Tips and Tricks to Facilitate Late Open Surgical Conversion after Endovascular Aortic Aneurysms Repair

Ann. Ital. Chir., 2024 95, 6: 1076–1084
https://doi.org/10.62713/aic.3487

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Endovascular repair has significantly improved the treatment of aortic aneurysms, particularly in older and high-risk patients. However, many studies have not found significant differences in long-term outcomes when comparing open and endovascular repair methods. Additionally, endovascular repair is associated with a higher rate of aortic-related reinterventions compared to open repair (OR), sometimes necessitating late open surgical conversion (LOSC).

The increasing number of endovascular aortic aneurysm repairs exposes vascular surgeons to a growing number of patients requiring late open surgical conversion (LOSC) after previous endovascular aneurysm repair (EVAR) or thoracic endovascular aortic repair (TEVAR). LOSC following endovascular procedures is associated with higher perioperative mortality and complication rates compared to primary open repair of aortic aneurysms.

This review summarizes the current knowledge, indications, possibilities, and techniques for LOSC after initial endovascular procedures. While the incidence of complications requiring LOSC remains relatively low, the number of endovascular procedures performed has increased significantly over the last decade, suggesting a rise in LOSC procedures as well.

Due to the complexity involved, LOSC procedures should be performed in high-volume centers by highly experienced vascular surgeons. This underlines the importance of educating the younger generation of vascular surgeons in both endovascular and open aortic surgery.

Keywords: aneurysm; aortic; endovascular; open; conversion

Introduction

Abdominal aortic aneurysm (AAA) usually presents as an asymptomatic disease, but the consequences of the disease are fatal, which is why open surgical and endovascular techniques have been established. The new European Society for Vascular Surgery (ESVS) guideline for AAA management recommends both open and endovascular repair of AAA—while the open surgical repair is the preferable option in patients with a long life expectancy, endovascular treatment is the first-line recommendation for patients with a reasonable life expectancy, as well as those with significant comorbidities [1]. Endovascular repair significantly improved the treatment of aortic aneurysms, especially in older and high-risk patients. However, it is not an ideal procedure. According to many studies there is no significant difference regarding mid- and long-term outcomes when comparing open and endovascular repair of aortic aneurysms [2, 3, 4]. At the same time, endovascular aortic aneurysm repair is associated with a higher aortic-related reintervention rate than open surgery [4]. Some reinterventions end up as late open surgical conversion (LOSC).

Submitted: 8 June 2024 Revised: 3 July 2024 Accepted: 22 August 2024 Published: 20 December 2024

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Indications for LOSC after Endovascular Aortic Aneurysm Repair

Reported single-center LOSC rates after endovascular aneurysm repair (EVAR) range from 0.72% to as high as 5% [5]. Different types of endoleaks were the most common indications for LOSC after endovascular aneurysm repair ten years ago [5, 6, 7]. However, in contemporary practice, endoleaks mostly do not require LOSC. In most cases, endovascular correction can be performed. Advanced devices and stent grafts, as well as new techniques such as endoanchors, chimney EVAR, and fenestrated EVAR (FEVAR), allow endovascular correction in most patients with type Ia endoleaks, which was the most important reason for LOSC after EVAR 10 years ago [5, 6, 8]. The most common treatment of type Ib endoleak consists of elongation of a stent graft limb to the external iliac artery with obstruction or preservation of the internal iliac artery on the same side [5]. Embolization with various types of embolization materials is the method of choice for the treatment of type II endoleak in contemporary practice as well [5].

The main reasons for additional open surgical treatment after EVAR in contemporary practice include stent graft col-

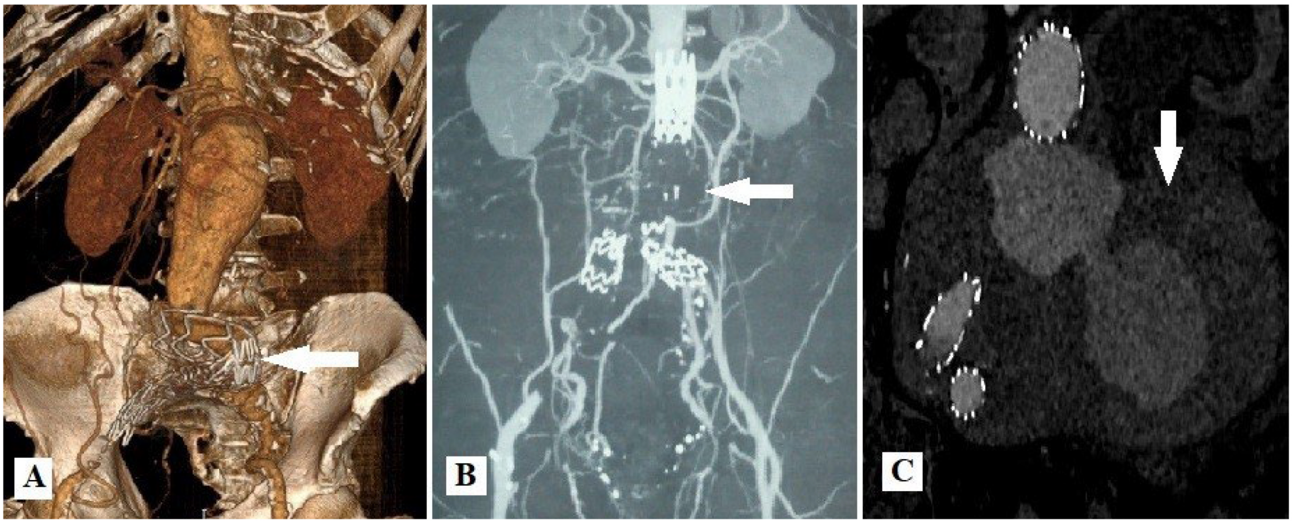

Fig. 1. Late complications after endovascular aneurysm repair (EVAR). Multidetector computed tomography (MDCT) of a patient with: (A) stent graft migration; (B) complete stent graft thrombosis; (C) late rupture of the aneurysm sac. (Source: Clinic for Vascular and Endovascular Surgery, University Clinical Center of Serbia. Informed consent was obtained from patients for usage of these materials.) Arrows pointed to stent migration (A), stent thrombosis (B) and late rupture (C).

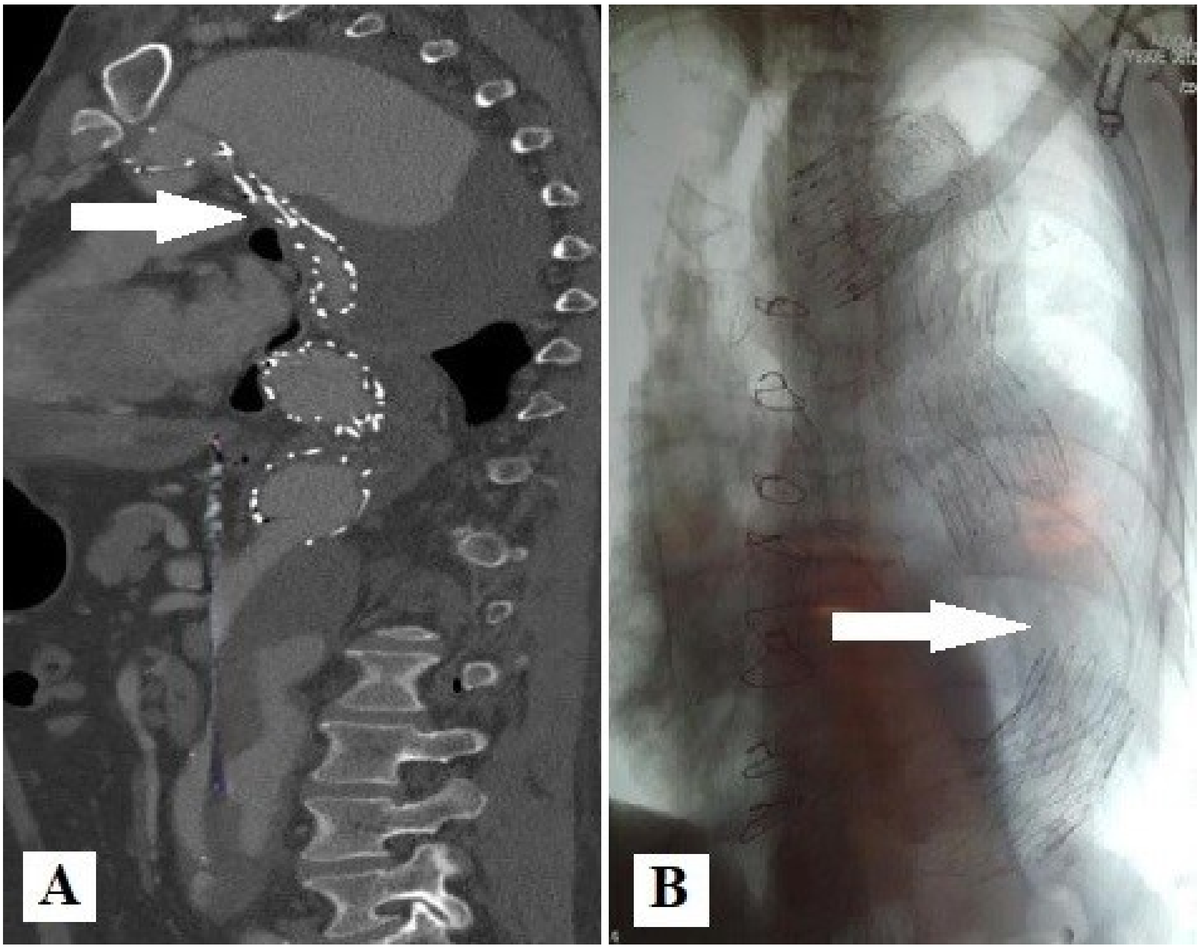

Fig. 2. Late complications after thoracic endovascular aortic repair (TEVAR). (A) MDCT of a patient with stent graft collapse; (B) Chest radiography of a patient with migration of the distal component of the stent graft. (Source: Clinic for Vascular and Endovascular Surgery, University Clinical Center of Serbia. Informed consent was obtained from patients for usage of these materials.) Arrows pointed to stent collapse (A) and stent migration on chest radiography (B).

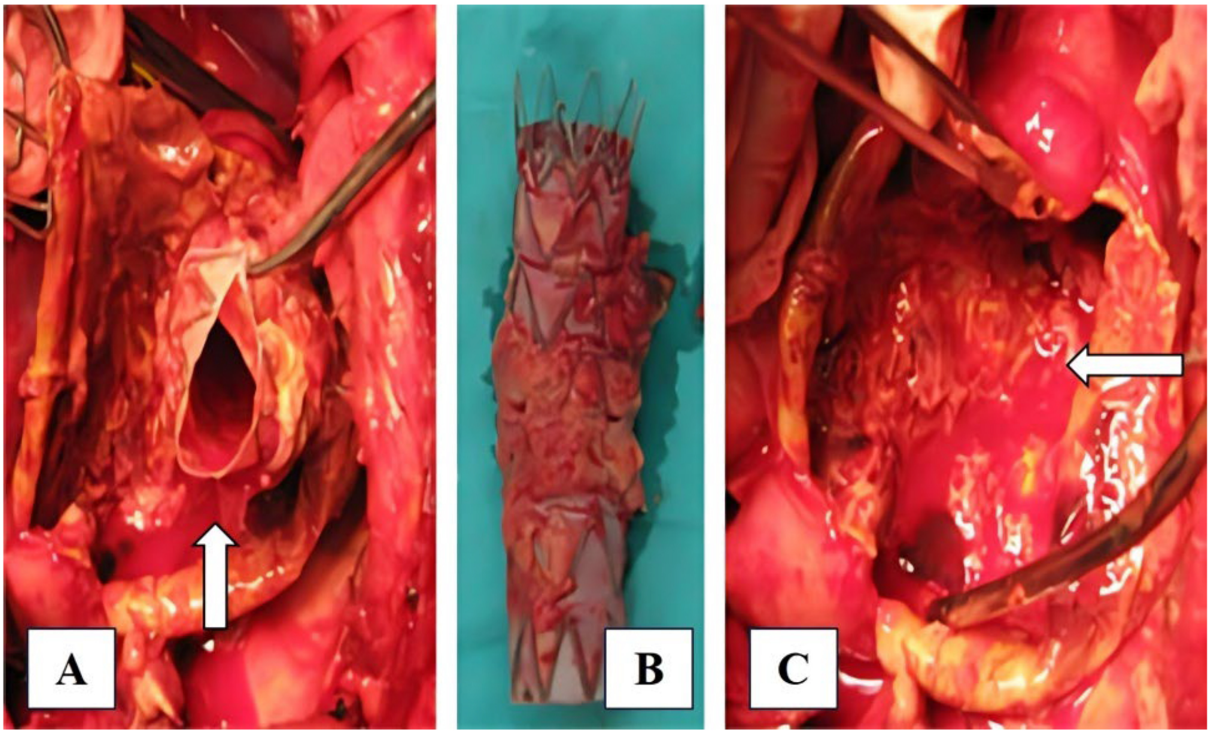

Fig. 3. Complete removal of thoracic stent graft. (A–C) Complete removal of thoracic stent graft. (Courtesy of Lazar Davidovic; Source: Clinic for Vascular and Endovascular Surgery, University Clinical Center of Serbia. Informed consent was obtained from patients for usage of these materials.) Arrow (A): Stent-graft; Arrow (C): Aneurysmal sac following the extraction of stent-graft.

lapse, migration, infection, complete stent graft thrombosis, some forms of late aneurysm sac rupture, as well as secondary aorto-duodenal fistula [5]. (Fig. 1).

The incidence of LOSC after thoracic endovascular aortic repair (TEVAR) is higher than previously thought, as observed even in very experienced endovascular centers [8, 9, 10]. Major long-term complications after TEVAR that require LOSC include endoleak type I, stent graft collapse, migration, and infection, as well as distal aneurysm formation, secondary aorto-esophageal fistula (AEF), and aorto-pulmonary fistulas (APF) [8, 9, 10, 11, 12, 13] (Fig. 2). In addition to LOSC, the treatment of endoleak type Ia after TEVAR includes various other options. One option is an additional endovascular procedure using the chimney technique or newly designed stent grafts, allowing extension of the proximal landing zone to potentially even zone 0 of the aortic arch [13]. Other options include hybrid procedures with supra-aortic debranching, which might ensure stent graft deployment to zones 1 and 2 according to the Ishimaru classification [12]. An increasingly common late complication is the so-called distal aneurysm formation after endovascular treatment of acute type B dissections [13]. It is a consequence of incomplete aortic remodeling of the non-covered segment of the dissected aorta. In some cases, distal aneurysm formation after endovascular repair of type B aortic dissection can be treated with an additional endovascular procedure. However, in other cases open repair (OR) is necessary.

An infection of aortic stent grafts is of great clinical importance due to the catastrophic consequences, despite its low overall incidence (about 1%) [14]. Infection of abdominal aortic stent grafts, including secondary aorto-duodenal fistula (ADF), is a common indication for LOSC after EVAR [15]. Moreover, infection of thoracic aortic stent grafts, including AEF and APF, is an even more common indication for LOSC after TEVAR [8, 9, 11, 12].

Tips and Tricks during LOSC after Endovascular Aortic Aneurysm Repair

The main technical considerations during LOSC after endovascular aneurysm repair include the choice of the surgical approach, the level of the aortic cross-clamping (ACC), the procedure with the stent graft, new aortic reconstruction, as well as adjunct procedures [5, 16].

Surgical Approach

In most cases, LOSC after EVAR can be performed using a standard midline laparotomy incision [5, 6]. LOSC after TEVAR typically requires a left posterolateral thoracotomy through the fourth or fifth intercostal space [8, 9, 11].

Aortic Cross-Clamping

The dissected part of the thoracic aorta should be avoided during LOSC after TEVAR due to periaortic inflammation, pleural adhesions, and even potential hematoma [13].

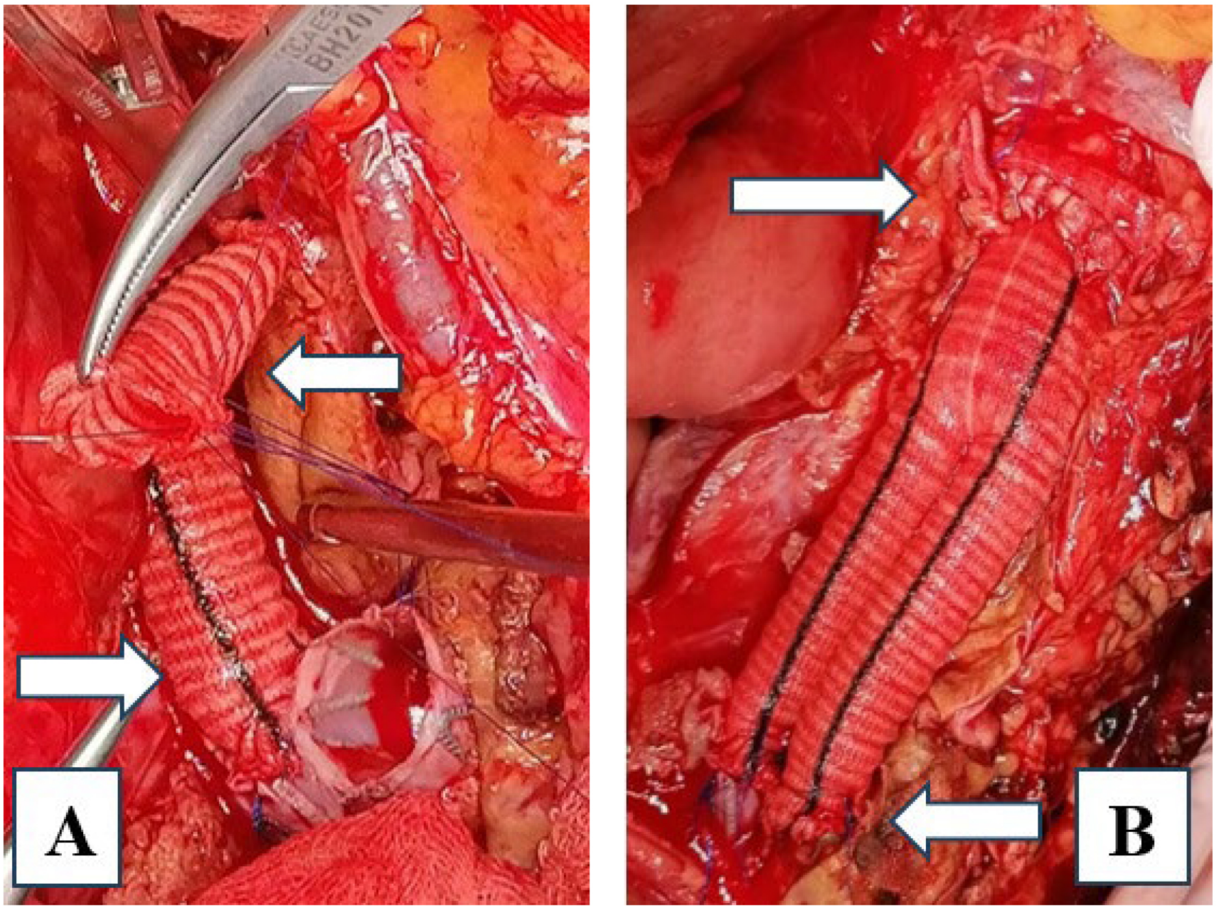

Fig. 4. Partial preservation of the abdominal stent graft. (A,B) Creation of the anastomosis between the Dacron graft and the preserved stent graft limbs. (Courtesy of Lazar Davidovic; Source: Clinic for Vascular and Endovascular Surgery, University Clinical Center of Serbia. Informed consent was obtained from patients for usage of these materials.) Arrows pointed to the place of anastomoses of synthetic (Dacron) graft and stent graft limbs.

Therefore, proximal bleeding control typically requires ACC between the left subclavian and left carotid artery [13]. Depending on the proximal landing zone length of the previously implanted stent graft, ACC can be performed even more proximally. Distal control of bleeding is usually achieved by clamping aorta at the level of diaphragm [13]. Segmental-sequential ACC, which allows retrograde perfusion of the spinal cord during proximal anastomosis creation, cannot be established under these conditions, increasing the risk of spinal cord ischemia (SCI) [13]. ACC proximal to the left common carotid artery also raises the need for cerebral protection, including even deep hypothermic circulatory arrest (DHCA), further raising intraprocedural risks [10].

LOSC after EVAR can be performed under infrarenal, suprarenal, or supraceliac ACC. A complete removal of stent graft with active suprarenal fixation requires primarily suprarenal or supraceliac ACC [5, 6, 7]. The distal bleeding control can be achieved by putting balloon occlusive catheters into both common iliac arteries after the opening of the aneurysm sac.

Procedure with Stent Graft

The procedure with the stent graft during LOSC after endovascular aneurysm repair includes its removal, partial, or complete preservation. The majority of authors recommend complete stent graft removal in cases of collapse, migration, and infection [1, 5, 10, 13] (Fig. 3).

The removal of a stent graft with active proximal fixation may be followed by severe aortic wall injury, increasing perioperative mortality and morbidity [6, 8]. Partial or complete preservation of the stent graft, which reduces perioperative morbidity and mortality, is recommended whenever possible [5, 13] (Fig. 4). Preservation of the aortic stent graft presents two new technical challenges: proximal bleeding control and creation of proximal anastomosis between the preserved stent graft and the new graft [10, 13]. Proximal bleeding control can be achieved by cross-clamping the main body or limbs of the stent graft, which often requires clamp placement over the aneurysmal sac. Direct clamping of the stent graft often causes damage and may lead to perforation, resulting in serious bleeding [5, 13]. To prevent bleeding, the proximal segment of the anas-

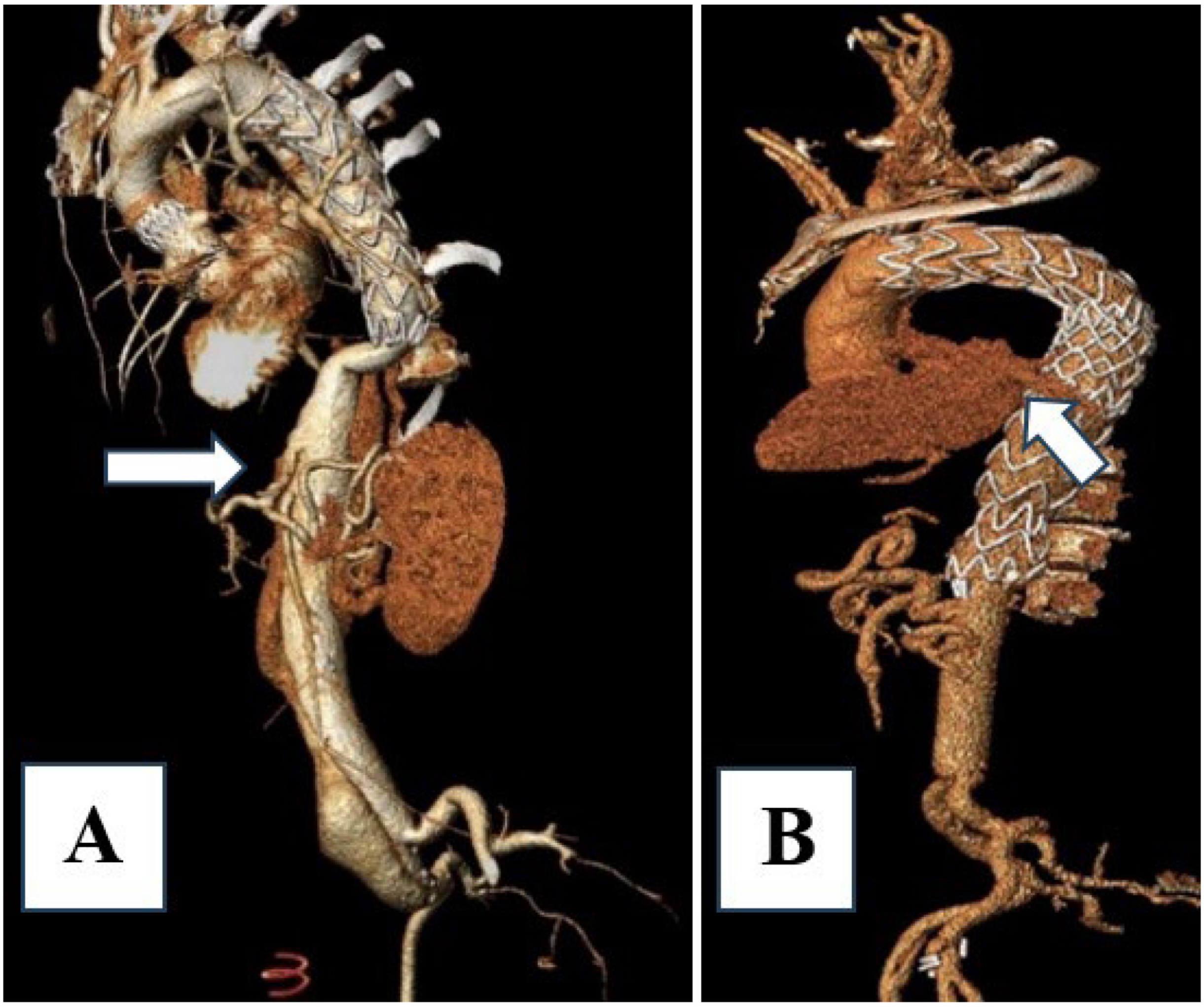

Fig. 5. Patined with distal aneurysm after endovascular treatment of type B aortic dissection. (A) MDCT of a patient with distal aneurysm formation a few years after endovascular treatment of type B aortic dissection. (B) MDCT of the same patient after open repair of the aneurysm. The procedure included Dacron graft replacement, along with reattachment of visceral arteries. The arrow shows the anastomosis between the preserved stent graft and the Dacron graft—the mismatch between them is evident. (Courtesy of Lazar Davidovic; Source: Clinic for Vascular and Endovascular Surgery, University Clinical Center of Serbia. Informed consent was obtained from patients for usage of these materials.)

tomosis between the preserved stent graft and the new graft should contain three layers: the stent graft itself, pledgets, and the aneurysm wall [10, 12]. The Padua group has described this as the infrarenal "neo-neck" technique [17].

Finally, a mismatch between the preserved stent graft and the new graft also complicates the creation of an anastomosis between them. Such mismatches are especially common in cases of LOSC after TEVAR [11, 13]. Thoracic stent grafts typically have diameters ranging from 30 to 38 mm, whereas the diameter of a thoracic graft used in open surgery typically ranges between 22 and 24 mm (Fig. 5).

New Aortic Reconstruction

The new aortic reconstruction during LOSC includes the use of standard grafts for open aortic surgery. However, treating aortic stent graft infection presents another challenge: reconstructing the aorta after removing an infected stent graft. One option is *in-situ* reconstruction using antibiotic-soaked Dacron graft or various biological grafts (such as a self-made graft from the superficial femoral vein, cryopreserved allograft, or a self-made graft from bovine pericardium) [16]. According to some studies, prosthetic graft replacement is associated with higher reinfection rates, graft-related complications, and decreased survival. Therefore, after complete removal of an infected aortic stent graft, *in-situ* reconstruction with biological graft material should be considered the preferred repair modality [1] (Fig. 6). In any case, new *in-situ* aortic reconstruction requires omentoplasty to reduce the risk of early and long-term reinfection [5, 13, 16].

Another option for aortic reconstruction after removal of an infected aortic stent graft includes extra-anatomic recon-

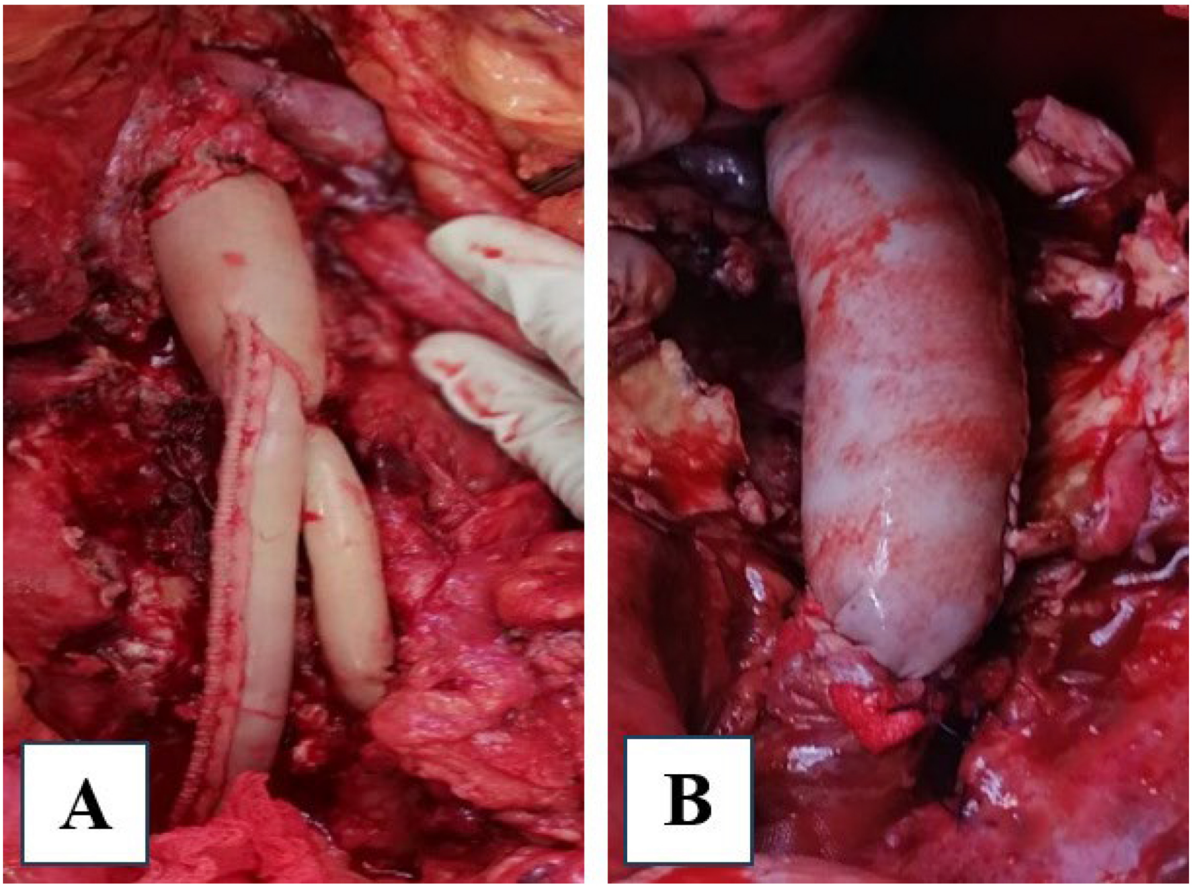

Fig. 6. New aortic reconstruction with a self-made graft using bovine pericardium after explantation of the infected graft. (A) Abdominal stent graft; (B) Thoracic stent graft. (Courtesy of Lazar Davidovic; Source: Clinic for Vascular and Endovascular Surgery, University Clinical Center of Serbia. Informed consent was obtained from patients for usage of these materials.)

struction. This procedure may be considered in frail patients, cases with extensive infections, and cases of secondary graft-enteric fistula [1]. In cases where patients have abdominal stent graft infection, the first step is axillo-bifemoral bypass, followed by laparotomy. The infected aortic stent graft is removed, and the infrarenal aorta and both iliac arteries are sutured (Fig. 7). This procedure is expected to yield better early and long-term results compared to other treatment options. However, study has not found significant differences regarding long-term survival between *in-situ* and extra-anatomic procedures for treating abdominal aortic stent graft infection [17].

An extra-anatomic reconstruction can also be used for the treatment of thoracic stent graft infection. In some cases, this procedure can be performed without ACC, cardiopulmonary bypass, or hypothermic cardiac arrest. During the initial stage of this procedure, the patient undergoes an ascending-to-descending thoracic aortic bypass through a sternotomy approach. The second step, during the same hospitalization, involves stent graft removal through a left thoracotomy [18].

Adjunct Procedures

A specific challenge during LOSC after TEVAR involves managing the intercostal arteries, which are often occluded by thrombus that has developed after stent graft implantation. In cases of thoracic stent graft infection, these arteries may lie within an infected area, making reattachment impossible or potentially dangerous due to infection. The inability to establish segmental-sequential ACC, combined with the challenge of reattaching significant intercostal arteries, increases the risk of SCI compared to primary OR of descending thoracic aneurysm [12]. In cases of secondary ADF, AEF and APF, complex and risky vascular procedures should be complemented with additional highly complex and challenging non-vascular procedures [13, 19, 20]. According to the European registry of endovascular aortic repair complications, the best results are accomplished with maximal radical therapy for secondary aortic fistulas [21].

Results

LOSC after endovascular aneurysm repair is a more severe and risky procedure compared to primary OR of descending thoracic aneurysms and AAAs for several reasons. Firstly, LOSC after EVAR often requires supraceliac or suprarenal

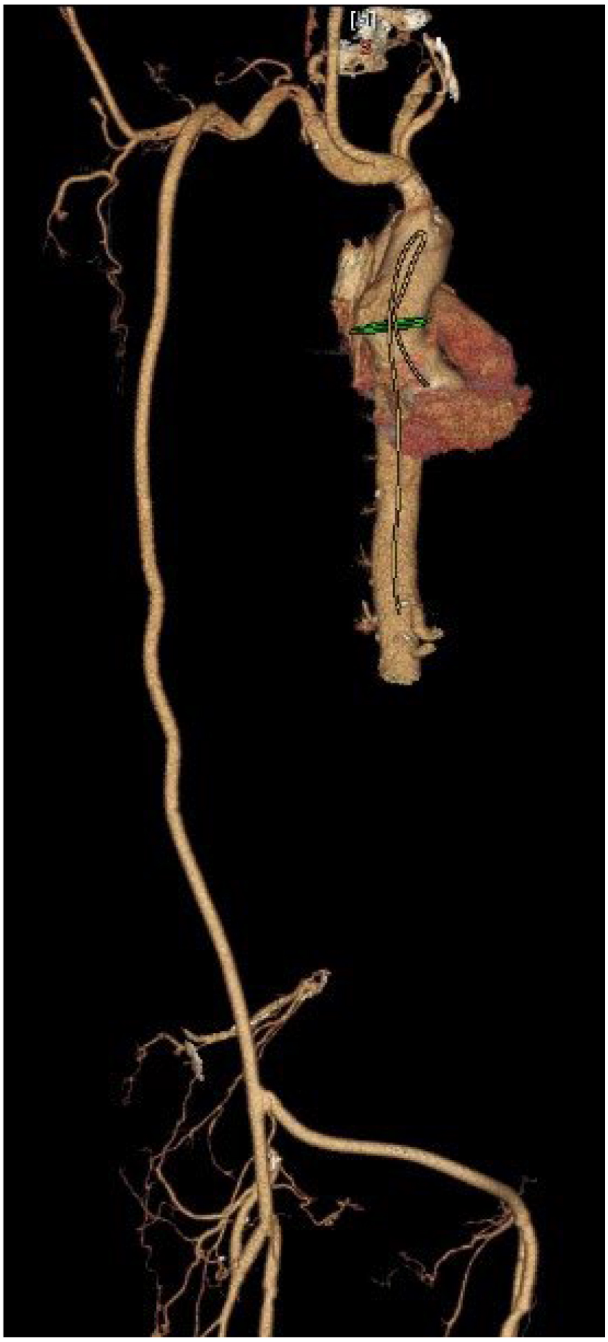

Fig. 7. Treatment of the infected aortic stent graft by using an extra-anatomical axillo-bifemoral reconstruction—postoperative control MDCT angiography. (Courtesy of Lazar Davidovic; Source: Clinic for Vascular and Endovascular Surgery, University Clinical Center of Serbia. Informed consent was obtained from patients for usage of these materials.)

ACC and aortic replacement with a bifurcated prosthesis. Severe bleeding accompanies this sort of procedure, as well as an increased need for red blood cell transfusion. The duration of LOSC is longer compared to primary OR of AAA, and there is a higher percentage of concomitant surgical procedures [5].

Analyzing the literature, the total mortality rate after one month in patients undergoing LOSC after EVAR ranged from 0% to as high as 67% [5, 17]. Many authors reported a significantly higher mortality rate in the urgent treatment group compared to elective cases. In a series of 30 patients who underwent LOSC after TEVAR, Melissano *et al.* [11] reported a perioperative mortality rate of 16.6%. They also noted the highest mortality rate in the subgroup of patients with stent graft infection or fistulization (20%) [11].

The challenging preparation of the descending thoracic aorta, the lack of ability to establish segmental-sequential ACC, difficulties in reattaching significant intercostal arteries, prolonged procedure duration, higher blood loss, and sometimes the need for cerebral protection contribute to increased perioperative mortality, paraplegia rates, and other severe complications in patients treated with LOSC after TEVAR [13].

Additionally, performing additional complex non-vascular procedures in cases of secondary AEF also increases perioperative mortality and morbidity [11, 13].

Due to these reasons, perioperative mortality and morbidity in patients undergoing LOSC after endovascular aneurysm repair are significantly higher compared to patients undergoing primary OR for descending thoracic aneurysms and AAAs.

Conclusions

Despite the advancements in endovascular devices, stent grafts, improved surgical skills, and techniques, late open surgical reintervention after EVAR or TEVAR remains an essential procedure. With the increasing number of endovascular aortic interventions performed, the incidence of complications necessitating LOSC is expected to rise. LOSC after endovascular aneurysm repair is inherently more complex and risky compared to primary open repair (OR) for aneurysmal disease.

It is crucial that LOSC procedures after endovascular aneurysm repair are conducted in high-volume centers by highly skilled vascular surgeons. Therefore, educating the younger generation of vascular surgeons in both endovascular and open aortic surgery is imperative to ensure optimal patient outcomes.

Availability of Data and Materials

Not applicable.

Author Contributions

Conception and design: LD, SD, AR; Analysis and interpretation: AR, DM, OK; Data collection: SD, AR, DM, OK; Writing the article: LD, SD, AR, DM, OK. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

Not applicable.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

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