLINES, SECTION EDITOR)

Transcaval TAVR—What the Radiologist Needs to Know

Shehbaz Shaikh[1] · **Thomas Song**[1] · **Dee Dee Wang**[2] · **Nick Reeser**[1] · **Adam Greenbaum**[2] · **William O'Neill**[2]

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Abstract Transcaval transcatheter aortic valve replacement is a new approach in performing percutaneous aortic valve replacement in which aortic access is obtained by way of the femoral vein and inferior vena cava. Computed tomographic angiography is used to determine patient suitability and in preprocedural planning. CTA is also part of routine follow-up care to assess for potential caval-aortic access site complications. Postprocedural imaging findings at the caval-aortic site include aortocaval fistula, aortic dissection, retroperitoneal hemorrhage, and pseudoaneurysm. The purpose of this manuscript is to familiarize the reader with the technical aspects of this new procedure and the periprocedural assessment of the caval-aortic access site with CTA.

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✉ Thomas Song
ThomasS@rad.hfh.edu

Shehbaz Shaikh
shehbazs@rad.hfh.edu

Dee Dee Wang
dwang2@hfhs.org

Nick Reeser
nickr@rad.hfh.edu

Adam Greenbaum
agreenb1@hfhs.org

William O'Neill
Woneill1@hfhs.org

[1] Department of Radiology, Henry Ford Hospital, 2799 West Grand Blvd, Detroit, MI 48202, USA

[2] Department of Cardiology, Henry Ford Hospital, 2799 West Grand Boulevard, Detroit, MI 48202, USA

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Introduction

Symptomatic aortic stenosis is associated with a rate of death greater than 50 % at 2 years, and there is no effective medical therapy to prevent or slow the progression of disease at the present time [1–3]. Surgical aortic valve replacement (SAVR) is the standard of care for symptomatic patients with low or intermediate surgical risk, thus excluding patients with significant comorbidities [4]. Transcatheter aortic valve replacement (TAVR) is an effective, percutaneous alternative in patients with high surgical risk and was first reported in 2002 [5]. TAVR is most commonly performed via femoral artery access with subsequent retrograde deployment of the prosthetic valve.

In patients with small iliofemoral vessels, advanced atherosclerotic disease, or prior stenting, safe femoral artery placement of the introducer sheath may not be possible due to size constraints. Transapical and transaortic approaches offer reasonable alternatives. A transapical approach involves direct left ventricular puncture with subsequent antegrade valve deployment via a small anterolateral thoracotomy. A transaortic approach involves an ascending aortotomy with subsequent retrograde valve deployment via a small median sternotomy. However, transapical and transaortic approaches are less than ideal for patients with a history of chest radiation, severe pulmonary disease, or coronary artery bypass grafting.

Caval-aortic access was first described in 2013. In a series of 14 swine, Halabi et al. demonstrated successful access into the abdominal aorta from the femoral vein and IVC [6••]. In July 2013, our institution performed the first in-man transcaval TAVR. Since then, cardiologists across the United States, as well as international centers, have started performing transcaval

TAVR. This can pose a challenge for a busy radiologist who is tasked with interpreting the postprocedural imaging, given the lack of familiarity with the procedure. The purpose of this manuscript is to review the technical aspects of this new procedure and the periprocedural assessment of the caval-aortic access site using computed tomography angiography (CTA).

Indications and Efficacy

Transcaval TAVR is indicated in high surgical risk cases in which transfemoral, transapical, and transaortic TAVR are contraindicated. Transfemoral TAVR is limited when the minimum vessel diameter is less than 6 mm because current commercially available transcatheter valves require large 18-F inner diameter sheaths. The placement of an introducer sheath into a vessel smaller than 8 mm may lead to an increased rate of complications, such as those from distal thrombi or plaque embolization [7]. Contraindications to transapical and transaortic approaches include but are not limited to severe pulmonary disease, morbid obesity, chest radiation, CABG or aortic root repair, and porcelain aorta. Transcaval TAVR utility may be limited if there are extensive abdominal aortic calcifications or interposed structures which prevent safe crossing at the infrarenal caval-aortic access site. Additionally, barriers to performing a "bailout" procedure with an aortic stent graft, such as the presence of an IVC filter or vessels which may be occluded from graft deployment (accessory renal or spinal arteries, etc.), may limit a transcaval option.

High technical success rates have been reported for transcaval TAVR. In a study of the first 19 patients undergoing transcaval TAVR, Greenbaum et al. demonstrated successful caval-aortic access and aortic valve implantation in 17/19 patients and no transcaval-related deaths [8••]. Short- and mid-term outcomes have been favorable. Although limited data on long-term outcomes exist, the first patient's 1-year postprocedural follow-up demonstrated no abnormality at the caval-aortic access site.

Caval-Aortic Access Technique

Transcaval TAVR is performed in an angiography suite under general anesthesia by a specialized team consisting of interventional cardiology, cardiothoracic surgery, anesthesia, and echocardiography. A gooseneck snare is advanced through the femoral artery into the infrarenal abdominal aorta and is the target site for caval-aortic access. The typical location is approximately halfway between the right renal artery and aortic bifurcation. A guidewire is passed through the femoral vein into the IVC with its tip directed at the snare target (Fig. 1a). Cautery is applied to the guidewire as it is advanced into the aorta with subsequent snaring (Fig. 1b). The guidewire is then advanced further into the proximal descending aorta (Fig. 1c). The aortic valve is then replaced in a retrograde fashion. Following successful valve deployment, the aortocaval fistulous tract is closed by off-label use of a commercially available ventricular septal defect or ductal occluder device [8••]. An angiogram is performed to assess the degree of aortocaval flow and the presence of complications prior to completion of the procedure.

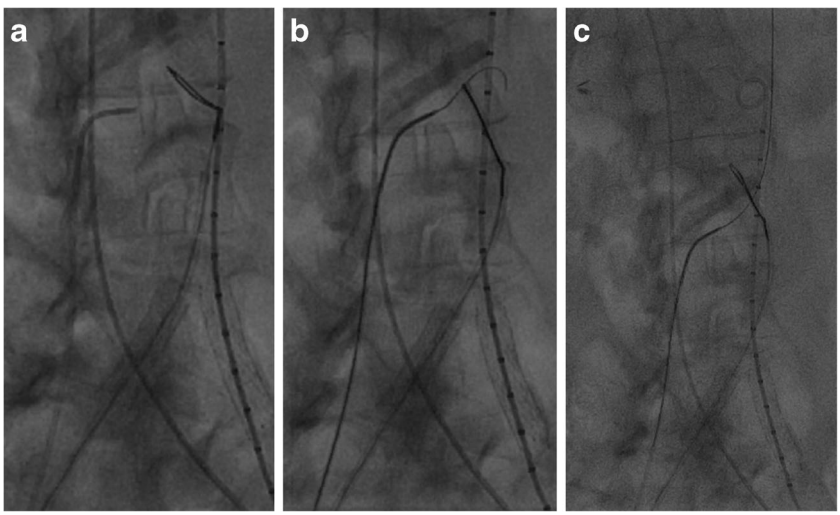

Fig. 1 Caval-aortic access on fluoroscopy. **a** A gooseneck snare is advanced from the right femoral artery into the infrarenal abdominal aorta. A guidewire is then advanced from the right femoral vein into the infrarenal IVC with its tip directed at the snare target. **b** Electrocautery is applied to the guidewire as it is pushed from the IVC into the aorta with subsequent snaring. **c** The guidewire is then advanced into the more proximal descending aorta

Fig. 2 Photograph of occluder device (Amplatzer Muscular VSD occluder, St. Jude Medical, St. Paul, MN)

Table 1 Specific examination components for caval-aortic access

Abdominal Aorta (Description of size, calcium, thrombus, course, etc.)
Caval-Aortic Distance
Interposed Structures
Nearby Structures (bowel, major or anomalous arteries, etc.)
Target Entry Site With Respect to Lumbar Vertebrae
Aortic Diameter at Target Site
IVC Diameter at Target Site
Orthogonal Projection (specify degrees and RAO/LAO)
Right CFV to Target Centerline Distance
Left CFV to Target Centerline Distance

CFV common femoral vein

Occluder Device

There are a variety of occluder devices on the market which are FDA-approved for the treatment of patent ductus arteriosus (Amplatzer Duct Occluder, St. Jude Medical, St. Paul, MN) and intracardiac defects (Amplatzer Muscular VSD occluder, St. Jude Medical, St. Paul, MN). The occluder device is a flexible, self-expanding double-disc structure adjoined by a cylindrical waist, which is comprised of braided nitinol wire (Fig. 2). It contains polyester fabric inserts which help close the fistula and provide a scaffold for the growth of tissue. The off-label use of occluder devices to close congenital and acquired aortocaval fistulas has been reported previously [9–11].

Preprocedural CTA Assessment

CTA is essential for determining patient eligibility and preprocedural planning. Specific methods for annular sizing, aortic root analysis, and iliofemoral measurements have been reported in the literature previously [12–14]. At our institution, the preprocedural TAVR protocol is a single intravenous contrast bolus gated CTA of the chest followed immediately by a nongated CTA of the abdomen and pelvis. Gated imaging spans from the lung apices to the inferior cardiac border and continues as a nongated study into the abdomen and pelvis to terminate at the level of the lesser trochanters. The nonionic contrast dose is typically 100 ml and injected at 3 ml/s with a bolus tracking threshold of 140 HU in the ascending aorta, at the level of the carina.

Transcaval planning measurements are provided in addition to the "traditional" TAVR measurements when the iliofemoral vessels are significantly narrowed (<8 mm) or tortuous. The goals of planning are to identify the optimal site for caval-aortic access and to identify a bailout option in the event that an endovascular stent graft needs to be placed. Postprocessing reconstructions, such as maximum intensity projection (MIP), multiplanar reformations (MPRs), and volume rendering 3-D reconstructions, are utilized to ensure accurate measurements of the vasculature.

Evaluation for a potential caval-aortic access site begins with identifying a region of the aorta devoid of wall calcification [15••]. Wall calcification can make crossing difficult and thus be avoided. Ideally, aortic plaque or thrombus should be avoided to prevent possible distal embolization. Additionally, the access site should involve the shortest IVC to aorta distance without any interposed structures, such as a small lumbar artery or vein. The access site is reported with respect to the lumbar vertebrae, and projection angles are provided to aid in fluoroscopic identification. Table 1 summarizes the pertinent characteristics of an optimal caval-aortic access site and measurements. Key images are used during the procedure as a visual summary of the optimal caval-aortic access site (Fig. 3).

Rescue technique planning is performed for appropriate preprocedural selection of an aortic stent graft. In the event of hemodynamic instability or persistent bleeding at the end or immediate postprocedure period, an aortic stent graft may be placed across the caval-aortic access site. The stent graft is advanced towards the aorta by way of the least stenotic of the two common femoral arteries. Nearby structures that may be occluded if a stent graft is placed, such as an accessory renal artery or lumbar artery, may limit a bailout option. Table 2 summarizes rescue planning measurements.

Postprocedural MDCT Evaluation

Imaging is part of the routine follow-up care for all patients who have undergone a transcaval TAVR. Routine follow-up

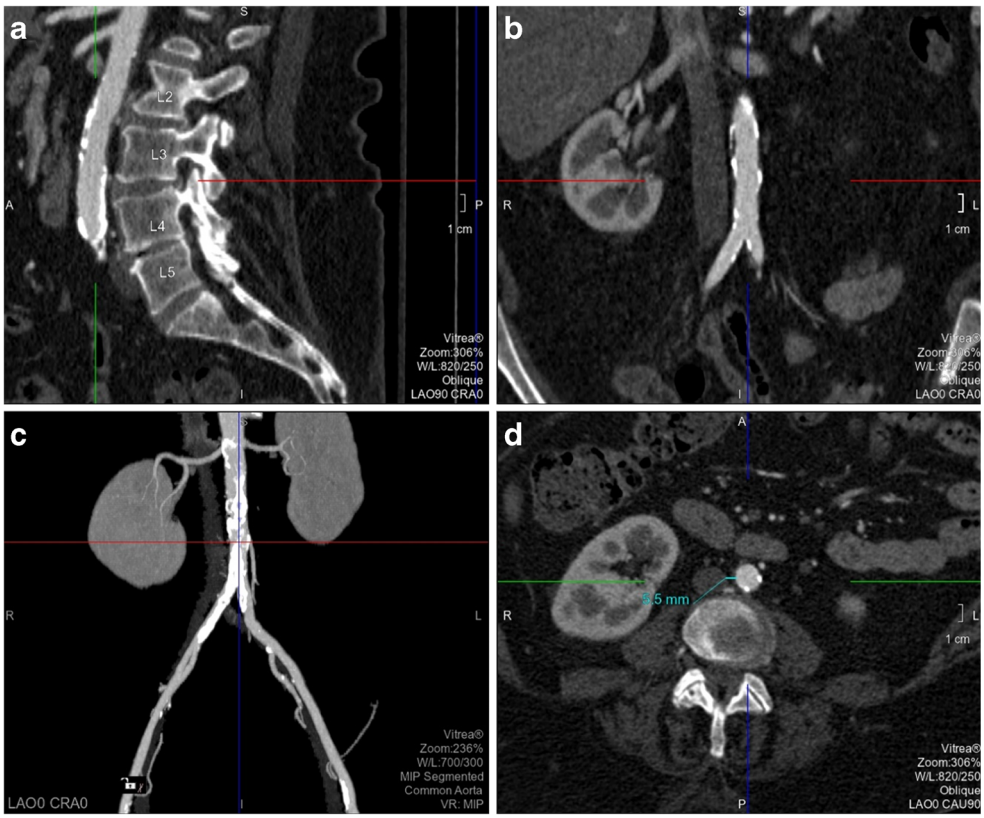

Fig. 3 Key images. **a** Sagittal CTA delineates the caval-aortic access site to be located at the level of the inferior endplate of L3. **b** Coronal CTA and **c** 3-D reconstruction demonstrate the proximity of the right renal vessels and aortic bifurcation with respect to the caval-aortic access site. **d** Axial CTA demonstrates a short IVC-aorta distance, no interposed structures, and defines the trajectory for caval-aortic access

CTA abdomen and pelvis without delayed phase imaging is performed at 1 week, 4 weeks, and 6 months. The goals of imaging are to identify occluder device position, aortocaval flow, and any potential vascular injury at the level of the aortocaval tract. At our institution, CTA abdomen and pelvis images are acquired from the lung bases to the level of the lesser trochanters in the arterial phase after the administration of 80 ml of nonionic contrast with a bolus tracking threshold of 125 HU at the level of the diaphragm in the descending aorta. At 12 months and beyond, a CTA abdomen and pelvis with delayed venous phase imaging at 3 min is performed to assess for any leak at the occluder site.

Table 2 Rescue planning exam components

Aortic Diameter +3cm and -3cm
Target Distance Above Aorto-Iliac Bifurcation
Target Distance Below Right Renal Artery
Right Leg Minimal Luminal Diameter from CFA to Aorta
Left Leg Minimal Luminal Diameter from CFA to Aorta

CFA indicates common femoral artery

+/− indicate above and below target cite measurements

Typical Caval-Aortic Access Appearances

The occluder device on CTA is a hyperdense double-disc structure adjoined by a cylindrical waist with round markers at each pole (Fig. 4). The occluder device may lie horizontal, perpendicular to the aorta and IVC, or in an oblique orientation after deployment across the caval-aortic tract.

A small periaortic hematoma near the caval-aortic access site is a common finding and is usually detected in the early postprocedure period. CTA findings include a thin rim of soft tissue thickening around the aorta, near the occluder device, without evidence for active contrast extravasation (Fig. 5). These are managed conservatively, and the degree of periaortic thickening will decrease over time.

Although an occluder device may be well seated within the vascular lumen, a varying degree of aortocaval flow can still exist and is a common finding (Fig. 6). It has been suggested that an aortocaval fistula helps reduce the amount of

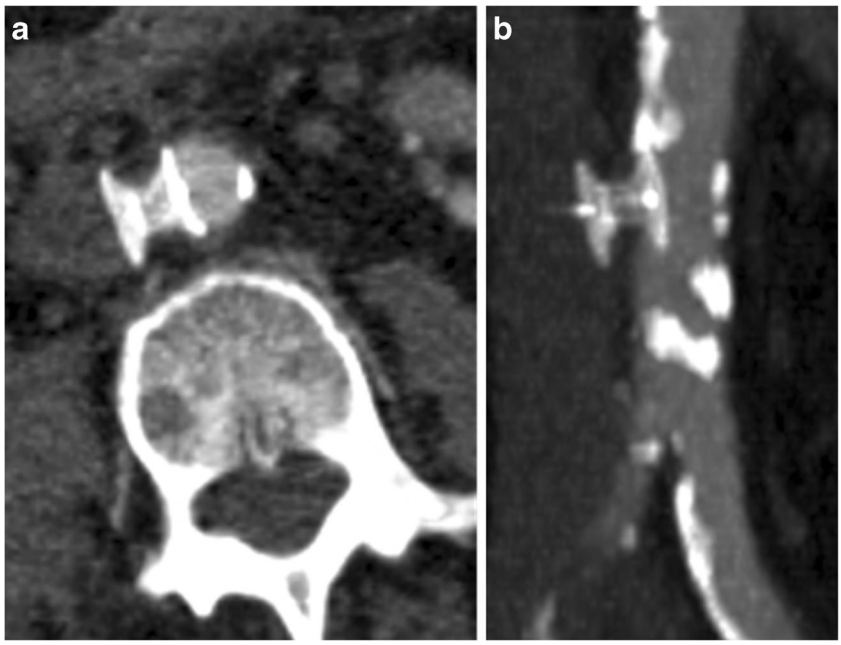

Fig. 4 CTA appearance of occluder device. **a** Axial and **b** coronal CTA images demonstrate a hyperdense double-disc structure between the aorta and IVC

retroperitoneal hemorrhage. In a study in swine, Halabi et al. hypothesized that caval-aortic access would allow for decompression into the venous system rather than hemorrhage into the retroperitoneum [6••]. On CTA, aortocaval flow is best assessed using coronal views to visualize contrast opacification of the IVC during the arterial phase. Opacification of the IVC will begin at the level of the occluder device and extend towards the right atrium. In the absence of hemodynamic instability, these will resolve and do not require intervention. Greenbaum et al. demonstrated a mean aortocaval fistula closure time of 42 days in a series of the first 19 patients [8••].

Caval-Aortic Access Complications

Major access-related complications include a large retroperitoneal hematoma or hemorrhage, aortic dissection, and

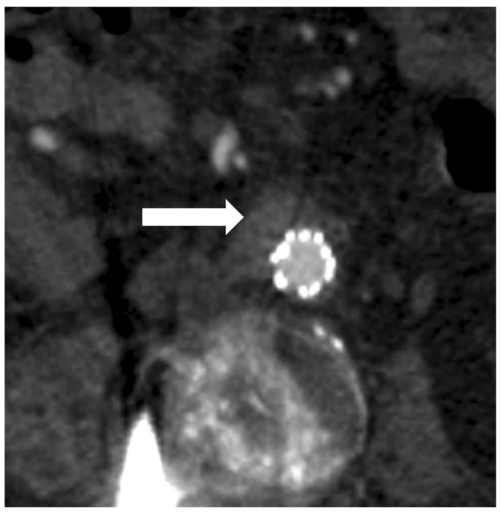

Fig. 5 Periaortic hematoma. Axial CTA slightly cephalad to the caval-aortic access site demonstrates periaortic soft tissue thickening consistent with a hematoma. The aortic stent graft was placed because of postprocedural hemodynamic instability

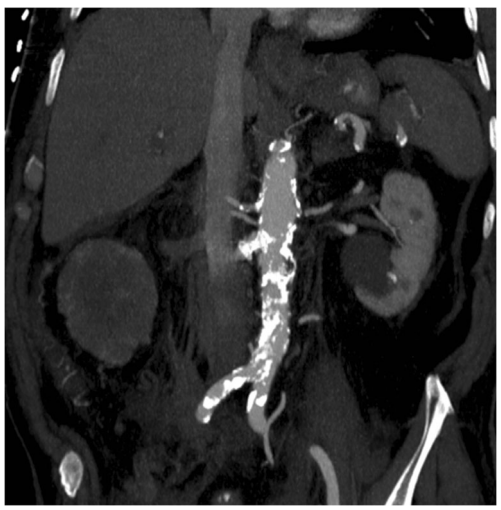

Fig. 6 Aortocaval flow. Coronal CTA demonstrates contrast opacification of the IVC during arterial phase imaging

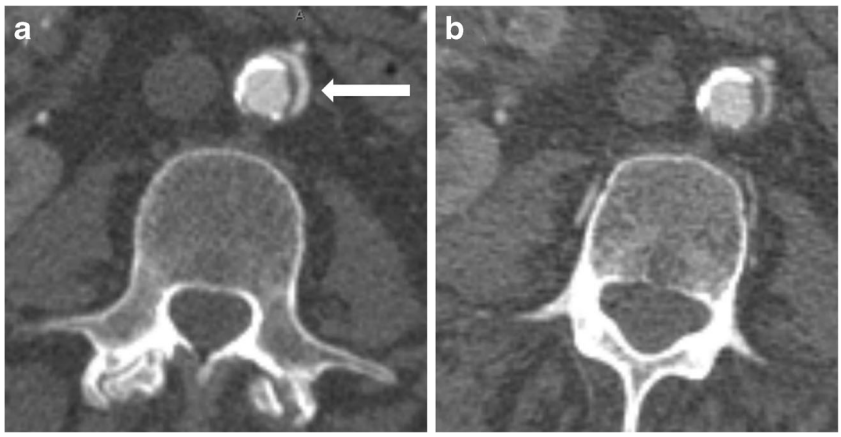

Fig. 7 Focal aortic dissection following transcaval TAVR. **a** Axial CTA obtained 1 week postprocedure demonstrates an intimal flap along the left lateral wall of the abdominal aorta slightly superior to the level of the caval-aortic access site. **b** Axial CTA obtained at 1 month demonstrates a stable focal aortic dissection

thrombosis of the aorta and/or IVC. Although relatively rare, an aortic dissection may occur as a result of caval-aortic access. In Greenbaum's review of the first 19 cases of transcaval TAVR, there were 2 aortic dissections [8••]. On CTA, the aortic dissections were focal and involved only a short segment. The clinical service may decide to manage conservatively and obtain closer follow-up to assess for propagation and complications. In our experience, no treatment was required and both cases were either stable or partially thrombosed on follow-up CTA (Fig. 7). Hemodynamic instability resistant to vasopressors is a rare occurrence but may develop either during the procedure or shortly afterwards. Hemodynamic parameters can be restored after placement of an aortic stent graft. Although a theoretical risk for thrombosis of the aorta or IVC and active extravasation exists, these complications have not been observed.

A small pseudoaneurysm may occur at the caval-aortic access site. A pseudoaneurysm occurs when arterial puncture allows for high-pressure blood to dissect into the perivascular tissues, resulting in a perfused sac that communicates with the vessel lumen [16]. There was 1 pseudoaneurysm observed in a series of the first 19 patients [8••]. CTA will demonstrate an arterially enhancing outpouching extending either superior or inferiorly from the caval-aortic access site, although a retroaortic course is possible (Fig. 8). In the presence of hemodynamic stability, these can be followed and will resolve over time. The mean resolution time without treatment in a cohort of the first 27 patients undergoing caval-aortic access TAVR at our institution was 41.3 days. A combination of a pseudoaneurysm plus a large retroperitoneal hemorrhage should prompt immediate contact with the referring clinician, as these may be the only imaging clues of an impending active extravasation (Fig. 9).

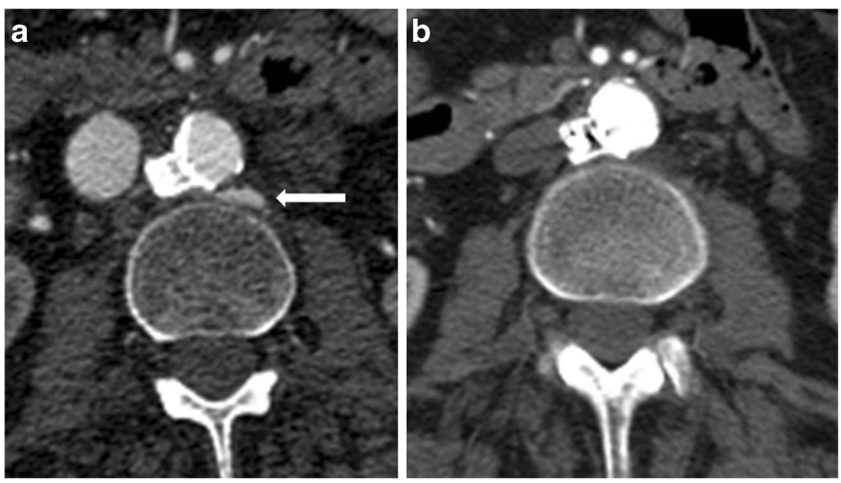

Fig. 8 Retroaortic pseudoaneurysm. **a** Axial CTA demonstrates a small pseudoaneurysm extending posterior to the aorta, which was not present at 1 month follow-up (**b**)

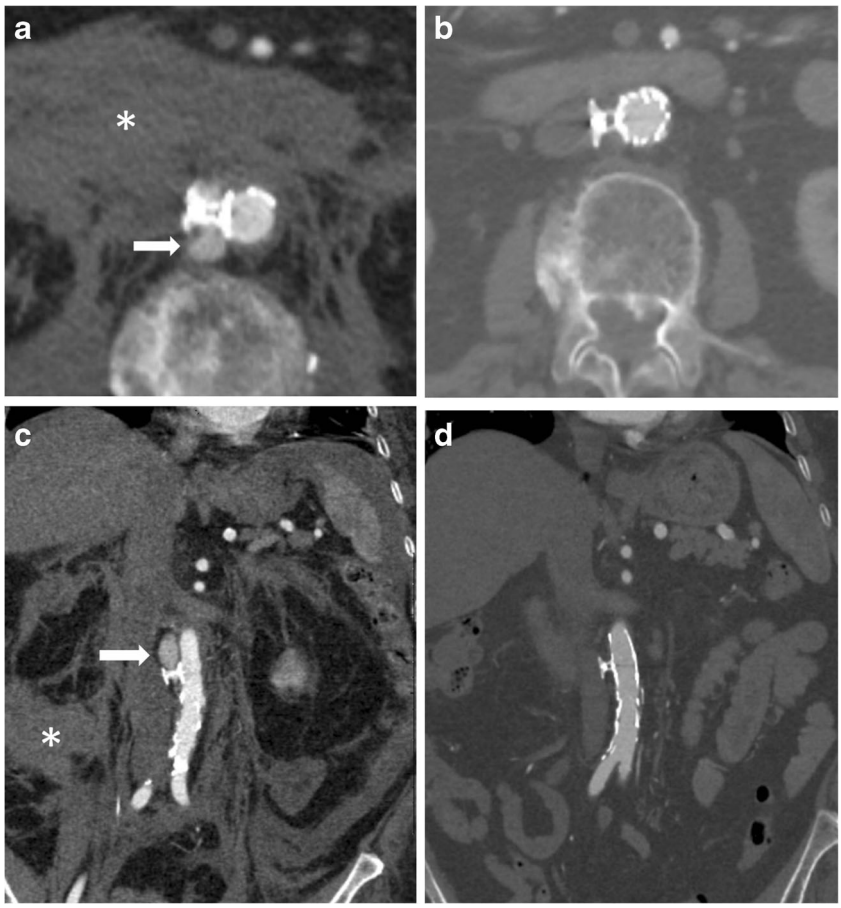

Fig. 9 Leaking pseudoaneurysm. **a** Axial and **b** coronal CTA immediately postprocedure in a patient with hemodynamic instability demonstrate a pseudoaneurysm extending superior and posterior to the level of the occluder device. There is a large area of hemorrhage (*) which was suspicious for active extravasation. The patient received an aortic stent graft and hemodynamic stability was achieved. **c** Axial and **d** coronal CTA 6 months postprocedure demonstrate resolution of the pseudoaneurysm and hemorrhage

Conclusion

Transcaval TAVR is used to treat the subsegment of patients unable to safely undergo transfemoral, transapical, or transaortic TAVR. In the near future, caval-aortic access may be incorporated into additional diagnostic and therapeutic procedures, within specialties such as cardiology, neurosurgery, and interventional radiology. As use of caval-aortic technique increases, radiologist familiarity with the basic periprocedural CT findings will be crucial for successful patient outcomes.

Compliance with Ethics Guidelines

Conflict of Interest S Shaikh, T Song, DD Wang, N Reeser, and W O'Neill all declare no conflicts of interest.

A Greenbaum has patents related to caval-aortic access and closure devices assigned to Henry Ford Health System.

Human and Animal Rights and Informed Consent All studies by A Greenbaum and W O'Neill involving animal and/or human subjects were performed after approval by the Henry Ford Health System Institutional Review Board. When required, written informed consent was obtained from all participants.

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