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Stent-graft applications in peripheral non-atherosclerotic arterial lesions

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PURPOSE
To retrospectively evaluate peripheral arterial lesions treated with stent-grafts in various territories and to identify the role of computed tomography angiography (CTA), both in diagnosis and follow-up.

MATERIALS AND METHODS
The study included 19 patients (11 male, 8 female) aged between 24 and 85 years. In all, 24 stent-grafts were used to seal an extravasation in 3 patients, a pseudoaneurysm/aneurysm in 12 patients, and an arteriovenous fistula in 4 patients. Self-expandable and balloon-expandable stent-grafts were used, all of which were covered with polytetrafluoroethylene material. Iatrogenic etiologies were responsible in 11 of the patients. In total, 5 superficial femoral, 2 deep femoral, 4 external iliac, 3 common iliac, 1 common carotid, 1 internal carotid, 1 subclavian, 1 renal artery, and 1 thyrocervical trunk lesion were treated.

RESULTS
The technical success rate was 100%, with no periprocedural complications. Mean follow-up was 18 months (range: 1–72 months). CTA was performed in 10 patients for diagnosis and in 7 patients for follow-up. There was no stent migration, but 1 stent crush. The total vessel occlusion rate was 16.6%, all diagnosed using CTA.

CONCLUSION
Stent-graft applications offer quick, single-step treatment, with few procedural complications. However, long-term durability remains a major concern. CTA is a very valuable tool, both for diagnosis and follow-up. Pseudoaneurysms and extravasations can be demonstrated successfully, as well as incomplete arteriovenous fistula closure, and patent or occluded stent-grafts.

Key words: • *stent-graft* • *aneurysm* • *vascular injury* • *computed tomography angiography*

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The use of endovascular techniques for the treatment of various arterial pathologies has increased significantly during the last decade (1). Almost all arterial territories have been treated, including aortic, coronary, cerebral, and peripheral arterial circulation; in most cases, promising results have been achieved for different types of lesions.

For iatrogenic, traumatic, and spontaneous arterial lesions in which the parent artery is essential and thus, must be preserved, stent-grafts appear to be an alternative tool among the various endovascular and surgical treatment methods (2–8). Nonetheless, the long-term patency and durability of stent-grafts still remains a major concern due to the lack of long-term randomized studies in the literature.

Computed tomography angiography (CTA) is a valuable tool in the diagnosis of vascular pathologies and is growing in popularity very rapidly due to the application of new technologies, such as multi-detector computed tomography (MDCT) (9, 10). CTA is a 3D technique that can provide views of the vessels from different orientations, as well as details of vessel walls. CTA can be useful for planning therapy by mapping out the arterial anatomy prior to intervention. We have been using 16-MDCT angiography for the last 2 years in our department and have used the CTA technique as a part of our peripheral stent-graft follow-up protocol because of its non-invasive nature and accurate image quality. Some of our diagnostic computed tomography (CT) images in this study were obtained with spiral CT.

Herein we report various non-aortic, non-atherosclerotic arterial lesions treated with endografts, some with patency of 6 years. The diagnostic significance of CTA as well as its use in the follow-up of our endograft cases are addressed.

Materials and methods

The study included 19 consecutive patients (11 male, 8 female) with a mean age of 53 years (range, 24–85 years) that underwent stent-grafting for peripheral arterial lesions in our institution's angio suite between September 2000 and November 2006. We retrospectively reviewed our electronic database and hospital charts for patient information with detailed follow-up results.

In total, 5 superficial femoral arteries, 2 deep femoral arteries, 4 external iliac arteries, 3 common iliac arteries, 1 common carotid artery, 1 internal carotid artery, 1 thyrocervical trunk, 1 subclavian artery, and 1 renal artery lesion were treated (Table).

Stent-grafts were used to seal an extravasation in 3 patients, a pseudoaneurysm/aneurysm in 12 patients, and an arteriovenous fistula in 4 patients. As summarized in the Table, etiologies were iatrogenic (2 diagnostic cerebral angiographies, 1 vertebral artery stenting, 1 intracranial arteriovenous malformation (AVM) embolization, 1 central catheteriza-

Patient demographics and details of arterial lesions, and diagnosis, treatment, and follow-up methods

Patient no.	Sex	Age	Artery	Pathology	Etiology	Treatment	Primary diagnostic tool	Primary follow-up tool
1	F	47	R subclavian	PA	Central catheterization	Jostent 6-12/28 mm on Powerflex 7 mm	CT	Doppler US
2	M	26	R common iliac	PA	Stabbing	Jostent 6-12/28 mm	CT	CTA
3	M	58	L ext. iliac	Extra.	Intra-aortic balloon placement	Jostent 6-12/28 mm on Ultrathin 8 mm	CT	Lost follow-up
4	F	68	L ICA	A	Spontaneous	Jostent and in-stent Protégé 8x30 mm	CT	CTA
5	M	54	R SFA prox.	Extra.	Vertebral artery stenting	Jostent 4-9/28 mm on Ultrathin 6 mm	CT	Doppler US
6	M	43	R SFA distal	PA	Fogarty for gunshot repair	Fluency 8 × 80 mm	DSA	Doppler US
7	F	73	R deep femoral	AVF	Cerebral angiography	Jostent 4-9/28 mm on Ultrathin 6 mm	Doppler US	Doppler US, DSA
8	M	41	L CCA	PA	Spontaneous	Jostent 4-9/28 mm on 8 mm balloon	CT	CTA
9	F	61	L ext. iliac-common femoral	Extra.	Intracranial stenting	2 Symbiot 5 × 20 mm and 5 × 30 mm	CT	CTA
10	F	57	L renal	A? PA??	Spontaneous?	2 Jostent premounted 5 × 16 mm	Doppler US	CTA
11	M	48	R superficial femoral	AVF	Traumatic	Atrium 7 × 38 mm and in-stent Protégé 8 × 40 mm	Doppler US	CTA, Doppler US
12	M	67	L superficial femoral	AVF	Spontaneous	3 Jostent 4-9/28 mm on 6 mm balloon	Doppler US	Doppler US, DSA
13	M	85	R superficial femoral	PA	Coronary angiography	Fluency 7 × 40 mm	CT	Doppler US
14	F	36	R common iliac	AVF	Spinal surgery	Fluency 10 × 40 mm	CT	Doppler US
15	F	56	L deep femoral	PA	Cerebral angiography	Jostent premounted 5 × 19 mm	DSA	Doppler US
16	F	57	R ext. iliac	PA	Ureteral balloon dilatation	Atrium 7 × 22 mm	DSA	Doppler US
17	M	24	R thyrocervical trunk	PA	Traumatic	Jostent premounted 3.5 × 16 mm	DSA	CTA
18	M	74	R common iliac	A	Spontaneous	2 Fluency 12 × 60 mm and 13.5 × 60 mm	MR	Doppler US
19	M	30	R ext. iliac	PA	Intracranial AVM embolization	Fluency 9 × 60 mm and 2 Wallstents 7× 40 mm, 9 × 40 mm	CT	Doppler US

F: female; M: male; L: left; R: right; AVF: arteriovenous fistula; AVM: arteriovenous malformation; A: aneurysm; Extra.: extravasation; PA: pseudoaneurysm; CCA: common carotid artery; ICA: internal carotid artery; SFA: superficial femoral artery; Prox.: proximal; Ext.: external; CT: computed tomography; CTA: computed tomography angiography; US: ultrasonography; MR: magnetic resonance, DSA: digital substraction angiography.

tion, 1 intra-aortic balloon placement, 1 Fogarty thrombectomy for gunshot repair, 1 intracranial stenting, 1 diagnostic coronary angiography, 1 spinal surgery, 1 ureteral balloon dilatation), traumatic (1 penetrating trauma - knife wound, 2 motor vehicle accidents), and spontaneous (5 incidents).

Diagnosis

Of the 19 patients, 10 (53%) were diagnosed using CTA and 7 (37%) underwent CTA during follow-up. Magnetic resonance angiography (MRA) was the preferred modality for diagnosis in 1 patient due to impaired renal function. Although the awareness of nephrogenic systemic fibrosis (NSF) is now widespread, there is still no standard approach for patients with impaired renal function. If there is a need for non-invasive arterial imaging with CT or MRI, options are performing CTA with low-dose iodinated contrast or MRA while avoiding certain gadolinium contrast agents that are reported to pose the risk of NSF (11). Digital substraction angiography (DSA) was used as the first diagnostic modality in 1 case of iatrogenic injury secondary to surgical thrombectomy (case 6). In patients with life-threatening bleeding, color Doppler ultrasound (US) with CT was used first to evaluate the site of bleeding. Then, patients were referred to the Vascular/Interventional Radiology Department for further evaluation and treatment. The diagnostic modalities that were used for each case are summarized in the Table.

Stent-graft treatment

All stent-grafts used in our patients were covered with polytetrafluoroethylene (PTFE). Balloon-expandable unmounted stent-grafts (Jostent Coronary Stent-Graft, Jomed Implantate GmbH, Germany) were used in 8 patients, pre-mounted balloon-expandable stent-grafts were used in 5 patients (Premounted Jostent and Advanta V12 PTFE stent-graft system, Atrium Medical Corporation, Rendementsweg SL Mgdrecht, The Netherlands), and self-expandable stent-grafts were used in the remaining 6 patients. Fluency Plus was used to treat 5 patients (Bard, Vascular Stent-graft, Angiomed GmbH & Co., Karisruhe, Germany) and 1 patient was treated with 2 Symbiot PTFE-covered self-expanding stent-grafts (Boston Scientific, Natick, MA, USA). All implanted stent characteristics, according to patient, are summarized in the Table.

Balloon-expandable stent-grafts 12–28 mm long and 4 mm in diameter (expandable up to 9 mm in diameter) were used. Stent-grafts were manually crimped onto 5–6 Fr, 5–8 mm peripheral angioplasty balloons (Opta Pro, Cordis Europa, Roden, The Netherlands). The vessel diameters were automatically calculated with reference to the graduated guidewire that was used as the baseline for the stent-graft diameter. Roadmap and angiographic control were used for the exact placement of the stent-graft. A retrograde common femoral arterial approach was used in 18 patients (5 left-sided and 13 right-sided). The only antegrade left common femoral arterial access was performed surgically for placement of superficial femoral artery (SFA) stent-grafts in case 12, in which all 3 of the stents were patent for more than 5 years.

Follow-up

Immediate technical success was defined as adequate stent-graft deployment at the desired site with a satisfactory angiographic result [no stenosis, dissection, or extravasation of contrast, and no residual fistula in arteriovenous fistula (AVF) cases]. Treated lesions remained excluded by the stent-graft and patency of the treated artery on imaging tools together with clinical well-being were taken into consideration for the follow up. In-stent re-stenosis on US and/or CTA follow-up was considered as 50% luminal diameter narrowing.

All patients were loaded with 300 mg clopidogrel post-operative therapy immediately after the procedure and then put on 75 mg clopidogrel for the next 3 months, and 100 mg acetylsalicylic acid per day for life.

All patients were called back a week after the procedure in order for an interventional radiologists to perform a detailed physical examination to evaluate if there was any access related problem or any evidence of recurrent bleeding. Follow-up was performed in all patients by using combinations of Doppler US, CTA, and conventional angiography, as summarized in the Table, depending on the injured artery. Doppler US is mainly used to demonstrate the flow pattern at the treated artery, seeking the secondary signs of stent-graft occlusion or stenoses. CTA is mainly used to show the site of the stent-graft in places that US would fail, such as the renal and iliac arteries. In patients with carotid, iliofemoral, renal, or subclavian artery pathologies treated with stent-grafts, follow-up is performed using Doppler US and CTA in combination. Patients with inadequate or suspicious US follow-up underwent CTA as the first choice. DSA is the preferred modality of imaging only if there is strong clinical/imaging evidence of a stent-graft problem of any kind. MRA was never used as a follow-up tool in this study.

All the medical records were reviewed retrospectively and relevant data, such as peripheral pulses, neurological deficits, and hemodynamic stability, were recorded from clinical exams. Relevant arterial flow velocity, pattern, and direction were noted on Doppler examinations, which were routinely scheduled at 3, 6, and 12 months post-procedure, and then annually, unless the patient had any complaints. Patients with pathological US findings were immediately scheduled for CTA and then DSA if needed. CTA was performed in patients with carotid artery stent-grafts at 6 and 12 months post-procedure, and then annually (Fig. 1). The remaining patients underwent CTA at the 9- or 12-month follow-up, depending on their particular follow-up schedule. In patients with complex AVF, Doppler US follow-up was performed for both venous and arterial systems. DSA was performed in 2 patients during follow-up. CTA was the primary choice of follow-up imaging in 7 patients. The follow-up imaging tools for each case are given in the Table.

CT protocol

MDCT examinations were performed on a Somatom Sensation 16 scanner (Siemens Medical Solutions, Erlangen, Germany). An explanation of the CT procedure was given to each patient before scanning. For administration of IV contrast material, an 18–20 gauge peripheral line was inserted into an antecubital fossa vein. The non-ionic iodinated contrast material (300 mg/ml) was intravenously injected through an antecubital vein using a power injector. Contrast flow rate and contrast volume were 4 ml/sec and 100 ml, respectively. Automated timing (Care Bolus; Siemens) was used to start the angio-

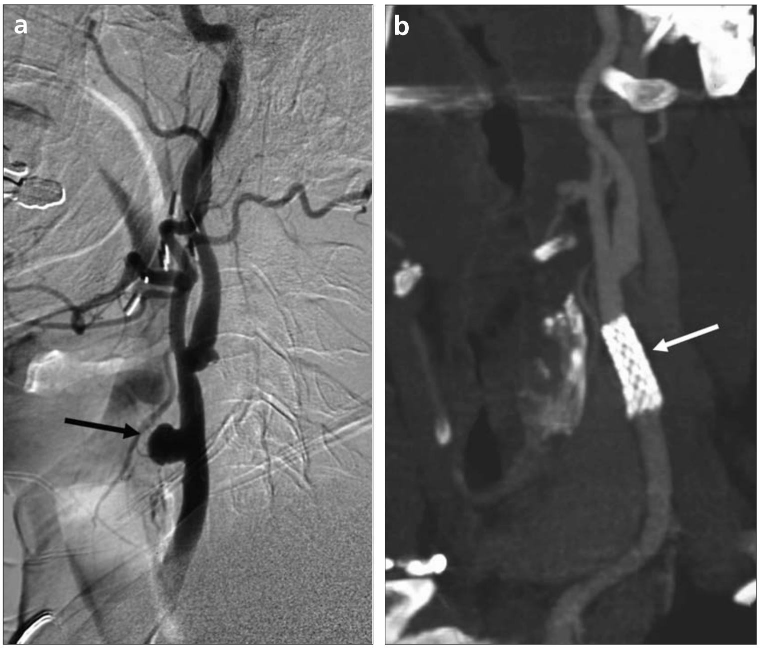


Figure 1. a, b. Case 8. A 41-year-old male with cryptogenic pseudoaneurysm of the left common carotid artery (CCA). DSA image **(a)** showing saccular mid-distal CCA aneurysm filling *(arrow)*. MDCT angiography (16-detector) thin coronal-oblique maximum intensity projection image **(b)** of stent-graft *(arrow)* follow-up 16 months after treatment.

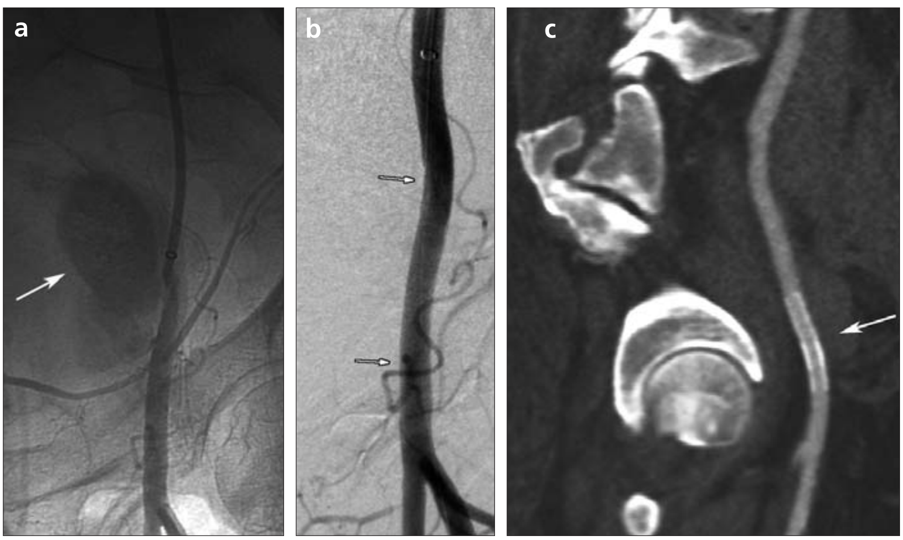


Figure 2. a–c. Case 9. Iatrogenic left external iliac artery injury secondary to an intervention for intracranial stenting. DSA image **(a)** shows active bleeding *(arrow)* from the distal left external iliac artery at the level of the bending point (hip joint). DSA image **(b)** after 2 overlapping stent-grafts were placed, showing the widely patent iliofemoral arteries with hardly visible coronary stent-grafts *(arrows)*. First year CTA follow-up image **(c)** demonstrating the patent stent-graft *(arrow)*.

graphic series, with the sample volume positioned in the ascending aorta or distal abdominal aortic lumen, depending on the localization of pathology, and an attenuation threshold of 100 HU was used. The scan parameters of angiographic series were: 120 kV; 150 mAs (eff); rotation time, 0.5 s; detector collimation, 16 × 0.75 mm; slice thickness, 1 mm; table feed/gantry rotation: 12 mm. All the data were reconstructed with medium kernel (B45f). The data were transferred to a Leonardo workstation (Siemens Medical Solutions, Erlangen, Germany). Two independent attending radiologists (BP, TH), both specialists in cardiovascular radiology, reviewed the images of each CT examination. Maximum intensity projection, volume rendering, and curved multiplanar reconstructions were generated using axial, coronal, and sagittal multiplanar reconstruction data. Stent patency, stenosis, extravasation, and additional pathologies were evaluated.

Results

An endovascular approach was the treatment choice in all cases due to the actively bleeding emergent nature and/or associated co-morbid conditions, which placed the patients at high risk for undergoing surgical alternatives. Mean clinical follow-up was 18 months (range, 1–72 months). Among the 19 patients, 2 were followed-up for 6 years and only 1 patient was lost to follow-up.

There were no side branch occlusions, rupture, distal embolization, surgical conversion, or major procedure-related complications.

In the 10 cases that were diagnosed with CTA and then underwent DSA, CTA was helpful in several ways. In addition, in understanding the extent of the injury with respect to patient clinical condition, CTA helped in locating the injury and appropriately tailoring our approach, in terms of access site and stent-grafts. Despite the relatively large volume of iodinated contrast agent used per patient during subsequent CTA and DSA exams for diagnosis, treatment, and follow-up, no contrast-related acute renal toxicity was noted in our series of patients.

In total, 24 stent-grafts were used in 19 patients. One patient (case 12) with complex spontaneous femoral AVF received 3 stent-grafts along the SFA to close numerous feeders and 1 patient received 2 overlapping stents across the external iliac artery/common femoral artery site due to incomplete sealing of extravasation with the first stent-graft (case 9) (Fig. 2). The patient with left renal artery pseudoaneurysm/aneurysm received 2 overlapping coronary stent-grafts in order to seal the entire main renal artery from the ostium to the bifurcation (Fig. 3). Again, 2 overlapping stent-grafts were used to seal a long atherosclerotic common iliac artery aneurysm (case 18).

In 3 cases, self-expandable nitinol (Protege, EV3, Minnesota, USA) and metallic (Wallstent, Boston Scientific, Nattick, MA, USA) stents were used in addition to the stent-grafts in carotid and external iliac circulation in order to obtain better stent opposition (Fig. 4) (cases 4, 11, and 19).

In 3 of the 7 patients with CTA follow-up, stent-graft occlusion was demonstrated. In the other case with femoral AVF, CTA was able to show the residual fistulous communication in detail, as with arteriography (Fig. 5).

The site of active bleeding was demonstrated with CTA in the 3 cases that were immediately brought to the angio suite to undergo stent-graft implantation. The post-stenting angiograms showed no evidence of further extravasation or filling of the aneurysm/pseudoaneurysm in any of the cases (Fig. 6).

Arterial bleeding and AVFs in 4 cases (cases 3, 5, 7, and 9), which occured secondary to percutaneous trans-arterial procedures, were already on anticoagulation medication (dispril, clopidogrel, or clexane) due to underlying diseases. In 3 of those patients, DSA was performed for continuous bleeding from the access site, which showed active contrast extravasation, and in the remaining 1 patient an AVF was demonstrated using CTA (case 14).

One patient with external iliac artery pseudoaneurysm (case 16) had a history of recurrent cervical cancer and several courses of radiotherapy to the pelvis. Percutaneous nephrostomy was then placed, followed by ureteral balloon dilatation, which resulted in severe hematuria. Subsequent DSA re-

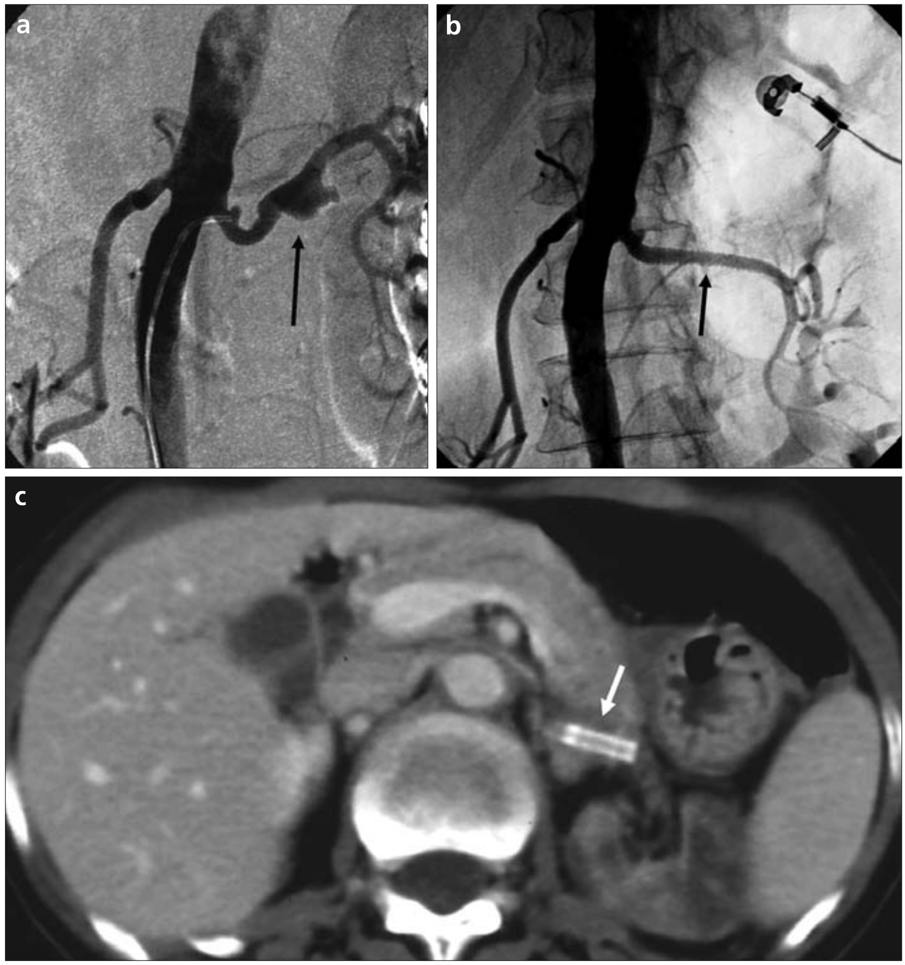


Figure 3. a–c. Case 10. A case of collagen tissue disorder with an h/o renal artery balloon angioplasty performed 8 years earlier. Abdominal aortogram **(a)** revealing left renal artery aneurysms/pseudoaneurysms *(arrow)*, spontaneous or secondary to the previous intervention. DSA image **(b)** immediately after 2 stent-grafts *(arrow)* were placed. Six-month control CT image **(c)** shows left kidney infarction with occluded renal artery stent-grafts *(arrow)*.

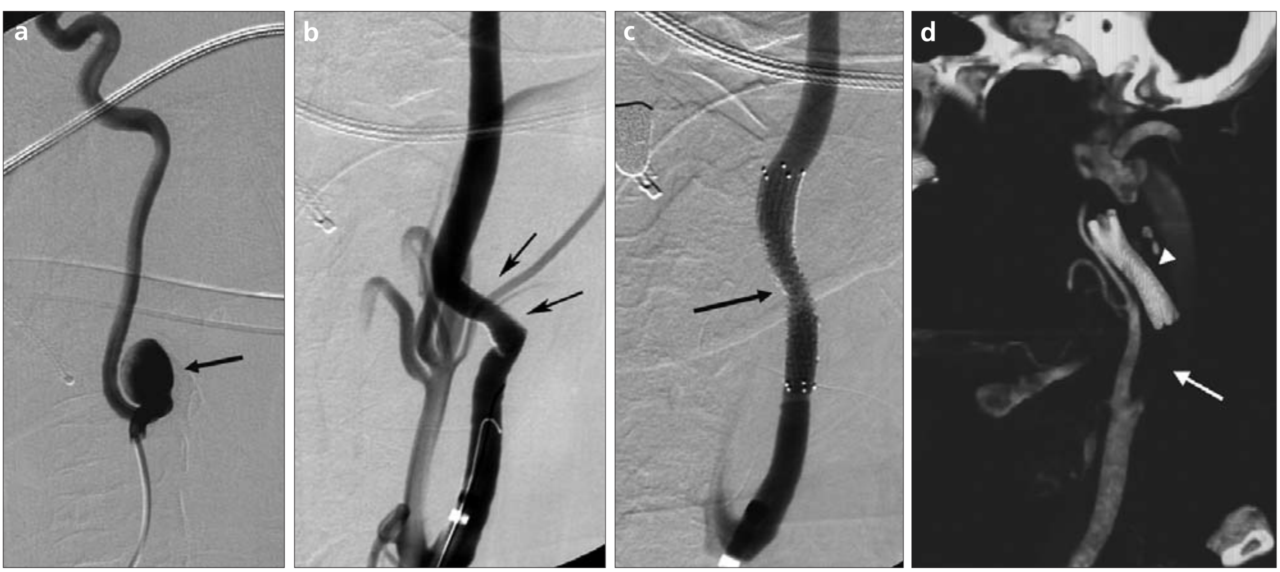


Figure 4. a–d. Case 4. A 68-year-old female with cryptogenic left internal carotid artery (ICA) aneurysm/pseudoaneurysm. Angiogram following selective injection of left ICA **(a)** reveals a saccular extracranial aneurysm *(arrow)*. Angiogram obtained immediately after stent-graft application **(b)** a tortuous ICA *(arrows)* is seen. Second in-stent self-expandable bare stent *(arrow)* placement **(c)** straightens the tortuous ICA. Nine-month follow-up CTA image **(d)** shows an occluded left ICA *(arrow)* despite the un-crushed stents *(arrowhead)*.

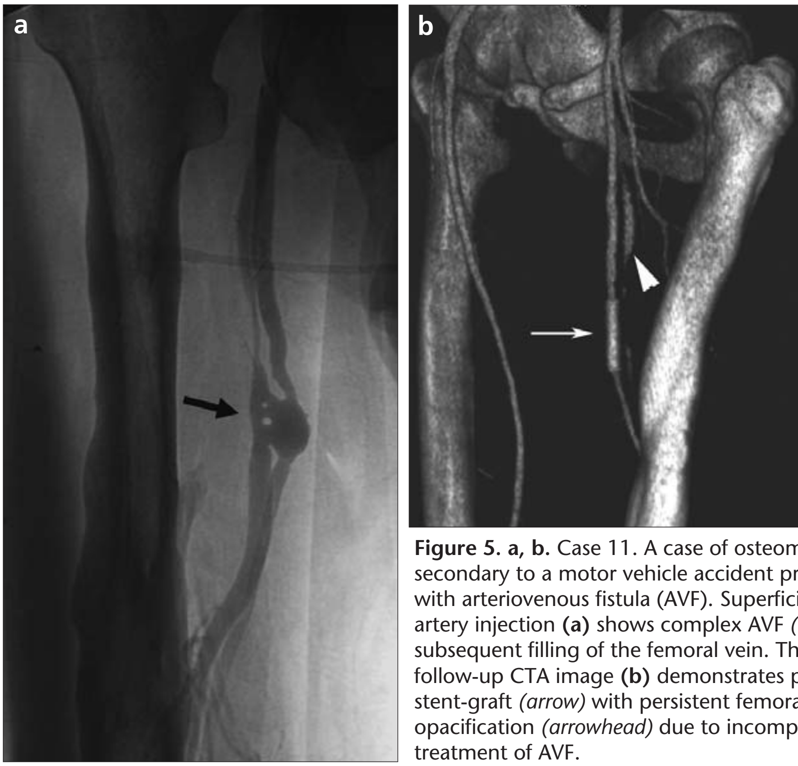
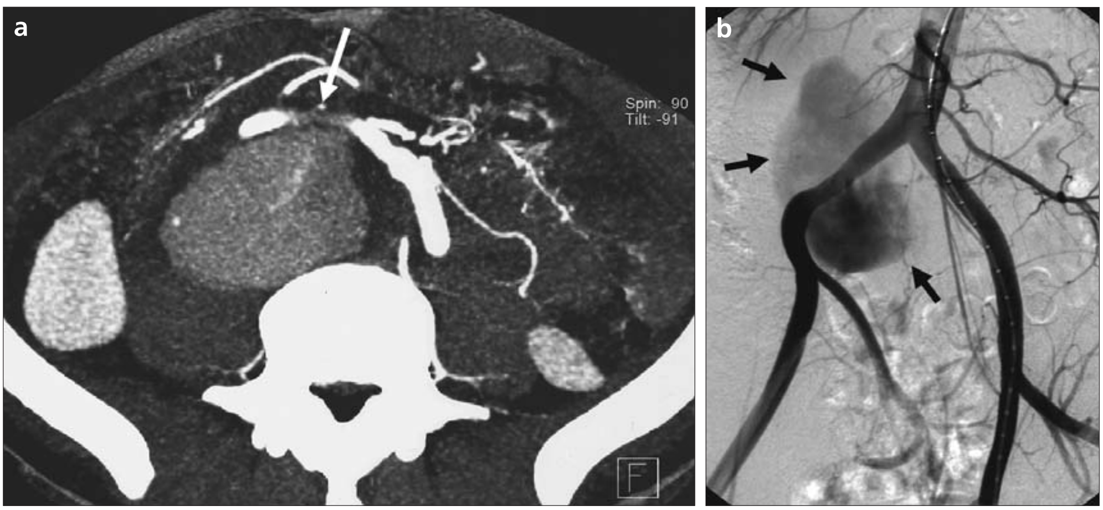


Figure 5. a, b. Case 11. A case of osteomyelitis secondary to a motor vehicle accident presented with arteriovenous fistula (AVF). Superficial femoral artery injection **(a)** shows complex AVF *(arrow)* and subsequent filling of the femoral vein. Three-month follow-up CTA image **(b)** demonstrates patent stent-graft *(arrow)* with persistent femoral venous opacification *(arrowhead)* due to incomplete treatment of AVF.

vealed the pathology at the external iliac artery.

Complete closure of the AVF was immediately accomplished in 2 cases. In the remaining 2 cases with AVF, since chronic AVF became an arteriovenous malformation with multiple tiny connections between the femoral arteries and veins, there were still some residual fistulous connections. In one of those 2 cases, 3 stent-grafts were placed along the SFA to close as many arterial feeders as possible (Fig. 7). This patient remained asymptomatic for AVF for the next 5 years and then presented with a swollen leg due to iliac venous thrombosis. He underwent transvenous embolization of the fistula and ended up with total occlusion of the fistula. The other patient with incomplete closure of an AVF received a stent-graft to the site of the main connections; some small feeders remained at the time of the control arteriogram as well as at the follow-up CTA (Fig. 5).



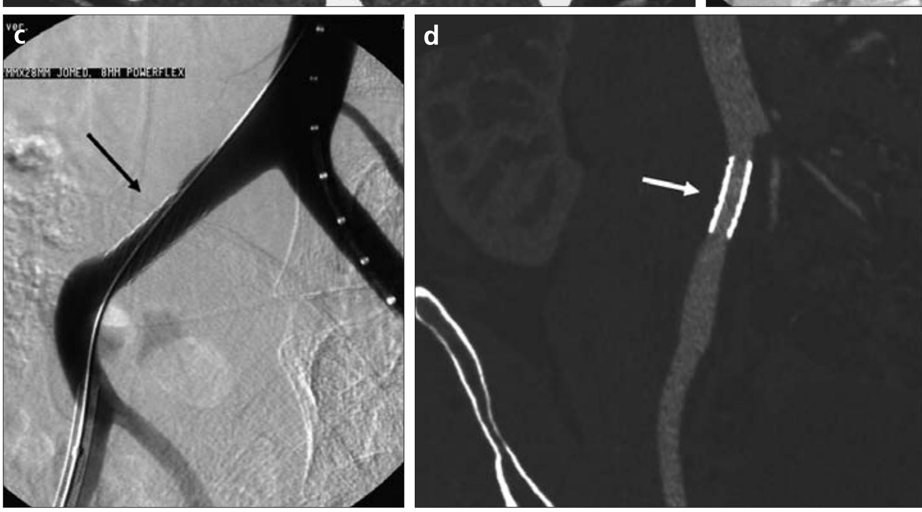


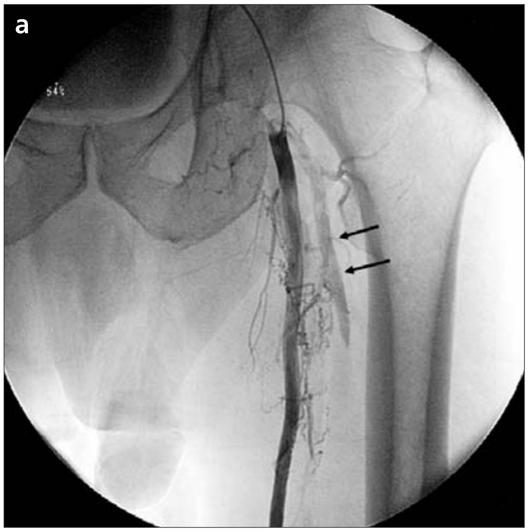
Figure 6. a–d. Case 2. Stabbing injury to the right common iliac artery. Axial MDCT angiography (16-detector) image **(a)** shows retroperitoneal hematoma and contrast extravasation from the iliac artery *(arrow)* into the hematoma. Pelvic arteriogram **(b)** confirms the pseudoaneurysm *(arrows)* filling from the right common iliac artery. DSA image **(c)** immediately after stent-graft *(arrow)* placement. MDCT (16-detector) angiography volume rendering 3D image **(d)** reveals the patent stent-graft *(arrow)*, with no in-stent stenosis across the right common iliac artery at the 18-month follow-up.

In the cases involving pseudoaneurysms/aneurysms of the iliac, femoral, and carotid arteries, the thyrocervical trunk, and subclavian and renal artery the pathological lesions were all successfully sealed from the circulation with no endoleak (Figs. 3, 4, 8–10).

The technical success rate was 100% and there were no procedure-related complications. The clinical courses were uneventful with a stable hemodynamic state in all cases. The average hospital stay was 2.5 days (range: 1–14 days), with 11 patients staying just 1 day. Underlying disease varied the length of hospitalization for each patient, and in iatrogenic cases length of stay was not directly related to the stent-grafting procedure itself. There was only 1 case (4%) of stent crush (Fig. 8d). The total occlusion rate was 16.6%, all demonstrated with CTA. A carotid stent-graft, a thyrocervical trunk stent-graft, and the renal artery stent-grafts were observed to be occluded at 9-, 12-, and 6-month follow-up, respectively.

The remaining patients were asymptomatic at follow-up, showing patent stent-grafts along the injured arteries (Table). Examples of patent stent-grafts in CTA are shown in figures 1b, 2c, 5b, and 6d. The patient with hip joint coronary stent-grafts has been doing well for almost 2 year, with no symptom of stent occlusion according to periodic Doppler US examinations, as well as CTA (Fig. 2c).

In one patient with a left extracranial internal carotid artery (ICA) stent-graft (case 4), intimal hyperplasia at the mid-stent causing 30% stenosis was detected at the 6-month follow-up with DSA, which was initially suspected based on Doppler US. Then, at 9-month follow-up she had a stroke and subsequent CTA showed an occluded stent-graft at the left ICA (Fig. 4). The other case with renal artery stent-grafts (case 10) presented to the emergency room with flank pain 6 months post-procedure. CTA revealed acute occlusion of the left renal artery associated with renal infarction, with no evidence of stent crush (Fig. 3c). She then underwent left total nephrectomy. The thyrocervical stent-graft was occluded at the 1-year follow-up with CTA, most likely due to distal crush. In this case with a small diameter stent-graft, reformat image



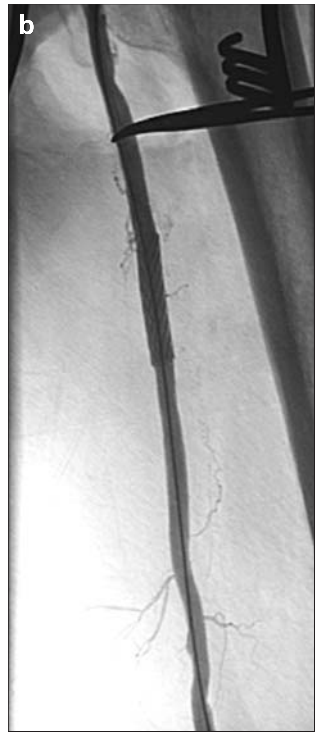


Figure 7. a, b. Case 12. Spontaneous complex femoral arteriovenous fistula (AVF). Left superficial femoral arteriogram **(a)** shows multi-level AVF from the superficial femoral artery to deep femoral vein *(arrows)*. Immediately after the first stent-graft placement some of the fistulas are already occluded **(b)**.

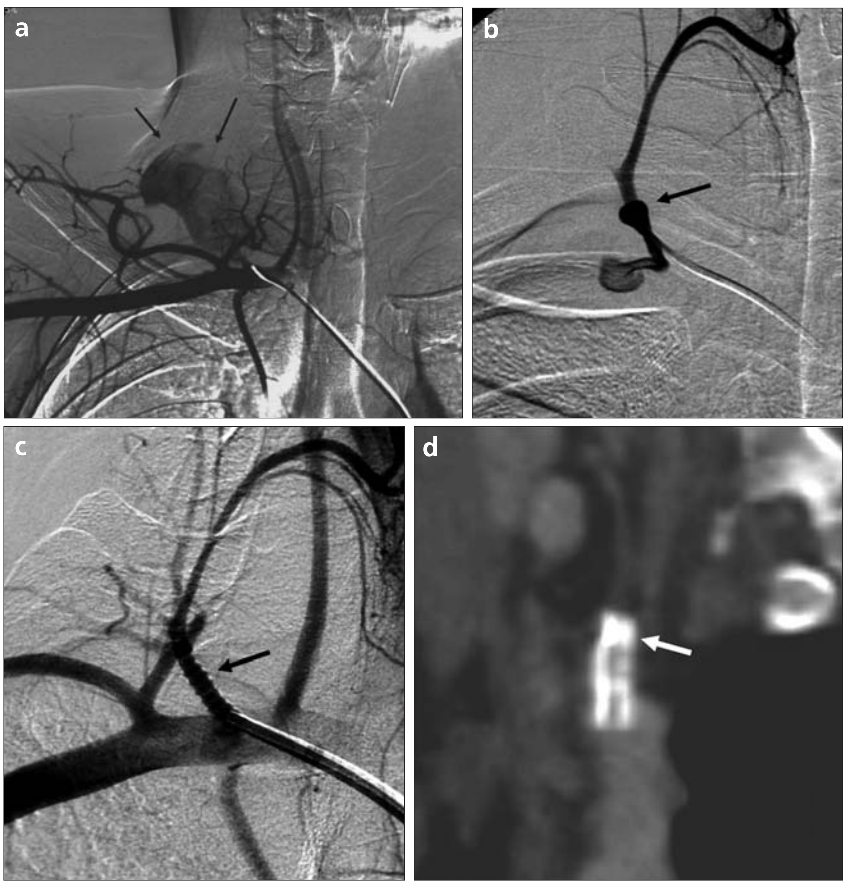


Figure 8. a–d. Case 17. A 24-year-old male presented with a severe neck hematoma following a motor vehicle accident. Emergent DSA image **(a)** shows contrast extravasation *(arrows)* from a branch of the left subclavian artery. Subsequent selective injection of the thyrocervical trunk **(b)** reveals a pseudoaneurysm *(arrow)*. Control arteriogram **(c)** immediately after stent-graft *(arrow)* deployment across the injury. One-year follow-up 16-MDCT angiography reformatted image **(d)** with low diagnostic quality. Raw axial images showed distal crush and occlusion of the stent-graft *(arrow)*.

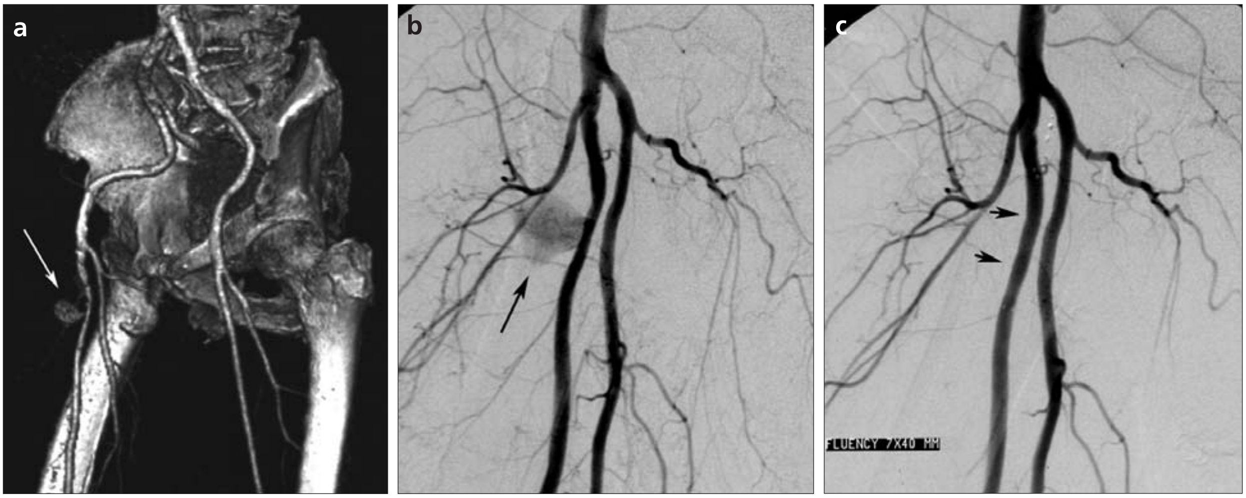


Figure 9. a–c. Case 13. An 85-year-old man with a severe right groin hematoma secondary to coronary angiography access. 3D pelvic CTA image **(a)** shows pseudoaneurysm formation *(arrow)* arising from the right superficial femoral artery. Subsequent selective right common femoral arteriogram **(b)** confirms CTA findings *(arrow)*. DSA image **(c)** immediately after stent-graft placement shows excluded pseudoaneurysm *(arrows)*.

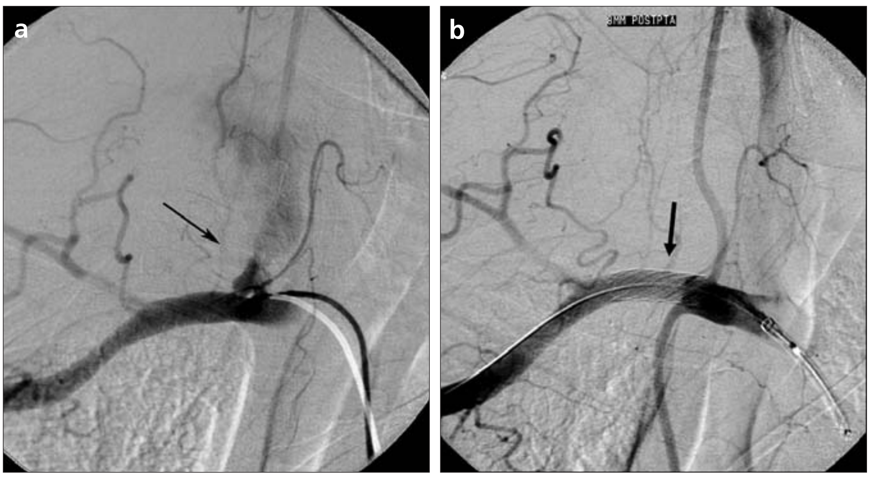


Figure 10. a, b. Case 1. An iatrogenic injury to the right subclavian artery during central venous catheterization. DSA image **(a)** shows a pseudoaneurysm with extravasation *(arrow)*. Complete seal of the pseudoaneurysm *(arrow)* immediately after stent-graft placement **(b)**.

quality in CTA decreased significantly (Fig. 8d).

Discussion

The utility of stent-grafts was first introduced by Parodi et al. for the treatment of abdominal aortic aneurysm via a transfemoral approach (12). There are also a limited number of studies in the literature regarding the treatment of non-aortic arterial lesions with endografts (13, 14). In particular, in patients with associated comorbidities that complicate surgical approaches, stent-grafts may be lifesaving in many cases, as we have demonstrated in our study (3–6). However, endovascular therapeutic approaches have their own complications, such as stent occlusion, deformation and kinking, the loss of vessel branches after placement, and intimal hyperplasia (4, 14–16). Stent-graft occlusion is the most important complication, with a reported incidence of 17% (17). Additionally, the success of the procedure depends mainly on the anatomy of the injured vessel and the available stent-graft system. The safety and efficacy of endovascular stent-grafts have been demonstrated in a number of peripheral arterial pathologies, including trauma and aneurysmal disease (7, 8, 18, 19). Balloon-expanding stent-grafts provide accurate sizing and localization, but they are prone to collapse and to late crush deformation due to external forces; moreover, substantial flexing may lead to an additional risk of compression and kinking (20, 21). Owing to their minimal foreshortening and precise positioning, one should use balloon-expanding stent-grafts at lesions adjacent to an ostium, bifurcation, or side branch (7). Self-expanding stent-grafts are more flexible and are resistant to external forces in superficial locations, such as the carotid or thigh regions (20). They should also be used when a relatively longer coverage is needed or in the presence of an associated dissection at the target vessel. The main disadvantage of stent-grafting is related to the adverse events associated with use of a large introducer sheath, which predispose to local puncture complications, such as hematoma and pseudoaneurysms; however, during this study none occurred.

In our 2 patients with non-atherosclerotic carotid artery pathology (cases 4 and 8), despite in-stent self-expanding stent placement, the stent in the ICA was occluded at the follow-up, whereas the common carotid artery (CCA) stent-graft has remained patent.

Several reports have shown that PTFE-covered self-expanding stent-grafts can be used in the treatment of several vascular injuries and pseudo aneurysms (2, 22–25). Self-expandable stent-grafts should be used when injured arteries are close to bending points, i.e. knee and hip joints (e.g. cases 6, 9, and 19). PTFE-covered stents were used in all cases due to PTFE's low level of traumatic effect to vessels at the placement site and its radial expansion characteristic that helps to seal vessel walls. The behavior of PTFE in vascular structures is well known since it has been used for a long time in vascular prostheses.

Iatrogenic arterial injury at the puncture site is a potential complication of diagnostic and therapeutic interventions (26, 27). Its risk increases in the presence of atherosclerotic aorto-iliac disease (27). Arterial rupture is a life-threatening complication; it can present acutely with significant blood loss or can insidiously lead to a pseudoaneurysm or arteriovenous fistula formation, as in some of our cases (cases 14 and 19) (28, 29). It is also well known that use of anticoagulation medication increases such risks of percutaneous procedure-related entry site complications, as in our 2 of our cases (cases 5 and 9) (30).

Injury to the subclavian artery and its branches are not very common because these vessels are protected by the overlying bony and muscular structures. Central venous catheterization was the main cause of damage to the subclavian artery at the access site and the resulting pseudoaneurysm in 1 of our patients. The diagnosis of the injury and exact location of the arterial puncture was diagnosed with CTA, which made us think that endovascular treatment could have been performed, as it was far enough from the ipsilateral vertebral and internal carotid arteries. Until recently, the treatment of choice would have been surgical intervention because of the noncompressible nature of the region and its close proximity to intra-thoracic structures. There are now a number of reports of the endovascular treatment of subclavian artery pseudoaneurysms in the literature (13, 14, 31, 32). There are very few cases of thyrocervical trunk injuries in the literature (33). Although it was controversial to preserve the thyrocervical trunk blood flow with a traumatic pseudoaneurysm, the stent-graft placed in this patient occluded, most likely secondary to crush injury of the distal end of the stent related to external compression by surrounding structures during upper body and limb movements. In this circumstance stent-graft occlusion and vessel patency can be observed with axial row CTA images, but in-stent restenosis cannot be determined with any method.

There are limited reports of cases with renal artery stent-grafts (7, 34). Our case had an almost 10-year history of hypertension, most probably associated with her collagen tissue disorder, for which she underwent single-session balloon angioplasty at a different hospital 8 years earlier and than presented to our center for a routine check up after receiving no post-procedure follow-up. After a series of tests, she underwent an arteriogram that showed aneurysm/pseudoaneurysm formation along the left renal artery. The etiology was not clear, but spontaneous aneurysm due to underlying connective tissue disorder was suspected. Due to a past history of renal angioplasty, dissecting aneurysm formation could not be definitively excluded. Stent-grafting was performed, but unfortunately it was not long lasting. Renal artery bypass surgery could be a better alternative for those kinds of patients, but underlying connective tissue disorder or vasculitis can limit the outcome of surgery as well.

Stenting of arteries over the joints, such as the common femoral artery, is generally avoided due to the risk of stent fracture, which may lead to acute closure and greater risk for neo-intimal hyperplasia (35). Case 9, treated with a Symbiot® PTFE-covered self-expanding coronary stent-graft at the left external iliac-common femoral artery was a challenging case from this point of view. Symbiot® is a low profile, flexible stent-graft, which is less prone to crush defects. Therefore, we prefer it for the occlusion of active bleeding at the hip joint in emergency situations. Those stent-grafts were patent based on 2-year follow-up Doppler US and CTA. Similarly, case 19 presented with acute retroperitoneal hemorrhage secondary to pseudoaneurysm formation, which occurred during cerebral AVM embolization. The microcatheter used for prolonged ONYX (Liquid embolic system, Micro Therapeutics, INC, Irvine, CA, USA) injection was left inside as a natural part of the treatment, with the tip at the internal carotid circulation extending along the aorta to the right common femoral artery, which may have complicated any surgery in addition to the large hematoma surrounding the pseudoaneurysm. A self-expandable stent-graft was placed across the arterial injury, with additional self-expandable metallic stents for better alignment of the stent-graft within the vessel wall over the hip joint. This patient was totally asymptomatic at 1-month follow-up, with patent stent-grafts based on Doppler US evaluation.

DSA is the standard procedure for luminal assessment after stent placement; however, this invasive technique has the drawbacks of moderate-to-high cost and rare, serious complications.

Doppler US, MRI, and CTA are used for non-invasive follow-up examinations after stent placement. Major advantages of Doppler US are cost-effectiveness and the absence of radiation exposure; however, the reproducibility and reliability of duplex US are mainly influenced by the experience of the examiner (36). The introduction of MDCT scanners has substantially increased the clinical use of CT angiography by offering fast data acquisition, increased volume coverage, decreased contrast medium dose, decreased acquisition time, and isotropic spatial resolution. The high sensitivity and specificity of MDCT angiography of the various parts of arterial systems are reported in the literature. Using CTA as the first diagnostic tool in iatrogenic complications, particularly while looking for retroperitoneal hemorrhages, can be very useful for demonstrating the site of arterial injuries, based on our experience. In this study CTA was used to confirm suspected vessel injury and to determine its location, to assess the feasibility of an endovascular procedure, and to detect associated extra-vascular injuries. The role of CTA in tailoring the endovascular repair of aortic aneurysms has been well described in the literature. Based on our experience, similar guidance can be obtained for peripheral arterial lesions, thus shortening the length of the procedure. After assessing the feasibility of the stent-grafting procedure, stent-graft choice can be made prior to the procedure by examining the size, location, tortuosity, and presence of nearby branches or dissection. The approach site can be determined in many ways well before the procedure. For example, if you have limited stent-graft choices, maybe you may have to use the axillary/brachial approach instead of the contra lateral groin approach for an iliofemoral lesion, only because you happened to have a stent-graft with a short delivery system. CTA appears to be really helpful prior to peripheral endovascular procedures (8); however, stent assessment with MRI and CT is challenging because of the metallic artifacts that may partially or completely obscure the vessel lumen while using both modalities. In phantom studies simulating iliac artery stents, MDCT was rated superior to MRI for steel, nitinol, and cobalt-based stents (37). X-ray beam hardening is the artifact characterized by decreasing intraluminal attenuation values and artificial narrowing of the stent lumen. The obscure effect of blooming artifacts through metallic stents is increased when stent diameters are smaller than 3 mm. Despite these limitations, MDCT has shown its potential for stent visualization in the cerebral, carotid, coronary, iliac, and peripheral arteries. Sharp-medium kernels are preferred to decrease X-ray beam hardening artifacts in stent evaluations with MDCT (38). The depiction of the in-stent lumen and of neointimal hyperplasia has been shown in the carotid stent using MDCT. Heuschmid et al. showed that medium and sharp kernels significantly improved mean visibility of in-stent lumens (38); however, they did not find a statistically significant difference in in-stent attenuation between medium-sharp and smooth kernels. They reported that coronal oblique reformation is the best view to assess stents placed in the lower extremity. Herzog et al. suggested that in-stent restenosis could be identified accurately by CTA in vitro (39); however, DSA is still considered to be the gold standard for determining the effectiveness of stenosis. In our limited number of patients with CTA follow-up, although we did not use CTA routinely in determining the in-stent re-stenosis rate, we think that CTA may be useful in assessing in-stent re-stenosis in relatively larger caliber vessels, such as the carotid or iliac arteries.

In our series of patients the utility of CTA in the follow-up of peripheral arterial injuries treated by means of stent-grafts provided valuable information, such as vessel patency, stent-graft occlusion or patency, hematoma resorption, aneurysm occlusion, and incomplete AVF closure, for further medical management of these patients.

In conclusion, CTA is a valuable non-invasive tool for diagnosing peripheral arterial injuries. As seen in our cases, it also provides important data for tailoring subsequent management. Stent-grafts are increasingly being used in the treatment of various arterial lesions. Long-term patency still remains a major concern, particularly in small caliber vessels. MDCT angiography seems to be useful in the follow-up of these patients. The patency or occlusion of stent-grafts, occlusion of aneurysms/pseudoaneurysms, as well as total/partial closure of AVFs can be assessed with MDCT angiography.

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