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Treatment of Aortoiliac Occlusive Lesions by Aortic Robotic Surgery: Learning Curve and Midterm Outcome

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Background: The learning curve and midterm results of aortoiliac occlusive disease (AIOD) revascularization by robot-assisted laparoscopic (RAL) surgery may be known.

Methods: A prospective single-center study was conducted in the vascular surgery department of Georges Pompidou European Hospital (Paris, France). Patients with AIOD treated by RAL from February 2014 to February 2019 were included. Demographic characteristics, past medical history, Trans-Atlantic Inter-Society Consensus (TASC) lesions classifications, mortality, primary and secondary patency, as well as complication rates were collected. Safety was analyzed by the cumulative sum control chart method with a conversion rate of 10%, operative time by cumulative average-time model, and primary and secondary patency by the Kaplan-Meier method.

Results: Seventy patients were included, 18 (25.7%) with TASC C lesions and 52 (74.3%) with TASC D lesions. Before discharge, 14 (24.3%) patients had surgical complications. Among them, 10 (14.3%) required at least one reintervention. One (1.4%) patient died during the hospitalization. The learning curve in terms of safety (conversion rate) was 13 cases with an operating time of 220 minutes after 35 patients. During follow-up (median 37 months [21; 49]), 63 patients (91.3%) improved their symptoms, 53 (76.8%) became asymptomatic, and 3 graft limb occlusions occurred. The primary patency at 12, 24, 36, and 48 months was 94%, 92%, 92%, and 92%, respectively, while the secondary patency for the same intervals was 100%, 98.1%, 98.1%, and 98.1%, respectively.

Conclusions: Robotic surgery in AIOD revascularization seems safe and effective; allowing to treat patients with few comorbidities and severe lesions, in a dedicated center experienced in RAL, with excellent patency. Prospective clinical trials should be performed to confirm safety.

INTRODUCTION

Management of aortoiliac occlusive diseases (AIODs) has to compromise between different therapeutic options and the patient's conditions.^{1,2} Endovascular therapy gives good long-term patency with a low risk of complications for short stenosis/occlusion³ but in extensive lesions, if endovascular

therapy may be an option, it is not free of perioperative risk and long-term occlusion. In case of complex aortoiliac lesions, aortobifemoral (ABF) bypass is still considered the gold standard to treat AIOD disease for fit patients.² ABF bypass is mainly performed by open surgery but small number of trained teams⁴ carry out this intervention in laparoscopy. Early benefits arose essentially from a faster

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intestinal recovery of normal bowel function resulting in a shorter hospital stay, and less abdominal wall complications.⁵ The main constraint to the development of this technique was the learning curve that requires extensive training to deal with the absence of flexibility of laparoscopic instruments and 2 dimension vision.

Our institution (Georges Pompidou's European Hospital, Assistance publique—Hôpitaux de Paris, Paris, France) is a regional center of reference for aortic diseases. Surgical strategies for aortic diseases are adapted to the patient's condition according to international recommendations,^{1,2} and minimally invasive therapy is privileged whenever possible. Aortic procedures are routinely performed in open or endovascular surgery, whereas laparoscopy was performed anecdotally in a few selected cases before the acquisition of a robotic surgery system. As robot-assisted laparoscopic (RAL) infrarenal aortic surgery has been reported in the literature with good early results using a transperitoneal direct approach.⁶ Since our institution was equipped with the DaVinci Si (Intuitive Surgical®, Sunnyvale, CA, USA) robotic system, we decided to begin a robotic aortic program overseen by 2 senior surgeons to treat AIODs with a transperitoneal retrocolic approach. As with laparoscopy, RAL does not have a European conformity (CE) marking for vascular surgery even if they are used in several hospitals.

The aim of our prospective study was to assess the feasibility (learning curve), safety, and midterm outcomes of robotic surgery aortofemoral bypasses.

METHOD

From February 2014 to February 2019, we conducted a prospective study in our center. Preoperative, operative, and postoperative data were collected. All patients gave informed consent before the procedure, our institutional review board approved the protocol and the study was performed according to the principles of the Declaration of Helsinki.

Population

Robotic surgery was offered to all patients with AIOD Trans-Atlantic Inter-Society Consensus (TASC) C and D¹ eligible to an aortounifemoral (AUI) or ABF bypass with no contraindication for laparoscopic procedure and deemed anatomically suitable for laparoscopic procedure by the senior surgeon in charge. Severe pulmonary, cardiac, or hepatic and host abdomen (peritonitis, pancreatitis, or multiple gastrointestinal resection) were considered as contraindications for laparoscopy.

Arterial lesions were evaluated on a preoperative computed tomography (CT) angiogram.

Robotic Aortic Surgery Technique

Under general anesthesia, a venous central catheter, arterial line, and nasogastric tube were set up. Aortofemoral RAL reconstructions were provided using the SI or Xi Da Vinci surgical system (Intuitive, Sunnyvale, California, USA).

Operating room disposition and patient position.

The patient was placed in a dorsal decubitus position with an inflatable pillow (Pelvic-Tilt™, O.R. Comfort, LLC, Glen Ridge, New Jersey) placed behind his left flank.

The Da Vinci robotic patient's cart was placed on the left side of the patient.

The main operator faced the robotic console, the first assistant surgeon standing in front of the patient's cart and the second assistant was placed on the right side of the first assistant surgeon (Fig. 1A).

Femoral bifurcation approach. A bilateral longitudinal or transverse approach of the femoral artery bifurcation was performed, and then sealed by adhesive incise drapes to prevent any pneumoperitoneum leaking.

Abdominal time. A video showing the main steps is available in the web supplementary (Video 1).

Pneumoperitoneum and trocar disposition. A pneumoperitoneum was insufflated up to 14 mm Hg through a Veress needle below the costal margin. A 5 mm-12 mm trocar was introduced for the camera on the left flank region (trocar 1, Fig. 1B). A first visual evaluation of the abdominal cavity was performed using a 30° camera to ensure safety and feasibility of a robotic approach.

The patient was then placed in the complete right lateral decubitus position, using the operating table tilt feature and the inflatable pillow, with the left arm lying on the right arm.

Six other trocars were introduced under camera supervision as shown in Figure 1B.

AirSeal® (SurgiQuest Inc., Milford, Connecticut, USA) was used to keep the intra-abdominal pressure constant during the whole procedure. An active suction/irrigation device was used (StrykeFlow II®, Stryker, Kalamazoo, Michigan, USA) and connected to a cell-saver system.

Aortic and iliac arteries approach. The transperitoneal left retrocolic retrorenal approach was mainly used to expose the left side of the aortoiliac axis. A surgical retractor was used (Endoretract®, Medtronic, Dublin, Ireland) to maintain a stable exposure.

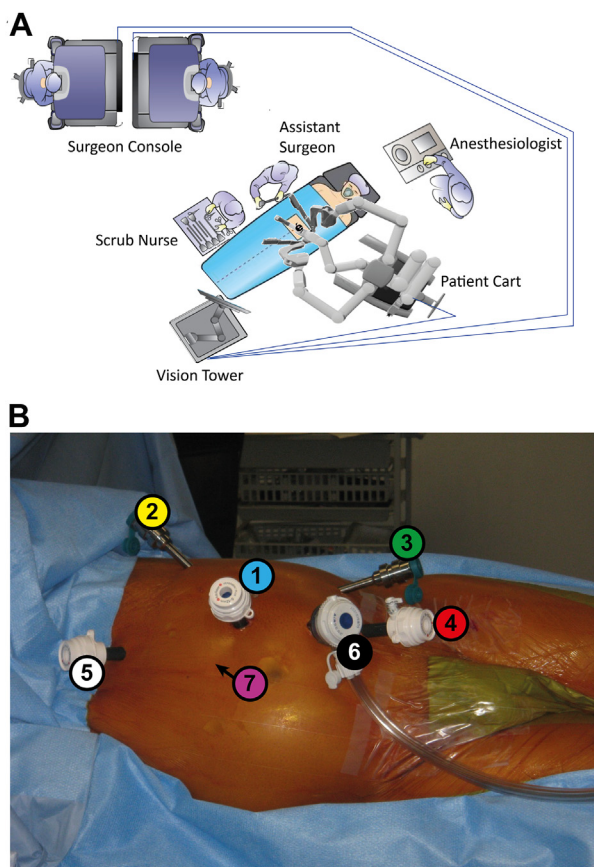


Fig. 1. Arrangement of the DA VINCI® robot modules and the medical teams in the operating room (A) and position of trocars (B) during aortofemoral bypass revascularization by robot-assisted laparoscopic (RAL) surgery. 1, camera trocar (diameter 5–12 mm); 2, robotic trocar 1 (diameter 8 mm); 3, robotic trocar 2 (diameter 8 mm); 4, distal clamp trocar (diameter 5–12 mm); 5, proximal clamp trocar (diameter 5–12 mm); 6, assistant trocar 1 (AirSeal® diameter 12 mm); 7, assistant trocar 2 (diameter 5–12 mm).

The renal-azygos-lumbar venous trunk was then sectioned to access the infrarenal aortic segment. Whenever possible, lumbar arteries were clipped. Alternatively, a prerenal approach could have been preferred.

Placement of the graft and tunneling. A conventional knitted polyester (LeMaitre Vascular®, Burlington, Massachusetts, USA) or polytetrafluoroethylene (PTFE) (Gore-Tex®, W.L. Gore & Associates, Newark, Delaware, USA) vascular prosthesis was introduced to the abdominal cavity through the left groin. Both graft limbs were ligated before insertion of the graft through the left groin in the abdomen, leaving the left limb at the level of the groin. Then, the graft is placed in front of the aorta

and the right limb is tunneled to the right groin using a long DeBakey aortic vascular clamp and under video camera supervision.

Aortic clamping and proximal anastomosis. A bolus of 5,000 UI of IV heparin was administered. The proximal and the distal clamps were inserted through the “trocar 4” and the “trocar 5”, respectively (Fig. 1B). The aorta was cross clamped below the renal arteries.

In case of proximal side-to-end anastomosis, the distal clamp was positioned in a way to clamp the inferior mesenteric and lumbar arteries. For end-to-end proximal anastomosis, the inferior mesenteric artery was clipped and common iliac arteries were both occluded using either a green stapling device (EndoGIA®, Medtronic®, Minneapolis, Minnesota) or a running PTFE suture (CV3®, W.L. Gore & Associates, Newark, Delaware, USA). A longitudinal aortotomy or a transection was performed by monopolar curved scissors (EndoWrist®, Intuitive Surgical Inc., Sunnyvale, California, USA). If required, an endarterectomy of the anastomosis chamber was completed with robotic needle holders (Intuitive Surgical Inc., Sunnyvale, California, USA).

A PTFE running suture secured with a 3 mm-large PTFE soft tissue patch (Gore-Tex, W.L. Gore & Associates, Newark, Delaware, USA) was used for the anastomosis. The graft was filled with heparinized saline from the left limb before releasing the clamps. If additional stitches were required, a PTFE wire was used. To reinforce the anastomosis, when the wall of the aorta seemed fragile, a PTFE felt was sewed with the aortic wall and the graft.

The robotic instruments were then removed as well as the patient’s cart. The left kidney and the left colon were put back in their anatomic position under video camera control, while the patient was repositioned in a supine position.

Optional minilaparotomy. An additional minilaparotomy could be performed when an additional intervention was planned at the same time (e.g.: nephrectomy) or for a suprarenal cross clamping.

Femoral distal anastomosis. According to the disease extension, a femoral endarterectomy was performed. The distal anastomosis location was either the common femoral artery or the profunda femoral artery when required. For ABF bypass, the femoral anastomosis was performed simultaneously.

In-Hospital Follow-Up

Fast-tracking postoperative care was encouraged: removal of the nasogastric tube in the recovery

room, meal on the evening of the operation, and standing in the evening or morning after the operation.

Follow-Up

During follow-up, patients were clinically and hemodynamically evaluated with an ultrasound after 1 month, 6 months, and yearly after. An additional CT scan was performed in case of any abnormal findings.

Data Collection

Demographic data, Fontaine stage,⁷ TASC classification,¹ operative times, length of hospitalization, surgical and systemic complications,⁸ reinterventions, primary and secondary patency were collected. The different operating times are defined in the "Supplementary Methods."

Systemic complications have been classified according as recommended by the Society for Vascular Surgery.^{8,9}

All data were prospectively obtained and evaluated according to the intention-to-treat principle and were collected with REDCap® (Vanderbilt University, Nashville, Tennessee, USA).¹⁰

Statistical Analysis

Analysis was performed with *R version* 4.2.0 (R Development Core Team, University of Auckland, Auckland, New Zealand),¹¹ mean and standard deviation (SD) values or proportion are given.

Categorical variables were expressed as proportions, continuous variables with normal distribution were presented as mean (SD) and non-normal variables were reported as median (interquartile range [IQR]). The learning curves of continuous data were analyzed according to the cumulative average-time model those of binary data according to the cumulative sum control chart method¹² (See Supplementary Methods"). Kaplan-Meier curves were used for patency of aortofemoral reconstructions.

RESULTS

Patients

From February 2014 to February 2019, 70 patients underwent aortoiliac revascularizations by RAL in our vascular surgery department. During the same period, we performed 102 ABF open procedures, 14 unifemoral open procedures, and 331 aortoiliac endovascular revascularizations.

The mean age was 57.8 ± 9.3 years (80.0% male). Demographic data and past medical history are summarized in Table I.

Sixty patients (85.7%) had stage IIB lesions (Fontaine classification), and fifty-two (74.3%) patient's lesions were classified as TASC D. Previous endovascular revascularization was performed in 31.4% ($n = 24$) from which 70.8% ($n = 17$) was common iliac artery stenting. In 7 patients (10.0%), AIOD was associated with an abdominal aortic aneurysm (AAA).

Procedures

The intervention consisted, via a retrorenal approach (87.1%), in performing ABF bypass (97.1%) in a polyester prosthesis (92.2%) anastomosed laterally (78.6%) [Table II]. Only 2 patients (2.9%) underwent a planned preoperative minilaparotomy, one patient for a left nephrectomy and one patient for whom suprarenal clamping was planned. Three other patients underwent a conversion during the procedure:

- One patient was converted to open for lack of exposure (Patient N° 22).
- Two patients (2.9%) were converted to open for bleeding (Patient N° 66 & 68) including a spleen wound requiring splenectomy.

Fifty-one patients (72.9%) underwent an associated aortic endarterectomy, and 14 (20.0%) underwent a femoral endarterectomy. The average total duration of the operation was 218.7 (± 41.1) min with a clamping time of 52.4 (± 13.3) min.

Learning Curve

According to the cumulative sum control chart learning curve model, 13 procedures were requested to reach an acceptable conversion rate (10%) (Fig. 2A). Furthermore, after 35 procedures, cumulative average operating time was 220 min (Fig. 2B1). After 45 procedures, cumulative average aortic cross clamping time was 52 min (Fig. 2B2).

Intrahospital Follow-Up

The median postoperative hospital stay was 7 days [6; 9], the mean time to nasogastric tube withdrawal was 0.59 (± 0.97) days and the resumption of transit at 2.24 (± 1.10) days. Intensive care unit admission was requested for 9 patients (12.9%) during a median of 4 [2; 12] days. Intrahospital postoperative complications occurred in 14 patients, including 10

Table I. Baseline characteristics of 70 patients with aortoiliac occlusive disease treated by robot-assisted laparoscopic surgery

Variables	n (%) or mean (\pm SD)
Age (years)	57.8 (\pm 9.3)
Male	56 (80.0)
BMI \geq 30 (Kg/m ²)	6 (8.6)
Active smoker or cessation <10 years	58 (82.0)
Hypertension	37 (52.9)
Diabetes	19 (27.1)
CAD	29 (41.4)
COPD	9 (12.9)
CKD under hemodialysis	1 (1.4)
Antiplatelet therapy	47 (67.1)
Anticoagulant therapy	4 (5.7)
ASA score	
ASA 2	42 (60.0)
ASA 3	27 (38.6)
ASA 4	1 (1.4)
Fontaine stage	
Stage IIA	4 (5.7)
Stage IIB	60 (85.7)
Stage III	2 (2.9)
Stage IV	4 (5.7)
TASC classification	
TASC C	18 (25.7)
TASC D	52 (74.3)
Previous arterial revascularization	
Aortoiliac stenting	22 (31.4)
Aortic stenting	3 (4.3)
Common iliac artery stenting	17 (24.3)
External iliac artery	6 (8.6)
Femoral endarterectomy	6 (8.6)

BMI, body mass index; CAD, coronary artery disease; CKD, chronic kidney disease.

patients requiring at least one reoperation [Supplementary Table S1].

In-hospital systemic complications [Supplementary Table S2] included acute coronary syndrome in one patient (1.4%), and acute renal failure in 12 patients (17.1%) with one temporary renal replacement therapy.

Three patients subsequently developed colonic ischemia (4.3%), including one medically treated (1.4%).

During hospital stay, one patient died. He was a 72-year-old male (1.4%, patient N° 6) [Supplementary Table S1] with multiple comorbidities: chronic ischemic heart disease, hypertension,

chronic obstructive pulmonary disease (COPD) with centro-lobular emphysema, previous acute pancreatitis, active smoking, and aortoiliac lesions TASC D. He presented a retroperitoneal hematoma on postoperative day 1, requiring a surgical drainage. On day 2 he was diagnosed with ileal and colonic ischemia and underwent a first ileal and right colonic resection and then on day 13, a left colectomy. He died of septic shock in intensive care on day 51. The in-hospital mortality was 1 (1.4%) patient.

Two other patients had particularly complicated postoperative outcomes [Supplementary Table S1]:

Patient N° 19, 50 years old, who underwent an ABF bypass for TASC D lesions, required a graft replacement (allograft) on day 6 for early infection and peritonitis due to a left colonic injury. The allograft bypass was removed and replaced by an axillo-bifemoral bypass on day 41 for secondary septic rupture.

Patient N° 27, 68 years old, with a history of a tobacco intoxication of 100 pack-years, COPD, aortoiliac lesions TASC D and a Fontaine stage IV PAD with dorsal necrosis of the right foot and bare extensor tendons. He underwent an ABF with a right femoropopliteal bypass. A few hours after surgery, he occluded the left limb of the graft treated with a thrombectomy and a left femoropopliteal bypass, and a transtibial amputation on the fifth day. On day 9, he was presented with a mesenteric and colonic ischemia associated with an acute occlusion of the superior mesenteric artery, treated with angioplasty—stenting and recto-colonic resection.

In comparison, the 10 patients (age 58.1 ± 11.2) with a reoperation [Supplementary Table S1] between the other 60 patients (age 57.8 ± 9.02) had, respectively, more comorbidities: the American Society of Anesthesiologists (ASA) score was 2.7 ± 0.52 vs. 2.4 ± 0.48 $P = 0.07$, 5 patients (50%) had a COPD versus 4 patients (6.7%) $P = 0.02$, 6 patients (60%) had a coronary artery disease versus 23 patients (38.3%) $P = 0.3$, 2 patients (20%) had a Fontaine stage IV versus 2 patients (3.3%) $P = 0.2$.

Extrahospital Follow-Up

The median follow-up was 37 months [21,49]. Two patients (2.9%) died during the follow-up period, due to a cardiac disease after 7 months in one case and from unknown cause in the other after 33 months. At the last follow-up (Fig. 3), 63 patients were clinically improved (91.3%) and 53 (76.8%) became asymptomatic.

Table II. Operating procedure characteristics of 70 patients with aortoiliac occlusive disease treated by robot-assisted laparoscopic surgery

Variables	n (%) or mean (±SD)
Technique	
Total RAL	68 (97.1)
RAL with minilaparotomy	2 (2.9)
Procedure	
ABF bypass	68 (97.1)
AUF bypass	2 (2.9)
Proximal anastomosis	
Lateral anastomosis	55 (78.6)
Terminal anastomosis	15 (21.4)
PTFE felt	60 (85.7)
Aortic approach	
Retrorenal	61 (87.1)
Prerenal	9 (12.9)
Graft	
Polyester	65 (92.9)
PTFE	5 (7.1)
Open conversion	3 (4.3)
Complementary procedure	
Aortic endarterectomy	51 (72.9)
Femoral endarterectomy	14 (20.0)
Planned nephrectomy	1 (1.4)
Splenectomy	1 (1.4)
Blood loss (ml)	450.9 (±404.4)
Operative time	
Docking	10.4 (±7.9)
Aortic approach	20.3 (±7.7)
Celioscopy	153.5 (±36.8)
Console	134.8 (±31.7)
Anastomosis	37.0 (±8.7)
Clamping	52.4 (±13.3)
Total	218.7 (±41.1)

Twenty late complications occurred during follow-up in 18 patients, requiring 8 reoperations: groin debridement ($n = 2$); graft thrombectomies ($n = 2$); femorofemoral bypass ($n = 1$); femoral reconstruction and allograft replacement ($n = 1$); abdominal wall repairs—secondary laparotomy ($n = 2$).

In addition, during follow-up, 6 superficial femoral artery stenting and 4 femoral bypass grafts were performed.

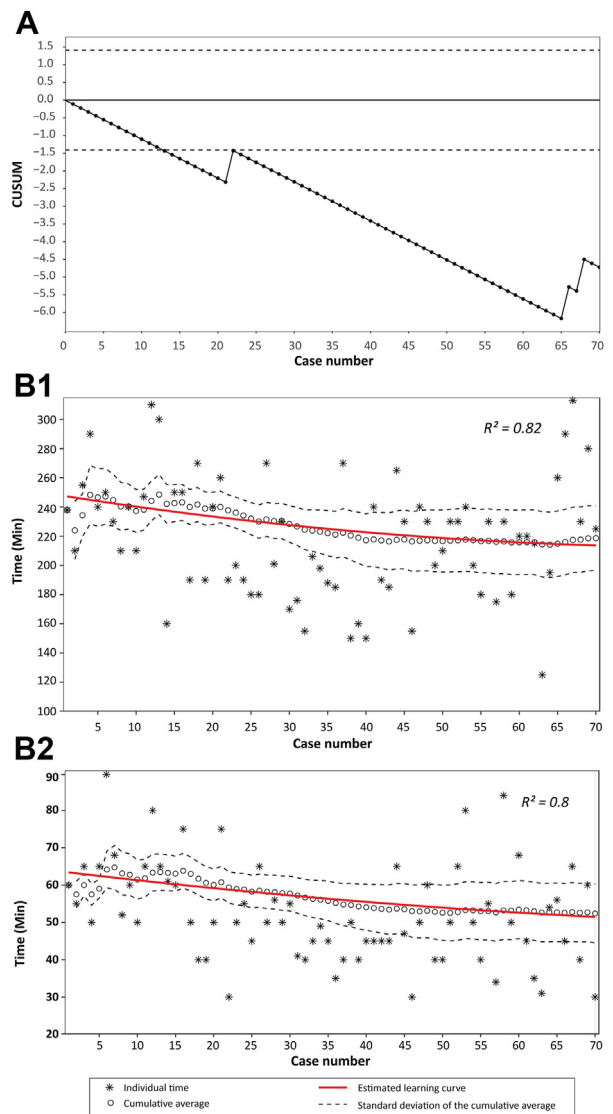


Fig. 2. Learning curves of the 70 patients with aortofemoral bypass revascularization by robot-assisted laparoscopic (RAL) surgery. Conversion rate was analyzed by the cumulative sum control chart (CUSUM) method (A), acceptable and unacceptable conversion rate was defined as 5% and 20%, respectively, and the type I and II errors set to 0.10. h_0 = threshold above which the failure rate was unacceptable; h_1 = threshold below which the failure rate was deemed acceptable, when it was reached, the learning of the procedure was considered complete for this criterion. Learning curves for operative time (B1) and clamping time (B2) were analyzed by the cumulative average-time model. Crosses mark = individual times; circles = calculated cumulative averages; dashed thin lines = standard deviations of the cumulative average; thick red line = estimated learning curve; R^2 = degree of accuracy of estimation.

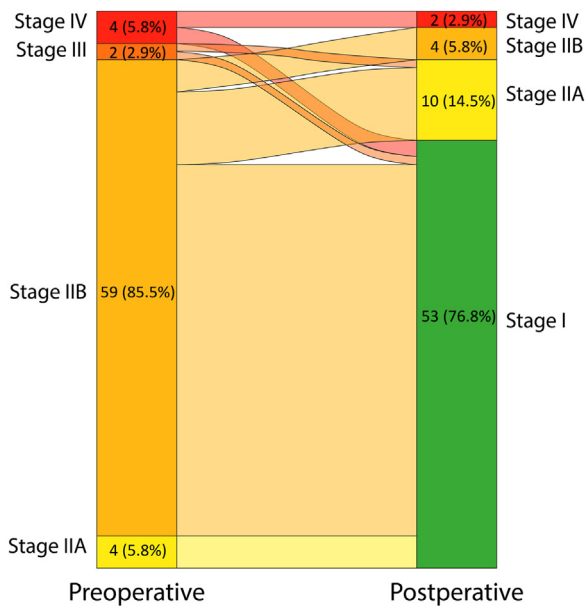


Fig. 3. Alluvial plot representing the clinical changes (Fontaine stage) between the conditions of the patients preoperatively and postoperatively (at 6 months).

Patency

Primary patency rate at 12, 24, 36, and 48 months was 94.2%, 92.5%, 92.5%, and 92.5%, respectively, while secondary patency rate was 100%, 98.1%, 98.1%, and 98.1%, respectively (Fig. 4).

DISCUSSION

In our experience, robotic surgery for AIOD is a safe alternative to open surgery, with excellent patency results in the midterm with an acceptable learning curve.

Minimally invasive open aortic surgery for AIOD using laparoscopy was first described in the literature with excellent results.^{13,14} However, a difficult training with a long learning curve was required to master the aortic anastomosis before reaching a safe daily practice application.¹⁴ In our experience, robotic surgery overcomes these problems and allows us, with a shorter learning period, to perform aortoiliac reconstructions with favorable results in the short and midterm.

Our study shows that RAL aortic surgery is safe with a low conversion rate (<5%) and more than 90% of symptom improvement with 92.5% primary and 98.1% secondary patency rates after 48 months. Nevertheless, postoperative severe complications occurred in patients with multiple significant severe comorbidities. Therefore, along with our experience, we decided to propose RAL surgery to patients with few comorbidities.

In this series, 13 procedures were required to consider the technique safe regarding the risk of conversion to open. In the specific case of AIOD where aortofemoral runoff is—by definition—poor, procedure duration appears more relevant than aortic cross clamping duration as a feasibility parameter. In our experience, the 2 surgeons who oversaw the program underwent specific training with a simulation program on the robotic system before and in between the first cases. Moreover, performing easier interventions with the robot like median arcuate ligament syndrome or exclusion of visceral artery aneurysms can help the physicians to get more experience with the system feel more confident with the robotic system management.

Our results are comparable to those reported in the literature [Table III], especially in terms of conversion rates (4.3 vs. 0.9–14.3%) and 30-day mortality (0.0 vs. 3.6%). The mean total operating time ranged from 194 min to 360 min and the median stay was 5 days across all series. The study by Novotný et al.¹⁵ described a similar learning curve, with an amount of 31 procedures to achieve an acceptable conversion rate and a stabilization of the total operating time.

Unlike Stádler et al.,¹⁷ all our procedures were performed through a retrocolic approach described by Coggia et al.¹⁸ instead of a direct transperitoneal approach for 2 main reasons. First, we believed that a retrocolic approach would potentially reduce the risk of digestive tract injury by decreasing the interactions with the retractors. Second, it allows a safe control of suprarenal and supraceliac aorta if required as well as lumbar arteries.

Compared to standard laparoscopy for AIOD, the RAL conversion rate appears to be lower (0.9–14.3% for RAL; 2.8–20.7% for laparoscopy) although a great variability was found in the literature [Table III] [Supplementary Table S3]. However, mortality rates are similar, and the median hospital stay appears slightly lower with RAL [Table III].

Midterm patency after RAL in AIOD in our experience is comparable to laparoscopic series. Lecot et al.¹⁹ reported 87 patients with laparoscopic ABF with a primary, assisted primary and secondary patency of 96.1%, 98.1%, and 99.4% at 1 year, and of 83.0%, 92.0%, and 97.0% at 5 years, respectively. Di Centa et al.¹⁴ described primary and secondary patency rates of 93% and 95.6%, respectively, at 3 years.

Although controversial, open surgical ABF bypass remains the gold standard treatment for AIOD in patients with complex aortoiliac lesions for fit patient.² According to meta-analysis data patency at 1 year, 5 years and 10 years of 96.3% [96–98], 91.0% [90–94] and 86.8%–92],

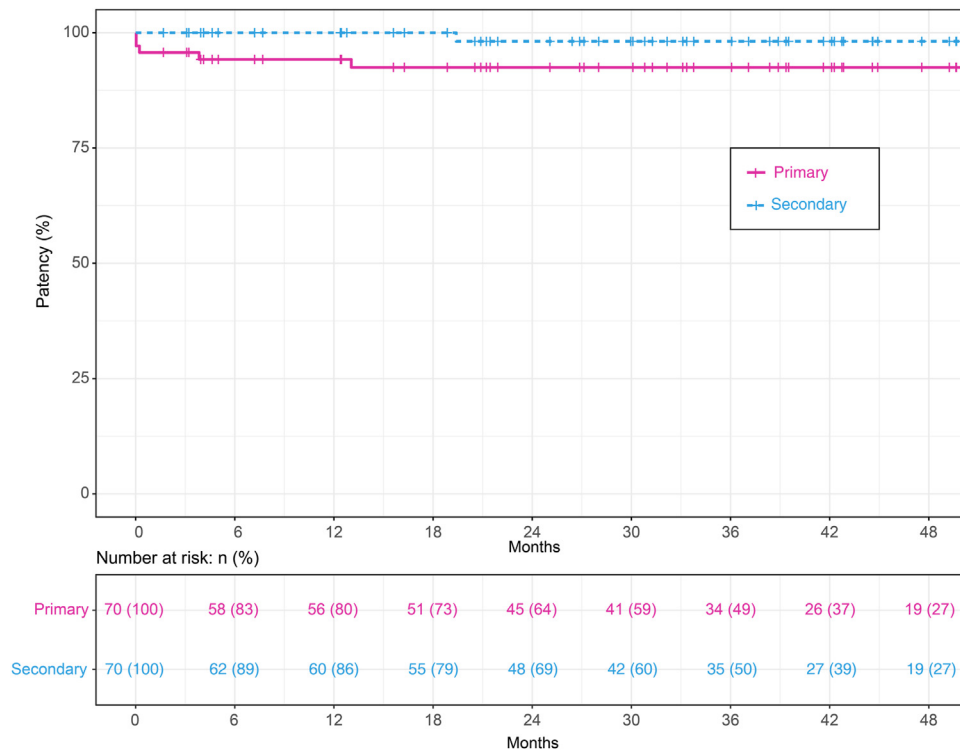


Fig. 4. Kaplan–Meier curve of primary and secondary patency of the 70 patients with aortofemoral bypass revascularization by robot-assisted laparoscopic (RAL) surgery over 4 years of follow-up.

respectively.²⁰ To our knowledge, there is no available randomized study comparing open surgery to RAL surgery, however a Norwegian multicenter randomized controlled study²¹ compared open to laparoscopic surgery. They described a longer median hospital stay (4.0 vs. 7.0 $P < 0.001$) in open surgery. Hence, we could expect length of hospital stay with RAL shorter than open surgery.

Endovascular is the first-line therapy² for short stenosis or occlusion, but total endovascular treatment for complex AIOD lesions is not free of perioperative risks and long-term results are unknown.²²

For some authors, the hybrid solution combining iliac-covered stenting and femoral endarterectomy was reported as a good alternative option.²³ In a recent randomized trial (hybrid versus open revascularization), hybrid reconstruction for iliofemoral occlusive disease was reported with good early results.²⁴ However, this trial was not designed for extensive and bilateral occlusive cases, and longer-term patency remains unknown.

Limitations

The major limitation of our study relies on its observational aspect. We believe that a multicenter study

comparing RAL to open and laparoscopic surgery is necessary to justify the use of a so-called expensive robotic system.

Current Place of RAL in Vascular Surgery

As other RAL users, our experience of RAL for AIOD revascularizations allowed us to extend RAL indications to AAA repairs.¹⁸ Following the same process, other interesting indications of RAL as type II endoleaks ligations,²⁵ digestive²⁶ or renal artery aneurysms repair,²⁷ and treatment of median arcuate ligament syndrome²⁸ have been described in the literature.

The fourth generation of Da Vinci robot, (Xi, Intuitive Surgical Inc., Sunnyvale, CA, USA), replaced the Si version (third version) in 2014. Among improvements, steric hindrance reduction of the robotic arms, and increase of rotation range make the procedure easier, reducing the risk of conflict between arms. Nevertheless, the quasi-monopoly situation of Intuitive Inc. in the surgical robotic field led this company to choose not to extend the CE marking process for vascular surgery indications without any scientific proof in terms of lack of feasibility, safety, or efficiency.

Table III. Published series of aortoiliac occlusive disease with aortofemoral bypass revascularization by robot-assisted laparoscopic surgery

Series	Years	N	30-day mortality n (%)	Conversion n (%)	Duration of operation mean (min) [min-max]	Median of stay [min-max]
Jongkind et al., Vascular, 2011, Amsterdam, Netherlands ¹⁶	2011	28 ^a	1 (3.6)	4 (14.3)	360 ^b [225–589]	5 [3–57]
Novotný et al., J. Vasc. Surg, 2011, Brno, Czech Republic ¹⁵	2011	40	0 (0.0)	2 (5)	274 [180–475]	withheld
Stádlér et al., Eur J Vasc Endovasc Surg, 2016, Prague, Czech Republic ¹⁷	2016	224	0 (0.0)	2 (0.9)	194 [127–315]	5 [withheld]
Our series	2023	70	0 (0.0)	3 (4.3)	218 [125–315]	5 [3–79]

When the series has been published several times, only the publication comprising the most patients was considered.

^aIncluding 4 simple endarterectomies.

^bMedian because mean are not available, only considers bypass surgery.

Despite our good results in the aortic surgery program at Georges Pompidou's European Hospital, a conflict between our new hospital governance and Intuitive Surgical has arisen. Our administration considered that given the absence of CE marking for the DA VINCI robot for vascular surgery, the aortic surgery program fell within the scope of research and wanted financial support from Intuitive Surgical. This was refused and led in 2019 to the complete closure of the robotic surgery program by our administration.

Aortic surgery by RAL is still carried out in France (Lyon Vascular Group, Clermont Ferrand University Hospital) and in Europe (Nemocnice Na Homolce, Prague, Czech Republic), but no longer in the APHP group."

CONCLUSIONS

In our dedicated center experienced in RAL surgery, management of complex aortoiliac occlusive lesions using that technique gives good results in terms of mortality, morbidity, and patency in short and midterm with an acceptable learning curve. Our results are comparable to standard surgical treatment conventional open or laparoscopic surgery. Compared to laparoscopy, RAL surgery gives similar results in terms of complications with a lower conversion rate and above all a shorter learning curve making the diffusion of the technique much easier. Compared to open surgery and because of its minimally invasive nature, RAL allows shorter

hospitalization length. Of course, prospective clinical trials with larger series are required for long-term results and to confirm safety. However, the expansion of vascular robotic surgery indications would benefit from new developments of robotic systems.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Willy Sutter: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Jean-Marc Alsac:** Writing – review & editing, Supervision, Conceptualization. **Iannis Ben Abdallah:** Writing – review & editing, Conceptualization. **Cassandre Michel:** Writing – review & editing, Data curation. **Pierre Julia:** Writing – review & editing, Conceptualization. **Jean-Philippe Empana:** Writing – review & editing, Conceptualization. **Salma El Batti:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.avsg.2024.02.018>.

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