The Importance of Cell Saver Usage in Complex Endovascular Repair of Thoraco-Abdominal Aortic Aneurysms

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Background: The use of the cell saver is well-established in open aneurysm repair; however, its role in endovascular repair is yet to be determined. The aim of this study was to analyze the effects of cell saver usage in patients undergoing complex endovascular procedures.
Materials and methods: Single-center retrospective cohort study, including consecutive patients undergoing fenestrated and/or branched repair for the treatment of thoracoabdominal and complex abdominal aortic aneurysms (CAAAs) between January 2019 and December 2022. The cell saver was a standard part of the intraoperative setup of these procedures, and its use was readily available. The primary endpoint was the percentage of patients, in which autologous blood collected was transfused (cell saver blood transfusion [CSBT]), alongside the useable amount obtained. Secondary endpoints included mean blood loss, postoperative hemoglobin levels, and 30-day mortality.
Results: A total of 170 patients (77.1% male, mean age 71.2 ± 9.2 years) were included, with a median blood loss of 700 mL (interquartile range [IQR] 400−1,200 mL). A total of 96 patients received some kind of blood transfusion (BT) (56.5%): 35 patients were (20.6%) allogenic BT, 31 patients were (18.2%) CSBT only, and 30 patients were (17.6%) a combination of both. In total, 61 patients (35.9% or 63.5% of all patients requiring BTs) received CSBT, with a median useable blood volume of 282 mL (IQR, 194.5−508 mL). Thirty-day mortality was similar in both groups. Although the CSBT group had lower intraoperative hemoglobin values (9.25 ± 1.55 vs. 10.36 ± 1.88 mg/dL; $P < 0.001$), both groups presented similar postoperative hemoglobin (Hb) levels.
Conclusions: Blood loss during complex endovascular repair is not insignificant. In this cohort, over 50% of included patients required some kind of BT, 32.3% of which received exclusively CSBT, while 31.3% had supplementary CSBT alongside allogenic BT. This data showcases its potential role in these repairs, paving the way for its standardization in the intraoperative setup of these complex procedures.

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INTRODUCTION

Endovascular aortic repair (EVAR) has become the mainstay of treatment for complex abdominal and thoracoabdominal aortic pathologies, with increasing numbers of fenestrated and branched EVAR (F/B-EVAR) procedures performed yearly.[1–4] Despite F/B-EVAR being minimally invasive, they remain complex and technically challenging and are associated with a wide variety of factors that play a role in assuring successful and long-lasting aneurysm exclusion. Although a significant proportion of current F/B-EVAR is being performed through percutaneous femoral access, they remain associated with significant blood loss, mainly through the introducer sheaths and different vascular access points.[5,6] Sen et al., reported an estimated average blood loss in patients undergoing F/B-EVAR of 799 ± 982 mL, significantly higher among patients with thoracoabdominal aortic aneurysms (TAAAs) compared to pararenal aneurysms (PRAs) [901 ± 1,194 vs. 623 ± 749, $P = 0.01$].[6]

Considerable blood loss, alongside the need for multiple allogenic blood transfusions (BTs), has been considered a potential intraoperative risk factor leading to inferior clinical outcomes.[6] Intra and perioperative anemia and hypotension may result in hypoperfusion of the vital organs, potentially resulting in mesenteric, renal, and extremity ischemia, as well as being a significant risk factor for postoperative myocardial infarction (MI). Additionally, hypotension secondary to significant blood loss has also been associated with an increased risk of spinal cord ischemia (SCI), one of the most catastrophic complications of these repairs.[5–7] According to the U.S. Aortic Research Consortium, adequate perfusion of the left subclavian and hypogastric arteries, an intraoperative mean arterial blood pressure (mABP) $\geq$ 90 mm Hg, as well as maintaining intraoperative hemoglobin levels $\geq$10 mg/dL are important factors for the protection against SCI during complex endovascular procedures.[8]

Although the use of cell savers has been commonly acknowledged in open TAAA surgery to minimize allogenic BT requirements, there is a scarcity of studies and recommendations regarding their use in complex endovascular aortic procedures.[6,9,10]

The aim of this study was to evaluate the role of the cell saver in patients undergoing F/B-EVAR, assessing the number of patients in whom the collected intraoperative blood was retransfused and its effect in the postoperative course, allowing a deeper insight into the potential benefits and standardization of cell saver usage in these complex procedures.

Type of Research

- Single-centre, retrospective cohort study.

Key Findings

- This study included 170 patients undergoing complex endovascular aortic procedures, with a mean estimated blood loss (EBL) of 700 (IQR, 400−1,200) ml. In this cohort, 96 patients (56.5%) required blood transfusion (BT): 20.6% were allogenic, 18.2% autologous blood and 17.6% received a combination of both. In global, 35.9% of patients (63.5% of patients requiring BTs) were retransfused with blood obtained through the cell saver, with a medium useable volume of 282 (194.5−508) mL.

Take Home Message

- Over half of the patients requiring BTs benefited from autologous blood reinfusion. In this context, the inclusion of the cell saver as a standard in the intraoperative setup of these procedures appears could be a useful adjunct.

MATERIALS AND METHODS

Study Design

Single-center, retrospective cohort studies from prospectively collected data in a high-volume aortic center. The local ethical committee approved the study, (no. 20−148) and the need for patient's written informed consent was waived due to its retrospective nature. The study was prepared in accordance with the The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[11]

Study Population

All consecutive patients undergoing F/B-EVAR for TAAA and complex abdominal aortic aneurysms (cAAAs) between January 2019 and December 2022 were included. The categorization of included aortic pathologies was defined according to the latest Society for Vascular Surgery reporting standards.[12,13]

TAAAs were categorized according to the Safi classification, while cAAAs were defined as aneurysms involving the renal and/or mesenteric arteries, extending up to the level of the celiac axis or diaphragmatic hiatus, including short neck infrarenal (<10 mm), juxtarenal, pararenal, and paravisceral aneurysms.[12,13] Implanted devices used were all manufactured by Cook Medical (Bloomington, IN, USA) and incorporated either fenestrations, branches, or a combination of both. In urgent cases, either off-the-shelf branched endografts (T-Branch) or physician-modified endografts (PMEGs) were implanted, depending on the aortic anatomy and patient stability. Both elective and urgent procedures were included, with urgent procedures being considered contained or frank ruptures, symptomatic patients, large aneurysms >10 cm, and those patients who underwent treatment within <48 hr of presentation.

Demographic characteristics were collected, including cardiovascular risk factors, such as smoking, hypertension, dyslipidemia, other medical risk factors, previous aortic history, medication, and type of aneurysm undergoing repair. Intraoperative variables collected included urgency of the repair, technical success, the type of endograft, operative time, blood loss, allogenic and autologous blood transfusions, perioperative hemoglobin (Hb) values, and operative complications. Technical success was defined as the successful implantation of F/B-EVAR, with the exclusion of the aneurysm and the absence of type I or type III endoleak in the first postoperative computed tomography (CT) scan. Thirty-day outcomes collected included postoperative renal impairment, defined as a decrease ≥20% of the baseline estimated glomerular filtration rate, MI, stroke/ transient ischemic attack (TIA), SCI, reinterventions, and mortality. Perioperative Hb levels collected included the last value documented preoperatively, lowest intraoperative value, immediate postoperative value, as well as at 24 hrs and 72 hrs postoperatively.

Cell Saver Usage

A continuous autotransfusion cell saver (CATSmart Plus, Fresenius Kabi, Lake Zurich, IL) device was readily available in the operative theater in all patients undergoing complex endovascular repairs as part of the standard set-up. Although the cell saver was routinely used for blood collection and aspiration in all treated patients, blood was only processed and transfused on an individual patient basis. Ultimately, the decision to use the cell saver for autologous BT was made in conjunction with the anesthesiologists and was based on the amount of blood collected, the intended minimum Hb level of ≥10 mg/dL during the intervention, the mABP, and the level of oxygen saturation.

Endpoints

The primary endpoint of the study was the percentage of patients in which autologous blood collected was transfused, alongside the useable amount obtained. Secondary endpoints included the effect of autologous BT on postoperative Hb levels, length of intensive care unit (ICU) and hospital stay, and 30-day mortality rates.

Statistical Analysis

Data analysis was performed using SPSS version 28.0 (IBM Corp, Armonk, NY). Continuous variables were tested for normality using the Kolmogorov–Smirnov test. Data with a normal distribution are presented as mean ± standard deviation (SD), while data without a normal distribution through median and interquartile ranges (IQR). Categorical data are expressed in numbers and percentages. Pearson x^2 and Fischer's exact tests were used for the analysis of categorical variables. Student's *t*-test and analysis of variance (ANOVA) were used to analyze parametric continuous variables, whereas the Kruskal–Wallis test was used for nonparametric data. A *P* value of < 0.05 was used to determine statistical significance.

First, a descriptive analysis of the general cohort was made. Subsequently, patients were analyzed by cell saver usage, by estimated blood loss (EBL), and by the type of BT received. For the blood loss analysis, 4 different blood loss categories were created according to the blood loss based on blood loss quartiles: (i) <25%, (ii) 25–50%, (iii) 50–75%, and (iv) >75%. Finally, a sensitivity analysis excluding urgent cases was performed.

Assuming the main source of blood loss in such complex cases comes from contralateral sheath use, we sought to compare fenestrated and branched EVAR (FEVAR and BEVAR) cases in terms of blood loss. Devices that incorporated fenestrations and branches were excluded from this analysis. All PMEGs were fenestrated and grouped within the FEVAR group. In addition, analysis was conducted to investigate differences among FEVAR patients with regards to the number of fenestrations (3 vs. 4).

RESULTS

General Cohort

A total of 170 patients, 77.1% of whom were male with an average age of 72 ± 9 years, were included. A detailed summary of the preoperative risk factors can be found in Table I. Over 40% of patients had a history of prior aortic treatment, mainly TEVAR (28.2%). Patients with cAAAs accounted for 54.1% of the cohort, while TAAAs accounted for 45.9%, the majority of which were degenerative (80%). Specifically, juxtarenal aneurysms (34.7%) and type II TAAAs (21.8%) were the 2 most encountered pathologies. Urgent repair was required in 52 patients (30.6%), of whom 16 (9.4%) had ruptured aneurysms. Half of those ruptured cases were contained, while 8 were frank ruptures with free retroperitoneal hemorrhage.

Technical success was achieved in 97.1% of patients, with complete intra and perioperative outcomes presented in Table II. In 5 patients, technical success was not achieved due to target vessel cannulation failure as follows: 2 celiac trunks, 2 accessory left renal arteries, and 1 right renal artery. All patients underwent ultrasound-guided percutaneous femoral access, while an additional upper arm axillary access was employed in 64 individuals (37.6%). Additional procedures were performed in 39.4% of patients, mainly relining the aortic bifurcation (21.8%) and the use of iliac branched devices (17.6%).

Intraoperative Blood Loss and Blood Requirements

The mean preoperative Hb was 12.57 ± 2.09 mg/dL, reaching the lowest intraoperative value of 9.96 ± 1.84 mg/dL. Postoperative levels during the first 72 h oscillated between 9.7 and 10.1 mg/dL (Table II). The average intraoperative blood loss was 700 mL (IQR 400–1,200 mL). A total of 96 patients received some kind of BT (56.5%), of which 35 (20.6%) received allogenic BT, 31 (18.2%) received autologous BT and 30 (17.6%) received a combined BT. In global, 61 patients (35.9%, or 63.5% of all patients requiring BTs) received CSBT, with a median useable transfused volume of 282 (194.5–508) mL.

Patients were subdivided into quartiles according to the amount of intraoperative blood loss (Table III). The use of CSBT increased significantly alongside intraoperative blood loss, from 0% in patients with a blood loss <400 mL, to 79.1% in those with blood loss >1,200 mL ($P < 0.001$) (Tables III and IV). Significant differences were found in the lowest levels of Hb recorded intraoperatively ($P < 0.001$). Immediate and 24-hr postoperative Hb values were also markedly affected throughout the blood loss groups ($P = 0.015$ and $P = 0.006$, respectively). However, at 72 h, postoperative Hb seemed similar in all groups ($P = 0.085$).

Table I. Preoperative demographics, aortic history, and aneurysm characteristics of the 170 included patients in this single-center analysis on the use of cell saver in complex endovascular aortic repair

Demographics and characteristics	Total cohort (*n* = 170)
Age - y	71.5 ± 9.2
Males	131 (77.1)
Body mass index - kg/m^2	26.3 ± 5.1
Hypertension	142 (83.5)
Dyslipidaemia	96 (56.5)
Smoking	93 (54.7)
Chronic kidney disease	76 (44.7)
COPD	47 (27.6)
Coronary artery disease	46 (27.1)
Diabetes mellitus	30 (17.6)
Chronic heart failure	27 (15.9)
Peripheral arterial disease	23 (13.5)
Cancer	17 (10)
Stroke/transient ischemic attack	16 (9.4)
Connective tissue disorder	4 (2.4)
Previous aortic history	74 (43.5)
TEVAR	48 (28.2)
EVAR	17 (10)
Frozen elephant trunk	15 (8.8)
AAA open repair	6 (3.5)
Aneurysm type	
Thoracoabdominal aneurysms	78 (45.9)
TAAA type I	14 (8.2)
TAAA type II	37 (21.8)
TAAA type III	11 (6.5)
TAAA type IV	13 (7.6)
TAAA type V	3 (1.8)
CAAAs	92 (54.1)
Suprarenal	9 (5.3)
Pararenal	13 (7.6)
Juxtarenal	59 (34.7)
Infrarenal	11 (6.5)
Degenerative aneurysms	136 (80)
Postdissection aneurysms	34 (20)
Urgent procedures	52 (30.6)
Ruptured cases	16 (9.4)
Contained ruptures	8 (4.7)
Frank ruptures	8 (4.7)

Data are reported as *n* (%), median (interquartile range) or mean ± standard deviation.

AAA, abdominal aortic aneurysm; COPD, chronic obstructive pulmonary disease; EVAR, endovascular aneurysm repair, thoracoabdominal aortic aneurysm; TEVAR, thoracic endovascular aneurysm repair.

Table II. Intra and perioperative outcomes of the 170 included patients in this single-center analysis on the use of cell saver in complex endovascular aortic repair

Peri-operative details	Total cohort ($n = 170$)
Type of endograft used	
Custom-made devices	107 (62.9)
Fenestrated	69 (40.6)
Branched	30 (17.6)
Fenestrated + Branched	8 (4.7)
T-branch (Cook Medical)	32 (18.8)
Physician modified endograft	31 (18.2)
Target vessels	646 (100)
Fenestrations	386 (60)
Branches	260 (40)
Concomitant procedures	67 (39.4)
Aortic bifurcation relining	37 (21.8)
Iliac-branched device	30 (17.6)
Technical success	165 (97.1)
Total operative time − mins	263 ± 86
Fluoroscopy time - mins	90 ± 103
Radiation dose - cGy/cm^2	3,402 ± 2,502
Contrast dose - mL	280 (175−350)
Surgical access	
Femoral access (percutaneous)	170 (100)
Additional upper arm access (right, cutdown)	64 (37.6)
Perioperative hemoglobin levels - mg/dL	
Preoperative Hb	12.57 ± 2.09
Lowest intraoperative Hb	9.96 ± 1.84
Immediate postoperative Hb	10.7 ± 1.42
24-hr postoperative Hb	9.75 ± 1.40
72-hr postoperative Hb	9.78 ± 1.40
Perioperative blood requirements	
Blood loss (mL)	700 (400−1,200)
Any type of BT	96 (56.5)
Only allogenic BT	35 (20.6)
Only autologous BT	31 (18.2)
Both allogenic and autologous BT	30 (17.6)
Any Allogenic BT	65 (38.2)
1 bag (250 mL)	24 (14.1)
2 bags (500 mL)	21 (12.4)
3 bags (750 mL)	13 (7.6)
≥4 bags (1,000 mL)	7 (4.1)
Number of bags/patient[a]	2.09 ± 0.12
Total allogenic BT − mL[a]	500 (250−750)
Any CSBT	61 (35.9)
Total CSBT transfused - mL	282 (194.5−508)
30-day mortality	4 (2.4)
30-day complications	40 (23.5)
Myocardial infarction (MI)	5 (2.9)
Spinal cord ischemia	7 (4.1)
Stroke/	3 (1.8)
Renal impairment	25 (14.7)
Dialysis (temporary/permanent)	3 (1.8)
30-day reinterventions	11 (6.5)
ICU stay	2 (1−4)
Overall hospital stay	10 (7−16)

Data are reported as n (%), median (interquartile range) or mean ± standard deviation.
BT, blood transfusion; CSBT, cell saver blood transfusion; Hb, hemoglobin; TIA, transient ischemic attack.
[a]In patients who received an allogenic blood transfusion.

Cell Saver

Patients who received CSBT underwent longer procedures (311 ± 92 min vs. 235 ± 69 min) and required more fluoroscopy time and contrast dose (Table V). Although the lowest intraoperative and postoperative Hb value was lower in the CSBT group (due to more significant intraoperative blood loss, 1,400 mL [1,000−2,060 mL] vs. 500 mL [275−750 mL] $P < 0.001$), the type of aortic pathology, percentage of urgent procedures, and ruptured aneurysms, as well as preoperative Hb values were similar in both groups. Although more patients receiving CSBT also required allogenic BTs (49.2% vs. 32.1%, $P = 0.033$), the total allogenic BT volume and a median number of allogenic bags per patient were similar in both groups, with patients in the CSBT group receiving a median additional blood volume of 282 mL (IQR 194.5−508 mL). The rate of 30-day complications was higher in the CSBT group (34.4% vs. 17.4%, $P = 0.047$), mainly at the expense of an increased rate of stroke/TIA and renal impairment. Despite this, 30-day mortality rates, ICU stay, and total length of stay were similar in both groups.

No differences were found between FEVAR and BEVAR cases with regard to blood loss {700 (400−1,205) vs. 650 (350−1,100), P 0.786, respectively}. On the other hand, there were more volumes of BT whether allogenic or cell saver blood, but they did not qualify to produce significant differences. As for the number of fenestrations (3 vs. 4) in FEVAR procedures, although numerically 4 fenestrated FEVAR had more blood loss, required more BTs, and larger volumes of allogenic and cell saver blood, the differences were not significant (Tables VI and VII).

Thirty-Day Outcomes

The average stay in intensive care was 2 nights (IQR 1−4), while the overall hospital stay was 10 (IQR 7−16) days. No differences were found regarding ICU

Table III. Patients divided according to amount of procedural blood loss

Peri-operative details	Intraoperative blood loss <400 mL (n = 39)	400–799 mL (n = 52)	800–1,199 mL (n = 36)	>1,200 mL (n = 43)	P-value
Preoperative medication					
Antiplatelet	33 (86.8)	44 (84.6)	28 (77.8)	33 (76.7)	0.56
DOAC	4 (10.3)	10 (19.2)	6 (16.7)	10 (23.3)	0.071
Warfarin	3 (7.7)	0 (0)	1 (2.8)	3 (7.0)	0.29
Type of aortic pathology					0.97
Thoracoabdominal aneurysms	21 (53.8)	26 (50)	21 (58.3)	24 (55.8)	
Complex aortic aneurysms	18 (46.1)	26 (50)	15 (41.7)	19 (44.2)	
Urgent procedures	10 (25.6)	14 (26.9)	11 (30.6)	17 (39.5)	0.52
Ruptured aneurysms	4 (10.3)	3 (5.8)	3 (8.3)	6 (13.9)	0.51
Intraoperative details					
Total operative time – mins	213 (168–266)	240 (196–267)	261 (229–313)	323 (255–384)	<0.001
Fluoroscopy time - mins	66 (47–83)	67 (51–82)	84 (66–110)	96 (67–127)	0.053
Radiation dose - cGy/cm^2	2,613 (1,414–4,578)	2,035 (1,138–4,270)	3,073 (2,183–4,702)	3,081 (1,790–6,158)	0.085
Contrast dose - mL	220 (140–300)	230 (170–300)	300 (190–400)	300 (200–393)	0.033
Hemoglobin levels – mg/dL					
Preoperative Hb	12.7 (10.8–14.8)	13.1 (11.5–14.6)	12.5 (10.2–13.4)	12.8 (11.4–13.8)	0.43
Lowest intraoperative Hb	10.8 (9.1–12.3)	10.5 (9.4–10.5)	8.6 (8.1–9.8)	9 (8–9.7)	<0.001
Immediate postoperative Hb	10.5 (9.3–11.5)	10 (9.1–11.1)	9.9 (8.3–10.8)	9.8 (9.1–10.3)	0.015
24 h-postoperative Hb	10.3 (9.2–11.4)	9.6 (8.4–10.8)	9.7 (8.3–10.3)	9.3 (8.5–9.9)	0.006
72 h-postoperative Hb	9.9 (8.9–11.1)	9.9 (8.8–11)	9.3 (8.6–10.4)	9.2 (8.4–10.1)	0.085
Blood requirements					
Any type of blood transfusion	4 (10.3)	21 (40.4)	29 (80.6)	42 (97.7)	<0.001
Only allogenic BT	4 (10.3)	12 (23.1)	11 (30.6)	8 (18.6)	<0.001
Only autologous BT	0 (0)	6 (11.5)	10 (27.8)	15 (34.9)	<0.001
Both allogenic and autologous BT	0 (0)	3 (5.8)	8 (22.2)	19 (44.2)	<0.001
Any allogenic BT	4 (10.3)	15 (28.8)	19 (52.8)	27 (62.8)	<0.001
1 bag (250 mL)	1 (2.6)	8 (15.4)	6 (16.7)	9 (20.9)	<0.001
2 bags (500 mL)	2 (5.1)	4 (7.7)	9 (25.0)	6 (14.0)	
3 bags (750 mL)	1 (2.6)	2 (3.8)	4 (11.1)	6 (14.0)	
≥4 bags (1,000 mL)	0 (0)	1 (1.9)	0 (0)	6 (14.0)	
Number of bags/patient	0 (0)	0 (0–1)	1 (0–2)	1 (0–3)	<0.001
Total Allogenic BT – mL	0 (0)	0 (0–250)	250 (0–500)	250 (0–750)	<0.001
Any CSBT - %	0	9 (17.3)	18 (50)	34 (79.1)	<0.001
Total CSBT transfused - mL	0	200 (151.5–299.5)	236 (198.3–386.8)	377 (209.5–781)	<0.001
30-day mortality	1 (1.9)	1 (2.2)	0 (0)	2 (5.1)	0.55
30-day reinterventions	4 (7.5)	2 (4.3)	1 (3.1)	4 (10.3)	0.29

30-day complications	7 (13.2)	10 (21.7)	10 (31.3)	13 (33.3)	0.11
MI	1 (2.6)	2 (3.8)	2 (5.6)	0 (0)	0.41
SCI	0 (0)	2 (3.8)	3 (8.3)	2 (4.6)	0.22
Stroke/TIA	0 (0)	1 (1.9)	1 (2.8)	1 (2.3)	0.68
Renal impairment	6 (15.4)	5 (9.6)	4 (11.1)	10 (23.3)	0.23
Nosocomial pneumonia/UTI	4 (10.3)	4 (7.7)	2 (5.6)	2 (4.6)	0.93
Access-related	0 (0)	2 ()	0 (0)	2 (3)	0.26
ICU stay (nights)	2 (1−4)	2 (1−4)	2 (1−5)	2 (1−5)	0.81
Total hospital stay (nights)	8.5 (7−16)	10 (7−14.3)	9.5 (7−16.8)	11.5 (7−20.3)	0.25

Data are reported as *n* (%), median (interquartile range) or mean ± standard deviation.
BT, blood transfusion; CSBT, cell saver blood transfusion; DOAC, direct oral anticoagulants; Hb, hemoglobin; ICU, intensive care unit; MI, myocardial infarction; OR, operative room; SCI, spinal cord ischemia; TAAA, thoracoabdominal aortic aneurysm; TIA, transient ischemic attack; UTI, urinary tract infection.

and hospitalization periods for patients with different categories of blood loss. The 30-day mortality and complication rate were 2.4% and 23.5%, while the 30-day reintervention rate was 6.5%. Two patients required balloon angioplasty and relining of a renal target vessel, one patient underwent stenting of the internal iliac artery due to stenosis of the origin, and one patient received an iliac limb relining due to a type IIIb endoleak. Four patients underwent femoral access vessel repair (3 pseudoaneurysms and 1 hematoma evacuation). One case had to undergo an explorative laparotomy for bleeding and dropping of Hb for which the gastroduodenal artery was identified as the bleeding source and clipped. One patient had to have sigmoid resection secondary to sigmoid ischemia. Additionally, one case suffered esophageal perforation due to aortic rupture and was explored surgically where the esophagus was repaired and hematoma was evacuated. All 4 cases of mortality were due to nonaortic-related causes, but secondary to multiorgan failure. Univariable logistic regression analysis found acetylsalicylic acid (OR 13.22, $P = 0.027$), glomerular filtration rate (OR 0.92, $P = 0.013$), ruptured aneurysms (OR 10.79, $P = 0.022$), blood loss (OR 1.00, $P = 0.031$), total operating time (OR) time (OR 1.02, $P = 0.005$), and volume transfused (OR 1.003, $P = 0.013$) to be associated with an increased risk of 30-day mortality (Table VIII). However, when included in a multivariable model, they were nonsignificant, possibly due to the small patient number.

DISCUSSION

Endovascular therapy has reached a level of maturity that could entitle it to be considered an equal if not superior alternative to open surgery for different thoracoabdominal and complex abdominal aortic pathologies.[1−4] Although endovascular procedures are widely performed via percutaneous methods, the amount of blood loss remains significant.[5,6] In a study that was conducted in in-vitro conditions, the leakage rates of the large introducer sheaths commonly used to accommodate multiple smaller ones in complex EVAR treatment were found to have significant leakage when multiple sheaths were inserted, which can become more significant depending on the duration of the procedure.[14] In the current study, the median blood loss was 700 mL, with maximum blood loss levels reaching up to 3,000 mL. Intraoperative blood loss has been associated with inferior clinical

Table IV. Intraoperative blood requirements according to the type of transfusion received

Peri-operative details	No BT ($n = 74$)	Only allogenic BT ($n = 35$)	Only CSBT ($n = 31$)	Combined BT ($n = 30$)
Operative details				
Total operative time – mins	216 (176–259)	241 (210–316)	273 (227–334)	346 (255–411)
Fluoroscopy time - mins	66 (53–78)	68 (46–100)	81 (67–119)	92 (69–137)
Radiation dose - cGy/cm^2	2,613 (1,513–4,773)	2,289 (1,428–4,358)	2,467 (1,676–4,672)	3,032 (2,032–5,626)
Contrast dose - mL	225 (170–300)	300 (160–400)	250 (195–400)	300 (200–373)
Intraoperative blood requirements				
Blood loss - mL	400 (200–500)	800 (400–1,150)	1,100 (800–2,000)	1,550 (1,000–3,000)
Any allogenic BT (n, %)	0 (0)	35 (100)	0 (0)	30 (100)
1 bag (250 mL)	0 (0)	12 (34.3)	0 (0)	12 (40.0)
2 bags (500 mL)	0 (0)	13 (37.1)	0 (0)	8 (26.7)
3 bags (750 mL)	0 (0)	6 (17.1)	0 (0)	7 (23.3)
≥4 bags (1,000 mL)	0 (0)	4 (11.4)	0 (0)	3 (10)
Total allogenic BT (mL)	0 (0)	500 (250–750)	0 (0)	500 (250–750)
Cell saver blood transfused (mL)	0 (0)	0 (0)	275 (200–347)	426 (214–837)

BT, blood transfusion; CSBT, cell saver blood transfusion; DOAC, direct oral anticoagulants; Hb, hemoglobin; ICU, intensive care unit; UTI, urinary tract infection.

outcomes, with intraoperative anemia and hypotension being related directly to SCI and other vital organ ischemia. Karkouti et al.,[15] demonstrated that massive blood loss (transfusion of ≥5 units of red blood cells [RBCs] on the day of surgery) is associated with an increased risk of short-term mortality. In this patient cohort, 46% of patients ($n = 79$) presented an EBL ≥800 mL, and 25% an EBL ≥1,200 mL. As expected, an increase in EBL was associated with an increase in surgical time, contrast dosage used, and lowest intraoperative and postoperative Hb values. To compensate for the increased blood loss, patients received more intraoperative BTs, through an increase in the amount of allogenic blood concentrates administered and the addition of autologous BT (0% < 400 mL, 17.3% EBL 400–800 mL, 50% EBL 800–1,200 mL, and 79% EBL >1,200 mL, $P < 0.001$). When looking at aneurysm characteristics, however, these did not differ significantly across EBL groups, so the percentage of patients undergoing urgent repair and the anatomical complexity of the aneurysms was similar across groups. This suggests that it is difficult to ascertain how much intraoperative blood loss will occur based only on preoperative data. It is for this reason that in our unit, setting up the cell saver has become a standard part of the intraoperative setup for complex endovascular procedures. All blood loss, which in the majority of cases will consist of that lost through the introducer sheaths and access points, is collected with the cell saver. However, the decision to then process the blood and autotransfuse is made on an individual patient level, depending on the amount of blood collected, the lowest intraoperative Hb, and hemodynamic stability, etc.

The cell saver depends mainly on 3 steps as follows: collection, processing, and reinfusion. Collection costs are usually feasible and fixed, while the following steps have added costs.[16] Processing the blood can be performed in various ways. One popular method is via centrifugation like the device we have used in this study. Other technologies include microfiltration and coarse filtration.[17] The coarse filtration method does not have a washing feature (collected blood with saline) that does not enable adequate removal of noncellular blood components, thereby risking autotransfusion safety. Microfiltration has added benefit over centrifugation where platelets could also be recovered along with the RBCs.[17,18] Cell salvage surely remains a financial burden for many institutions. Blood collection in the cell saver has an acceptable cost but processing it to be transfused to the patient carries the greatest expense.[13,19]

Table V. Perioperative, intraoperative and postoperative outcomes of the 170 included patients included in this single-center analysis on the use of cell saver in complex endovascular aortic repair, categorized by cell saver blood transfusion

Peri-operative details	No CSBT (n = 109)	CSBT (n = 61)	P - value
Preoperative medication			
Antiplatelet	89 (82.4)	49 (80.3)	0.84
DOAC	13 (12.1)	17 (27.9)	0.013
Warfarin	3 (2.8)	4 (6.6)	0.25
Type of aortic pathology			
TAAA	57 (52.3)	31 (50.8)	0.32
Complex aortic aneurysms	62 (56.9)	30 (49.2)	0.32
Urgent procedures	32 (29.4)	20 (32.8)	0.73
Ruptured aneurysms	12 (11.0)	4 (6.5)	0.42
Operative details			
Total operative time − mins	235 ± 69	311 ± 92	<0.001
Fluoroscopy time - mins	77 ± 58	116 ± 152	0.018
Radiation dose - cGy/cm^2	3,193 ± 2,197	3,770 ± 2,948	0.16
Contrast dose - mL	250 (165−300)	300 (200−400)	0.023
Hb Levels - mg/dL			
Preoperative Hb	12.56 ± 2.23	12.60 ± 1.83	0.89
Lowest intraoperative Hb	10.36 ± 1.88	9.25 ± 1.55	<0.001
Immediate postoperative Hb	10.23 ± 1.48	9.79 ± 1.29	0.052
24-hr postoperative Hb	9.90 ± 1.50	9.48 ± 1.19	0.063
72-hr postoperative Hb	9.94 ± 1.49	9.50 ± 1.20	0.052
Blood requirements			
Blood loss - mL	500 (275−750)	1,400 (1,000−2,060)	<0.001
Any type of blood transfusion	35 (32.1)	61 (100)	<0.001
Only allogenic BT	35 (32.1)	0 (0)	<0.001
Only autologous BT	0 (0)	31 (50.8)	<0.001
Both allogenic and autologous BT	0 (0)	30 (49.2)	<0.001
Any allogenic BT (n, %)	35 (32.1)	30 (49.2)	0.033
1 bag (250 mL)	12 (11.0)	12 (19.7)	0.204
2 bags (500 mL)	13 (11.9)	8 (13.1)	
3 bags (750 mL)	6 (5.5)	7 (11.5)	
≥4 bags (1,000 mL)	4 (3.7)	3 (4.9)	
Number of bags/patient[a]	2 (1−3)	2 (1−3)	0.042
Total allogenic BT (mL)[a]	500 (250−730)	500 (250−730)	0.042
Cell saver blood transfused (mL)	0	282 (194.5−508)	<0.001
30-day mortality	2 (1.8%)	2 (3.3%)	0.62
30-day reinterventions	7 (6.4%)	4 (6.6%)	0.76
30-day complications	19 (17.4%)	21 (34.4%)	0.047
MI	3 (2.8)	2 (3.3)	1.0
SCI	4 (3.7)	3 (4.9)	0.70
Stroke/TIA	0 (0)	3 (4.9)	0.043
Renal impairment	12 (11.0)	13 (21.3)	0.076
Nosocomial pneumonia/UTI	6 (5.5)	6 (9.8)	0.35
Access-related complications	2 (1.8)	2 (3.3)	0.62
ICU stay (nights)	2 (1−4)	2 (1−4.3)	0.51
Total hospital stay (nights)	9 (7−17)	11 (7−16)	0.32

Data are reported as n (%), median (interquartile range) or mean ± standard deviation.
BT, blood transfusion; TAAA, thoracoabdominal aortic aneurysm; DOAC, direct oral anticoagulants; Hb, hemoglobin; TIA, transient ischemic attack; SCI, spinal cord ischemia; ICU, intensive care unit; MI, myocardial infarction.
[a]In patients who received an allogenic blood transfusion.

Table VI. Analysis of FEVAR versus BEVAR

Blood details	FEVAR ($N = 99$)	BEVAR ($N = 63$)	*P*-value
Blood loss	700 (400−1,205)	650 (350−1,100)	0.786
Allogenic BT	0 (0−250)	0 (0−500)	0.075
Cell saver BT	239 (189−445)	318 (216−659)	0.145

FEVAR, fenestrated endovascular aneurysm repair; BEVAR, branched endovascular aneurysm repair; BT, blood transfusion.

Table VII. Analysis within FEVAR; 3 vs. 4 fenestrations

	Number of target vessels		
Blood details	3 ($N = 18$)	4 ($N = 81$)	*P*-value
Blood loss	500 (400−1,000)	800 (400−1,500)	0.281
Any BT needed	8 (40%)	50 (60.2%)	0.133
Allogenic BT	0 (0−250)	0 (0−250)	0.367
Cell saver usage	5 (25%)	34 (41%)	0.211
Cell saver BT	373 (198−475)	239 (182−461)	0.581

FEVAR, fenestrated endovascular aneurysm repair; BEVAR, branched endovascular aneurysm repair; BT, blood transfusion.

Table VIII. Univariable logistic regression analysis on 30-day mortality

	Univariable analysis	
Variable	Hazard ratio (95% confidence interval)	*P*-value
Age	1.14 (0.98−1.34)	0.098
Hypertension	0.164 (0.022−1.225)	0.078
ASA	13.22 (1.33−131.26)	0.027
GFR	0.92 (0.86−.98)	0.013
Ruptured AAA	10.79 (1.41−82.54)	0.022
Blood loss	1.00 (1.00−1.01)	0.031
Total OR time	1.02 (1.01−1.03)	0.005
Volume transfused	1.003 (1.001−1.005)	0.013
Allogenic BT	5.03 (0.51−49.44)	0.166

Included variables: age, sex, BMI, hypertension, dislipidemia, current smoking, DM, acetylsalicylic acid (ASA) score, chronic kidney disease (CKD), preOP Creatinine and glomerular filtration rate (GFR), chronic obstructive pulmonary disease (COPD), chronic heart failure (CHF), coronary artery disease (CAD), peripheral arterial disease (PAD), previous stroke, cancer, aneurysm type, ruptures, type of endograft used, number of fenestrations or branches, use of cell saver, any blood transfusion, and cell saver usage.

Therefore, some may argue that the standard use of the cell saver could increase the cost of these already costly procedures. However, collection costs are relatively low, with processing and reinfusion being the costlier steps. Given that processing and reinfusion are made on an individual patient basis, these will only be relevant in patients with important blood loss. Furthermore, some studies have found that cell saver blood usage is cost-effective, given the reduction of the total volume of allogeneic blood required, while avoiding storage and the risks of transfusion-related infectious diseases.[20−22] Furthermore, in the cases of Jehovah's Witnesses, autologous blood may represent the only way to provide BTs during the operative course.[23] Additionally, there has been a decline in donors over the past years.[23−25] This, alongside increased quality control of donated blood units, has increased the associated cost of allogenic blood.[23−25]

The use of CSBT has also been associated with potential clinical benefits, including a reduction in potassium-induced arrhythmias, inflammatory cytokines, and pulmonary and cerebral impairment.[23−25] Furthermore, in cases of emergency, preoperative preparation could be challenging, and the use of cell savers may help save the situation.[23] The association of anaesthetists produced a consensus document, recommending the use of cell savers whenever there was expected blood loss to reduce allogenic BT and/or severe postoperative anemia.[10] It further endorsed the daily use of the cell saver in surgeries where blood loss presents potential complications.[10] Significant blood loss in patients undergoing complex EVAR for the treatment of cAAAs and TAAAs has been associated with mesenteric, renal, extremity ischemia, and with an increased risk of SCI, making adequate blood pressure and Hb control in these procedures of vital importance.[5–7]

While the role of cell salvage has been shown to improve overall recovery and reduce transfusion complications in patients undergoing open aortic and nonaortic repair, data regarding its use in endovascular therapy is lacking.[26,27] In this single-centre retrospective study, 56.5% of patients undergoing complex aortic endovascular repair required some kind of BT, of which more than half received either exclusively cell saver blood transfusion or a combination of cell saver and allogenic blood reinfusion. Given that cell saver collection is not associated with a high cost, we believe this justifies including cell saver blood setup and collection as part of the standard intraoperative setup for these procedures.

Limitations

This study was a single-centre, retrospective cohort study. Although there is no patient-selection bias, as the cell saver was part of the routine setup of these procedures, practice among surgeons or anesthesiologists could have varied between patients. Furthermore, as there is no specific protocol and the decision to process and reinfuse the blood was made on an individual basis, these results may vary with other centers and standards of practice. Additionally, a collection of <400 millilitres of blood was not considered significant, and the intraoperative blood collected was discarded, and exact details of the collected blood were not documented if blood reinfusion did not occur.

CONCLUSION

Blood loss during complex endovascular repair is not insignificant. In this cohort, over 50% of included patients required some kind of BT, 32.3% of which received exclusively CSBT, while 31.3% had supplementary CSBT alongside allogenic BT. This data showcases its potential role in these repairs, paving the way for its standardization in the intraoperative setup of these complex procedures.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Ahmed A. Ali: Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tarek Hamwi:** Resources, Data curation. **Laura Sikman:** Data curation. **Jan Stana:** Writing – review & editing, Supervision, Resources. **Jan-Michael Abicht:** Resources, Methodology, Conceptualization. **Nikolaos Tsilimparis:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation. **Carlota F. Prendes:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Methodology, Investigation, Formal analysis, Conceptualization.

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