Chimney grafts preserve visceral flow and allow safe stenting of juxtarenal aortic occlusion

Adel Bin Jabr, MD, Björn Sonesson, MD, PhD, Bengt Lindblad, MD, PhD, Nuno Dias, MD, PhD, Tim Resch, MD, PhD, and **Martin Malina, MD, PhD,** *Malmö, Sweden*

Objective: **Chimney grafts have proven useful for urgent endovascular repair of juxtarenal aortic aneurysms. Stenting of juxtarenal aortic occlusive disease is not routinely advocated due to the risk of visceral artery obstruction. We report on the potential applicability of chimney grafts in 10 patients with juxtarenal aortic stenosis or occlusion. To our best knowledge, chimney grafts have not been applied previously in this challenging setting.**

Methods: **Ten high-risk female patients (mean age, 68 years) with severe stenosis or occlusion of the aorta at the level of the visceral arteries were offered stenting. "Chimney" stents or stent grafts (20-40 mm long) were implanted from a brachial approach into visceral arteries that needed to be covered by the aortic stent. The chimney stents were then temporarily obstructed by balloon catheters to prevent visceral embolization until the aortic stent or stent graft was deployed.**

Results: **All procedures were technically successful, and patency was obtained in all visceral arteries and the aorta without distal embolization. One patient died after 9 days of acute heart failure. The nine surviving patients presented no complications, and all stented vessels remained patent at up to 6 years. Another patient died after 5.5 years due to lung cancer. All three patients with renal impairment have improved renal function, and a reduction in antihypertensive medication has been possible.**

Conclusions: **Chimney grafts may allow stenting of juxtarenal aortic occlusive disease by protecting the patency of visceral arteries. Further evaluation with more patients and longer follow-up is required. (J Vasc Surg 2013;57:399-405.)**

The chimney graft technique has been proposed for endovascular repair of aortic aneurysms without an adequate sealing zone, at least in the acute setting.[1-5] The chimney graft is deployed into a vital aortic side branch alongside the main aortic stent graft in order to extend the fixation zone, for example, in a juxtarenal aortic aneurysm. The chimney technique has been successfully applied in juxtarenal, suprarenal, thoracoabdominal, and aortic arch aneurysms.[6-9] It also has been used to manage complications such as type I endoleaks[10] and accidentally covered aortic branches during endovascular stent grafting.[11,12] Furthermore, chimney grafts have been used in ruptured thoracoabdominal aneurysms.[13-15]

We propose yet another indication for chimney grafts, namely, juxtarenal aortic occlusive disease. Juxtarenal aortic occlusion is often caused by an initial stenosis near the aortic bifurcation, which may lead to retrograde thrombosis of the abdominal aorta (Fig 1). Stenting such a thrombosed aortic segment carries a risk of releasing embolic particles that may occlude the visceral arteries (Fig 2). Other patients may have a primary stenosis at the level of the visceral vessels (Fig 1). Visceral artery obstruction during midaortic stenting may then be caused by embolization of dislodged plaque fragments, coral reef encroachment of the ostium, or flow obstruction by the stent mesh itself (overstenting). Furthermore, chronic stenosis of the visceral arteries may coexist and require stenting as well.

The present study evaluates the applicability of chimney grafts in protecting visceral branches during stenting of juxtarenal aortic occlusive disease.

METHODS

Since January 2006, 10 female patients with juxtarenal aortic occlusive disease were offered endovascular repair because they were deemed noncandidates for open surgery. Patient data are given in Table I. All patients had an occlusion or high-grade stenosis of the abdominal aorta adjacent to the origin of the visceral arteries. Eight of the patients belonged to American Society of Anesthesiologists (ASA) classification 3, and all had multiple comorbidities. They were fully informed about the technique and the associated risks.

The indications for intervention were either critical bilateral lower limb ischemia (n = 3) or bilateral claudication combined with renovascular hypertension (n = 7). Three of the patients also had heart failure secondary to renal insufficiency. Visceral embolism was part of the indication in two cases.

Operative technique. All procedures were performed with the patients under general anesthesia. Access was

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Reprint requests: Martin Malina, MD, PhD, Vascular Center, Skåne University Hospital, 20502 Malmö, Sweden (e-mail: malinamd@gmail.com).
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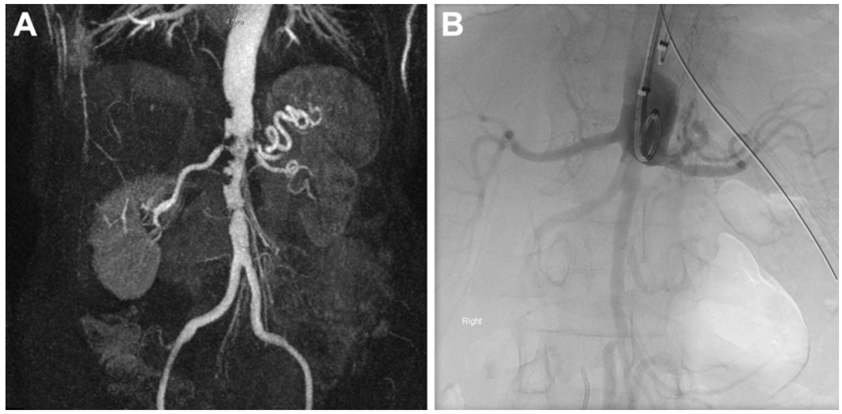

Fig 1. The two main types of juxtarenal aortic occlusive diseases. **A,** Coral reef plaques. **B,** Distal aortic thrombosis, usually caused by iliac obstruction.

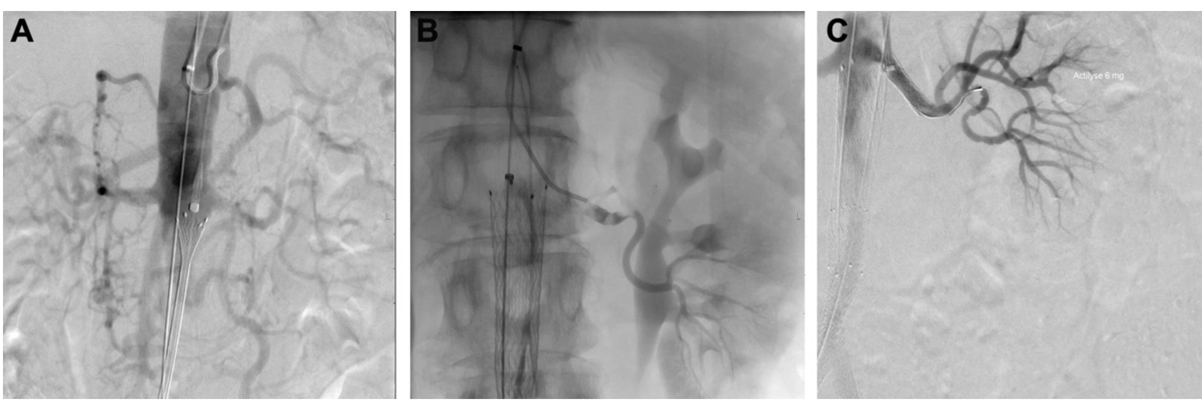

Fig 2. Stenting a juxtarenal aortic occlusion without applying the "chimney technique" carries a risk of visceral occlusion. **A,** Intraoperative angiogram during stent deployment. **B,** After stent deployment, the left renal artery is occluded by emboli. **C,** Restored renal perfusion after on-table thrombolysis and renal stenting.

gained percutaneously from a bilateral femoral and a unilateral or bilateral brachial approach. Patients were systemically administered heparin in order to achieve an activated coagulation time >250 seconds. Aortic occlusion was crossed with a 0.014-inch PT Grafix (Boston Scientific Corp, Miami, Fla) or 0.035-inch hydrophilic guidewire (Terumo Corp, Tokyo, Japan) from above in order to avoid unintentional subintimal dissection of the aortic wall at the level of the visceral arteries. The brachial wire could be snared from below if necessary. A through-and-through ("body floss") wire was thereby obtained, and a femoral sheath could be passed into the thoracic aorta.

The visceral arteries were catheterized from the right and/or left brachial approach, and the visceral (chimney) stents or stent grafts (20-40 mm long) were parked in the target vessels (Fig 3). Thereafter, the aortic stent or stent graft was introduced from a femoral approach. The visceral stents were deployed, keeping the balloons inflated to protect the visceral arteries from potential debris until the aortic stent was fully released. The visceral balloons were deflated after aortic flow had been restored, allowing any potential debris to be flushed downstream. Visceral flow was thereby temporarily obstructed for 10 to 20 minutes. The longest obstruction occurred in patients who required extensive concomitant iliac stenting in order to obtain aortic flow. Both self-expanding and balloon expandable stents were used (Table II).

The top end of the aortic stent was placed proximal to the aortic lesion but slightly distal to the upper end of the visceral stents. The visceral stents thus lie beside the aortic stent and serve as "chimney grafts" for the visceral arteries. Completion angiography was performed to verify rapid flow in the aorta and the stented visceral arteries. Vascular closure devices were used in the groins, and compression or arteriorrhaphy was applied to the brachial arteries upon withdrawal of the sheaths.

Informed consent was obtained from all patients, and the study was approved by the ethical committee of Lund University.

Table I. Clinical features of patients with endovascular repair of juxtarenal aortic occlusive disease with chimney grafts

						GFR, mL/min (1.73 m²)[b]			
Patient No.	*Age, years*	*Anatomical diagnosis*	*ASA classification*	*No. of risk factors*[a]	*Symptoms*	*Preoperative*	*Postoperative*	*1-6 years*	*Follow-up, years*
1	72	Aortic occlusion	3	2	Bilateral critical limb ischemia	22	—	—	—
2	68	Aortic and renal stenoses	3	3	RF with CHD and HT, bilateral claudication	20	29	46	2.5
3	66	Aortic and renal stenoses	3	5	Acute RF and HT, bilateral claudication	8	8	27	3
4	73	Aortic, renal, and SMA stenoses	3	4	Renovascular HT with CHD, bilateral claudication	29	28	54	1.5
5	72	Aortic occlusion	3	2	Bilateral critical limb ischemia	92	95	73	1
6	59	Aortic and renal stenoses	3	3	Renovascular HT, bilateral critical limb ischemia	71	102	67	4
7	68	Aortic, renal, and SMA stenoses	2	2	Renovascular HT, bilateral claudication	50	50	51	7
8	62	Aortic and renal stenoses	3	4	Renovascular HT, bilateral claudication	48	30	31	4.5
9	73	Aortic and SMA stenoses	3	2	Fractured SMA stent, bilateral claudication	66	56	51	1
10	68	Aortic and renal stenoses	2	2	Renovascular HT, bilateral claudication	61	57	—	0.2

ASA, American Society of Anesthesiologists; *CHD,* congestive heart disease; *HT,* hypertension; *RF,* renal failure; *SMA,* superior mesenteric artery.
[a]Risk factors: cerebrovascular disease, ischemic heart disease, CHD, HT, RF, mesenteric ischemia, chronic obstructive pulmonary disease, diabetes, previous abdominal surgery.
[b]Creatinine-based estimates of relative glomerular filtration rate (GFR; see http://www.egfr.se/eGFRen.htm).

RESULTS

Early outcome. Median operation and fluoroscopy times were 5.2 hours (range, 1.5-7.3 hours) and 1.7 hours (range, 0.6-2.3 hours), respectively. Median length of stay was 2 days (range, 1-9 days).

The use of chimney grafts was technically successful in all 10 patients. All stents were patent at final angiography. One patient died of severe uncompensated heart insufficiency and multiple organ failure on the ninth postoperative day. A sudden postoperative reduction in her vascular resistance may have been a contributory factor. Another patient developed a retroperitoneal hematoma due to an intraoperative iliac rupture. The rupture was immediately covered with a peripheral stent graft. The hematoma resolved spontaneously. No patient experienced perioperative visceral or lower limb embolization.

Follow-up data. One patient developed blue discoloration of her left fourth toe at the seventh postoperative month. Follow-up computed tomographic angiography (CTA) revealed no evident source of microembolization. The aorta, iliac arteries, both renal arteries, and superior mesenteric artery were patent without stenosis. Another patient died of lung cancer 5.5 years after the operation. At 1 to 6 years of follow-up, CTA in seven patients showed patency of the stented vessels without evident restenosis or other related complications. One patient did not undergo CTA because of renal insufficiency, although her renal function had improved after stenting. The renal function of the three patients with chronic renal impairment (patients 2, 3, and 4) had improved, with an increase in glomerular filtration rate (23-47, 9-24, 30-55 mL/min, respectively) and a reduction in antihypertensive medication.

DISCUSSION

We previously reported on the applicability of chimney grafts to preserve the renal and superior mesenteric arteries as well as the supra-aortic branches during stent graft repair of abdominal or thoracic aortic aneurysms with an inadequate proximal fixation zone.[2,13,16] Endovascular aneurysm repair is attractive because it potentially avoids the morbidity, mortality, and costs of major transabdominal surgery or thoracotomy.[16,17]

Endovascular repair of aortic occlusive disease seems equally tempting.[18,19] However, midaortic juxtarenal occlusive lesions are less suitable for stenting because stenting of this particular segment carries a risk of occluding the visceral arteries. Therefore, open repair is still widely recommended even though a significant proportion of patients have extensive cardiovascular comorbidities that render them high-risk candidates for transabdominal aortic surgery. Aortic surgery for occlusive disease in juxtarenal and suprarenal segments is particularly challenging, and few, if any, data from such patient series exist. Recent reports on less complex infrarenal procedures suggest operation time of 3.5 hours, with 10% mortality and 2-week length of hospital stay.[20,21] Our operation time was longer than that, but the patients, who were older and belonged

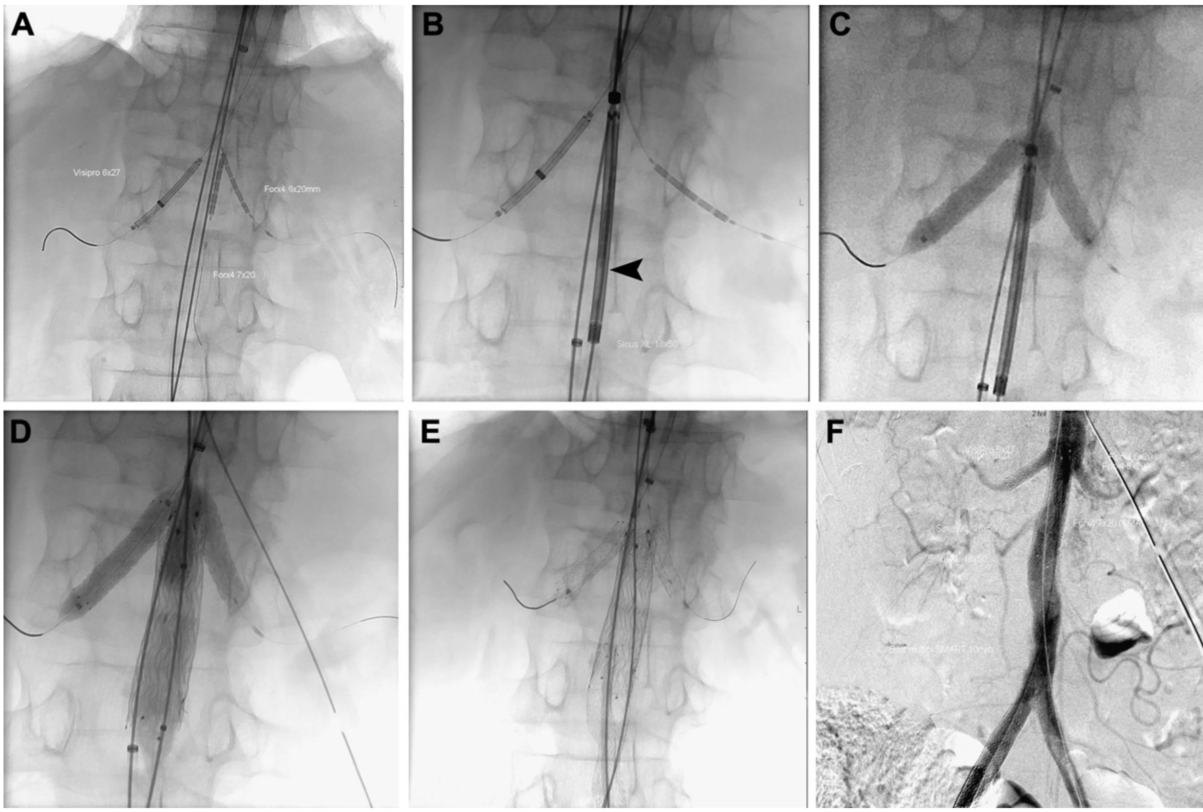

Fig 3. Intraoperative angiography of midaortic stenting with chimney technique. **A,** Undeployed stents parked in the superior mesenteric and both renal arteries from a brachial approach. **B,** Undeployed aortic stent has been added (*arrowhead*). **C,** Visceral stents have been deployed, and the balloons are kept inflated in order to protect the viscera from aortic debris until aortic flow is reestablished. **D,** The aortic stent has been deployed and is dilated while the visceral balloons are still in place. **E,** All visceral and aortic stents have been deployed. The visceral balloons were deflated after reestablishment of aortic flow. The visceral stents protrude slightly above the aortic stent. **F,** Completion angiography demonstrates patent renal, mesenteric, and aortic stents with no residual stenosis.

to a higher ASA classification, could be discharged sooner after the endovascular treatment.

An extra-anatomic "axillofemoral" reconstruction provides an alternative option but fails to improve visceral perfusion in most patients (eg, patients 2-4 and 6-10). Laparoscopic surgery of the aorta is not widely available and, to our knowledge, has not been applied in midaortic occlusive disease.

The present study evaluates the feasibility of extended use of chimney grafts for aortic occlusive diseases at the level of the visceral arteries. This technique offers several potential advantages. First, it protects the visceral arteries from emboli released during aortic stenting. Visceral embolization is prevented by occluding the visceral arteries temporarily with a balloon catheter while the aortic stent is being released. Several patients had occlusions extending into the iliac segment that required concomitant placement of kissing stents to obtain adequate iliac outflow. The visceral balloons were not deflated until completion angiography confirmed brisk aortic flow. In spite of this technique, temporary occlusion of the visceral arteries lasted only 10 to 20 minutes, which probably is shorter than that occurring during a corresponding open procedure.

Second, although Z-stents can be placed across the renal arteries safely in endovascular aneurysm repair, stents used for occlusive disease have a more dense mesh and therefore may obstruct the visceral branches.[22] Chimney stents prevent the mesh of the aortic stent from directly covering the ostium of the visceral artery, so-called overstenting.

It is feasible to perform these procedures with patients under local anesthesia. However, we selected general anesthesia for the comfort of our patients, considering a median operation time of 6 hours, puncture sites in most extremities, the need for repeated adequate breath-holding, painful high-pressure angioplasties, and occasional need for brachial arteriorrhaphy.

The choice between a balloon expandable and a self-expanding stent depends on several factors. Balloon expandable stents are rigid and are mainly used when great radial force is required. The more flexible self-expanding stent is preferred for long lesions in curved arterial

Table II. Endovascular stents/stent grafts used in 10 patients with juxtarenal aortic occlusive disease

Patient No.	*Aorta*	*Left renal chimney*	*Right renal chimney*	*Superior mesenteric artery chimney*	*Iliac stents*
1	18-mm Sinus[a]	6-mm Forx4[e]	6-mm Visipro[b]	7-mm Forx4[e]	+
2	13.5-mm Fluency[f]	7-mm Visipro[b]	7-mm Visipro[b]	8-mm Protégé[c]	+
3	14-mm Protégé[c]	7-mm Visipro[b]	6-mm Visipro[b]	0	0
4	14-mm Protégé[c]	6-mm Visipro[b]	0	8-mm Visipro[b]	0
5	18-mm Sinus[a]	6-mm Advanta[d]	0	0	+
6	8-mm Express[g]	7-mm Protégé[c]	0	0	0
7	8-mm Jostent[h]	6-mm Jostent[h]	0	7-mm Saxx[i]	0
8	14-mm Protégé[c]	6-mm Protégé[c]	6-mm Protégé[c]	8-mm Protégé[c]	+
9	16-mm Advanta[d]	6-mm Visipro[b] 6-mm Protégé[c]	6-mm Visipro[b] (not chimney)	7-mm Jomed (not chimney)	0
10	12-mm Protégé[c]	6-mm Visipro[b] 6-mm Protégé[c]	0	8-mm Protégé[c] 7-mm Visipro[b]	0

[a]Sinus, XL, self-expanding nitinol stent (Optimed, Ettlingen, Germany).
[b]Visipro, balloon expandable peripheral stent (ev3, Plymouth, Minn).
[c]Protégé, self-expanding peripheral stent (ev3).
[d]Advanta, balloon expandable stent graft (Atrium Medical Corp, Hudson, NH).
[e]Formula, balloon-expandable renal stent (Cook Inc, Bloomington, Ind).
[f]Fluency, self-expanding stent graft (Bard Corp, Karlsruhe, Germany).
[g]Express LD, balloon expandable stent (Boston Scientific Corp, Natick, Mass).
[h]Jostent, balloon expandable stent (Abbott Laboratories, Abbott Park, Ill).
[i]SAXX stent, self-expanding PX-M30 stent (C. R. Bard, Murray Hill, NJ).

segments, typically the superior mesenteric artery. The self-expanding stent may require enforcement by a balloon expandable stent to avoid compression at the ostium. Sometimes the balloon expanded stent needs to be extended distally with a softer self-expanding stent in order to avoid kinking a tortuous vessel at the end of the primary stent. Balloon expanded stents do not require predilation, whereas self-expanding stents are sometimes preferred when the stenosis is difficult to cross with a sheath.

We did not always attempt to dilate the aorta to its normal diameter (Table II). Dilation of extremely calcified lesions dislodges the coral reef plaques laterally, which may perforate the very thin adventitia (Fig 4). Aortic rupture may not be readily sealed by covered stents because of gutters along the stents between the protruding calcifications. Furthermore, these are extremely calcified and very narrow vessels in female patients. Frequently, the outflow segment also is compromised. Many such patients do not require an aortic diameter larger than 8 mm.

The body floss technique was applied in half the patients. Some aortic occlusions could not be crossed via the true lumen because the wire kept entering the subintimal space. Therefore, the wire was snared in the subintimal space, thus ensuring that the true lumen was entered immediately proximal and distal to the occluded segment. In this manner, extended dissection of the aorta beyond the visceral arteries could be avoided. There were also cases when the coral reef plaques offered such resistance that it was impossible to cross the lesion with a catheter unless the wire was stretched from both ends with the through-and-through approach. Finally, some of the visceral lesions could only be crossed upon forceful push from the brachial approach. Such push could not always be achieved unless the sheath was supported by the body floss technique.

The main drawback of chimney grafts in aneurysm repair is the risk of type I endoleak. Blood may flow along the chimney through so-called "gutters."[8,12,23] However, in occlusive disease, endoleak is not a concern unless the aorta ruptures. Covered stents were used in cases where the risk of rupture was considered high and in soft or not-yet organized lesions with a potential risk for peripheral embolization upon stenting.

Another potential problem with stenting is the risk of late restenosis or stent compression. However, we did not observe any early occlusion or restenoses at follow-up. An additional risk is iatrogenic dissection or perforation of the aorta during extensive attempts to cross the obstructed part of the aorta. We tried to minimize such risk by accessing the lesion both from above and from below whenever subintimal dissection was suspected.

Open surgery is poorly tolerated by patients such as those in this small case series. Nevertheless, for fit patients open surgery may remain the treatment of choice with proven results and long-term durability.[24]

CONCLUSIONS

The extended use of chimney grafts for juxtarenal aortic occlusive disease proved to be valuable in selected patients who were unfit for open repair. The chimney graft protects or even improves blood flow in compromised visceral branches and allows endovascular treatment of more patients. A greater number of patients and longer follow-up are required before this technique can be widely advocated.

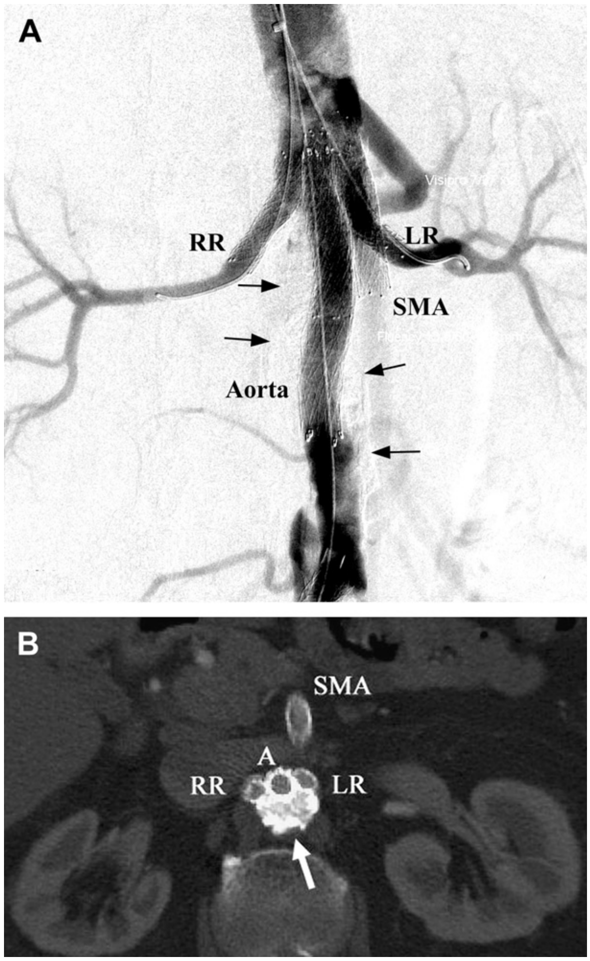

Fig 4. Patient with excessive midaortic (and iliac) calcification (*arrows*) stented with chimneys in the right (*RR*) and left renal (*LR*) and superior mesenteric arteries (*SMA*). **A**, Completion angiography. **B**, Follow-up computed tomography at 18 months. The CT demonstrates how the massive aortic plaque is pushed posteriorly by the aortic stent (*A*). The final aortic diameter of 8 mm proved sufficient for this patient, who had external iliac arteries only 5 mm in diameter (not shown).

AUTHOR CONTRIBUTIONS

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Analysis and interpretation: AB, BS, BL ND, TR, MM
Data collection: AB
Writing the article: AB, BS, BL, ND, TR, MM
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