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Outcomes of Retroperitoneal vs Transperitoneal Approach for Open Abdominal Aortic Aneurysm Repair Stratified by Aortic Cross-Clamping Site

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- BACKGROUND:** The approach for open infrarenal abdominal aortic aneurysm (AAA) repair is mainly surgeon driven based on experience and previous training. Although the midline transperitoneal (TP) approach remains the most common, the retroperitoneal (RP) approach is usually used in more complex cases where suprarenal cross-clamping is necessary. As previous literature is conflicting on optimal outcomes between the 2 approaches, we aimed to compare RP vs TP outcomes stratified by aortic clamp level.
- STUDY DESIGN:** The Vascular Quality Initiative database was queried for all patients who underwent open AAA repair from January 2012 to February 2024. Patients were stratified according to aortic cross-clamp site: infrarenal, interrenal, suprarenal, and supraceliac. We used multivariate logistic regression to analyze the outcomes of RP vs TP within each clamp site while adjusting for baseline and clinically relevant variables.
- RESULTS:** A total of 8,842 patients were included. Compared with TP, RP approach was associated with higher odds of postoperative dialysis (adjusted odds ratio [aOR] 1.74, 95% CI 1.07 to 2.83, $p = 0.025$) with infrarenal cross-clamping. However, at higher clamping sites, RP was associated with lower odds of bowel ischemia (aOR 0.40, 95% CI 0.20 to 0.80, $p = 0.009$) with interrenal clamping; lower odds of dialysis (aOR 0.66, 95% CI 0.44 to 0.99, $p = 0.048$), bowel ischemia (aOR 0.52, 95% CI 0.32 to 0.85, $p = 0.009$), and 30-day mortality (aOR 0.48, 95% CI 0.30 to 0.79, $p = 0.004$) with suprarenal clamping; and lower odds of in-hospital (aOR 0.35, 95% CI 0.16 to 0.80, $p = 0.013$) and 30-day mortality (aOR 0.41, 95% CI 0.17 to 0.98, $p = 0.046$) with supraceliac clamping.
- CONCLUSIONS:** In this large multi-institutional study, we identified that differential outcomes of RP vs TP approaches for open AAA are modified by aortic cross-clamping level. RP is associated with lower postoperative complications and better survival compared with TP in cases requiring more proximal cross-clamping sites. However, the TP approach is associated with lower risk of renal complications in cases restricted to infrarenal clamping. (J Am Coll Surg 2025;241:16–26. © 2025 by the American College of Surgeons. Published by Wolters Kluwer Health, Inc. All rights reserved.)

Despite the development of endovascular techniques for abdominal aortic aneurysm (AAA) repair in recent years, open surgical repair remains prevalent due to its

lower long-term rates of overall mortality, rupture, and reintervention compared with endovascular aneurysm repair (EVAR).¹ AAA may be accessed most commonly

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Abbreviations and Acronyms

AAA	=	abdominal aortic aneurysm
aOR	=	adjusted odds ratio
EVAR	=	endovascular aneurysm repair
PLICU	=	prolonged length of ICU stay
PLOS	=	prolonged length of hospital stay
RP	=	retroperitoneal
TP	=	transperitoneal
VQI	=	Vascular Quality Initiative

via either the retroperitoneum or transabdominally, with differential outcomes. Several studies comparing perioperative outcomes of the transperitoneal (TP) and retroperitoneal (RP) approach for AAA repair suggest that the RP approach may result in lower rates of ileus, shortened hospital length of stay, and improved respiratory function, compared with the TP approach.²⁻⁶

Surgeons use these 2 approaches differentially at their own discretion, owing to the lack of clear indications. Studies of the usage of these 2 approaches by surgeons have found that the RP approach was more commonly used for aneurysms with more proximal extension with concomitant renal and visceral revascularization required.⁷ When excluding all concomitant procedures, there were no significant differences in outcomes between the TP and RP approaches for AAA repair.⁷ This is supported by research demonstrating no clear superiority between approaches for elective repair regarding mortality or complications, including hematoma, abdominal wall hernia, or chronic wound pain.⁸ However, the RP was associated with a shorter ICU stay and shorter hospital stay in one study.⁹

Anatomic complexity has a strong influence on open AAA repair, with different sites of cross-clamping used on the basis of the extent of the aneurysm and location within the aorta. AAAs most commonly occur below the renal arteries; hence, infrarenal cross-clamping is sufficient for successful repair of the majority of aneurysms.⁹ However, aneurysms extending more proximally require higher cross-clamping sites (suprarenal and suprarenal). Even infrarenal AAAs with a hostile infrarenal aortic neck unsuitable for EVAR are often repaired via an open approach with suprarenal aortic cross-clamping.¹⁰ Additionally, suprarenal clamping may be performed during treatment of infrarenal aneurysms if the aneurysm extends into one of the renal arteries or if there is concomitant renal artery stenosis requiring concomitant renal artery bypass.^{11,12} However, cross-clamp location is associated with differential outcomes after open AAA repair, with clamping above the renal arteries, at

any level, being associated with an increased risk of acute kidney injury and postoperative dialysis.¹³ Additionally, clamping above both renal arteries or above the celiac artery was associated with increased MI.¹³ Interestingly, perioperative and long-term mortality has been found to be unaffected by the cross-clamp level.¹³ Therefore, clamp location and the anatomical-driven indications for clamping may influence the outcomes of open AAA repair.

Although both RP and TP access enable clamping above the renal arteries, suprarenal clamp sites are more easily accessed through the retroperitoneum than the standard midline TP approach.¹⁴ However, there are currently no clear guidelines or solid indications on the use of either approach given the preoperatively determined location of the aortic cross-clamp. When considering the safety and efficacy of each clamp site for the treatment of infrarenal AAA, the influence of either an RP or TP approach must be evaluated because of its substantial effects on postoperative adverse outcomes and survival, as well as its influence on technical feasibility. Therefore, this study aims to expand on previous work to establish whether the outcomes of the open AAA repair approach (RP or TP) are modified according to the site of the aortic cross-clamp (infrarenal, interrenal, suprarenal, or suprarenal) to provide the most suitable approach specific to the anatomic characteristics of each patient's AAA.

METHODS

A retrospective analysis was performed of all open infrarenal AAA procedures in the Vascular Quality Initiative (VQI) database between January 2012 and February 2024. This project is approved by the VQI Research Advisory Committee (ID 5462). The VQI is a prospective initiative for collecting data managed by the Society of Vascular Surgery. This registry encompasses data from more than 1,000 institutions across the US and Canada, with the goal of enhancing outcomes in vascular surgery. It houses deidentified data on significant vascular procedures, encompassing demographics, comorbidities, procedural specifics, and results. Regular stringent audits are conducted to maintain the quality of the data in the registry. The IRB exempted the requirement for individual patient consent under the provisions for deidentified human subject data and quality improvement research.

Cohort

Patients undergoing open AAA repair in this study were grouped according to the level of aortic cross-clamp required into 4 groups: infrarenal (below both renal arteries), interrenal (above 1 renal artery), suprarenal (above both renal

arteries), and supraceliac (above celiac artery). Within each cross-clamp site, patients were stratified according to the exposure technique into RP and TP approaches.

Variables

Baseline variables included demographics (age, sex, race, and ethnicity), family history of AAA, maximum AAA diameter, medical comorbidities (diabetes, hypertension, coronary artery disease, obesity, congestive heart failure, COPD, and chronic kidney disease), dialysis, smoking history, previous procedures (coronary artery bypass graft, percutaneous coronary intervention, carotid revascularization, lower extremity revascularization, and major amputation), American Society of Anesthesiology class, procedure urgency, anesthesia, preoperative medication use (statin, aspirin, P2Y inhibitors, anticoagulants, beta-blockers, renin–angiotensin–aldosterone inhibitors), surgeon expertise (according to mean annual case volume), and center volume. Operative variables include total procedure duration and amount of blood loss. In cases requiring clamping above either renal arteries (interrenal, suprarenal, and supraceliac), renal ischemia time as well as concomitant renal bypass and cold perfusion usage were also recorded.

Patients with missing information on cross-clamp site or operative approach were excluded from our study. Operations done for ruptured AAA or open conversion after EVAR were also not included. Additionally, our exclusion criteria encompass patients with a history of previous AAA repair (open or EVAR), concomitant infringuinal bypass, and concomitant abdominal procedure not related to the aneurysm repair, as well as patients with concomitant renal bypass within the infrarenal clamp group.

Outcomes

The primary outcomes in our study were in-hospital mortality, 30-day mortality, postoperative dialysis, bowel ischemia, and MI. Secondary outcomes include return to operating room, prolonged length of postoperative hospital stay (PLOS), and prolonged length of ICU stay (PLICU). Postoperative dialysis is defined as initiation of dialysis postoperatively (including ultrafiltration) only if the patient was not dialysis-dependent preoperatively. Postoperative bowel ischemia is defined as evidence of ischemia by colonoscopy, presence of bloody stools in a patient who dies before colonoscopy or laparotomy, or presumptive diagnosis with conservative treatment. MI diagnosis rationale was either clinically evident MI, ischemic changes on ECG, or rise in cardiac biomarkers. Patients were considered to have PLOS or PLICU if the duration of stay was more than 7 and 4 days, respectively.

Statistical analysis

Comparison of continuous variables was performed using Student's *t*-tests or Wilcoxon rank-sum test, whereas comparison of categorical variables was performed using Fisher's exact test or Pearson's chi-square test. Statistical significance was accepted at a *p* value of <0.05. Univariate analysis was performed to compare the crude rates of the primary and secondary outcomes of open AAA repair procedures performed using RP vs TP in each cross-clamp group. Multivariable logistic regression models were used to analyze primary and secondary outcomes. Stepwise backward selection modeling identified statistically significant confounders with a *p* value of <0.1 to be adjusted for in the final models along with other variables with clinical relevance (based on the relevant recent literature and clinical judgment). The covariates adjusted for in our regression models include age, sex, race, ethnicity, smoking status, medical comorbidities (diabetes, hypertension, coronary artery disease, congestive heart failure, COPD, anemia, chronic kidney disease, dialysis), aneurysm size, family history, previous vascular procedures, preoperative medication, renal ischemia time, cold renal perfusion (using 4°C crystalloid fluids to reduce the metabolic needs of the kidneys and create local hypothermia), concomitant renal artery bypass, and American Society of Anesthesiology class. Outcomes in the final models were clustered by center ID to reduce bias from hospital-level unmeasurable factors and to account for intragroup correlation. Hosmer-Lemeshow goodness of fit testing was used to assess model fit, and area under the receiver operator curve was used to evaluate model accuracy. All the variables included in the final models had <5% missing data. Analyses were performed using Stata version 18.0 statistical software (StataCorp, College Station, TX).

RESULTS

Baseline characteristics

Our study included a total of 8,842 patients, including 6,329 (71.58%) who underwent AAA repair through the TP approach and 2,513 (28.42%) who underwent AAA repair through the RP approach (Table 1). After stratifying by cross-clamp location, the 4 groups were as follows: infrarenal (4,270; 48.3%), interrenal (1,531; 17.3%), suprarenal (2,492; 28.2%), and supraceliac (549; 6.2%). Compared with the TP group, patients undergoing repair through RP approach were more likely to be women (31.09% vs 25.52%, *p* < 0.001), White (87.50% vs 84.11%, *p* < 0.001), with smoking history (92.91% vs 90.76%, *p* = 0.004), hypertensive (84.93% vs 82.77%, *p* = 0.004), and to have a history of COPD (35.51% vs 33.30%, *p* = 0.048) and chronic kidney

Table 1. Baseline Characteristics

Characteristic	RP	TP	p Value
Total, n (%)	2,513 (28.42)	6,329 (71.58)	—
Age, y, mean (SD)	69.58 (8.08)	68.83 (8.23)	<0.001*
Obesity, BMI >30 kg/m ² , n (%)	719 (28.65)	1,698 (26.89)	0.096
Sex, n (%)			<0.001*
Male	1,731 (68.91)	4,714 (74.48)	
Female	781 (31.09)	1,615 (25.52)	
Race, n (%)			<0.001*
White	2,198 (87.50)	5,320 (84.11)	
Non-White	314 (12.50)	1,005 (15.89)	
Ethnicity, Hispanic or Latino, n (%)	66 (2.64)	160 (2.54)	0.799
Medicare insurance, n (%)	1,323 (54.22)	3,039 (49.43)	<0.001*
Smoking history, n (%)			0.004*
Former smoker	1,199 (47.73)	2,916 (46.10)	
Current smoker	1,135 (45.18)	2,825 (44.66)	
Family history of AAA, n (%)	289 (11.56)	641 (10.16)	0.054
Max AAA diameter, mm, mean (SD)	61 (13)	60 (16)	0.055
Comorbidity, n (%)			
Diabetes	411 (16.37)	1,014 (16.03)	0.696
HTN	2,131 (84.93)	5,230 (82.77)	0.014*
CAD	845 (33.69)	2,166 (34.29)	0.591
CHF	197 (7.85)	486 (7.68)	0.794
COPD	892 (35.51)	2,107 (33.30)	0.048*
Anemia	654 (26.12)	1,593 (25.25)	0.397
CKD	829 (33.43)	1,847 (29.50)	<0.001*
Dialysis	11 (0.44)	29 (0.46)	0.896
Cross-clamp site, n (%)			<0.001*
Infrarenal	746 (17.47)	3,524 (82.53)	
Interrenal	409 (26.71)	1,122 (73.29)	
Suprarenal	1,015 (40.73)	1,477 (59.27)	
Supraceliac	343 (62.48)	206 (37.52)	
Previous procedure, n (%)			
Previous CABG/PCI	694 (27.62)	1,767 (27.93)	0.765
Major amputation	33 (0.52)	10 (0.40)	0.451
Previous bypass/PVI	450 (7.11)	175 (6.96)	0.806
Previous CEA/CAS	129 (5.13)	270 (4.27)	0.077
ASA Class IV–V, n (%)	989 (39.37)	2,323 (36.76)	0.022*
Elective, n (%)	2,170 (86.39)	5,386 (85.14)	0.134
Anesthesia, n (%)			<0.001*
General	1,540 (61.31)	3,453 (54.58)	
General + epidural	972 (38.69)	2,874 (45.42)	
Preoperative medication, n (%)			
P2Y12 inhibitor	227 (9.04)	547 (8.65)	0.563
Statin	1,825 (72.68)	4,613 (72.96)	0.793
Aspirin	1,536 (61.12)	3,937 (62.27)	0.314
Beta-blocker	1,417 (56.41)	3,473 (54.96)	0.217
RAAS inhibitor	1,128 (46.19)	2,827 (45.93)	0.826
Anticoagulant	142 (6.03)	312 (5.22)	0.145

(Continued)

Table 1. Continued

Characteristic	RP	TP	p Value
Surgeon case volume, n (%)			<0.001*
Q1 <25th percentile	720 (25.10)	2,148 (74.90)	
Q2 25th–75th percentile	850 (28.81)	2,100 (71.19)	
Q3 >75th percentile	943 (31.18)	2,081 (68.82)	
Center case volume, n (%)			0.001*
Q1 <25th percentile	840 (28.80)	2,139 (71.80)	
Q2 25th–75th percentile	744 (26.32)	2,083 (73.68)	
Q3 >75th percentile	929 (30.60)	2,107 (69.40)	

*Statistically significant.

AAA, abdominal aortic aneurysm; ASA, American Society of Anesthesiologists; CABG, coronary artery bypass graft; CAD, coronary artery disease; CAS, carotid artery stenting; CEA, carotid endarterectomy; CHF, congestive heart failure; CKD, chronic kidney disease; HTN, hypertension; PCI, percutaneous coronary intervention; PVI, peripheral vascular intervention; RAAS, renin–angiotensin–aldosterone system; RP, retroperitoneal; TP, transperitoneal.

disease (33.43% vs 29.50%, $p < 0.001$). There was no significant difference among both groups with regard to coronary artery disease (33.69% vs 34.29%), obesity, positive family history of AAA (11.56% vs 10.16%), maximum aneurysm diameter (61 ± 13 vs 60 ± 16 mm), previous vascular procedures, or preoperative medications prescribed ($p > 0.05$). The majority of AAA repairs were done through the TP approach; however, the higher the clamp site, the greater the proportion of RP usage. This is demonstrated in the infrarenal group (RP 17.47% vs TP 82.53%), interrenal group (26.71% vs 73.29%), and suprarenal group (40.73% vs 59.27%) and then the majority of cases in the supraceliac group were done through RP exposure (62.48% vs 37.52%, $p < 0.001$). Similarly, the higher the surgeon annual case volume (Q1 RP 25.10% vs TP 74.90%; Q3 31.18% vs 68.82%, $p < 0.001$) and center case volume (Q1 RP 28.80% vs TP 71.80%; Q3 30.60% vs 69.40%, $p = 0.001$), the greater the proportion of RP exposure. In our study, the annual number of open AAA repairs performed in each center quantile were as follows: Q1 (less than 25th percentile) 8 cases or less per year, Q2 (25th to 75th percentile) 9

to 25 cases per year, Q3 (more than 75th percentile) 26 cases or more per year.

There was no significant difference in operative duration between RP and TP in the infrarenal and interrenal groups; however, RP was 0.4 hours shorter in suprarenal (4.1 vs 4.5 hours, $p < 0.001$) and supraceliac groups (4.5 vs 4.9, $p = 0.013$; Table 2). Similarly, there was no significant difference in blood loss volume except in the supraceliac group, where RP had 0.5 L less blood loss (2.3 vs 2.8 L, $p = 0.011$). Finally, more cases with renal bypass and cold perfusion were done via RP approach compared with TP in the suprarenal group (renal bypass 11.5% vs 5.01%, $p < 0.001$; cold perfusion 16.6% vs 9.2%, $p < 0.001$) and in the supraceliac group (renal bypass 23.0% vs 6.3%, $p < 0.001$; cold perfusion 23.9% vs 12.8%, $p = 0.002$).

Univariate analysis

There was no significant difference in in-hospital mortality between RP and TP groups among all clamp sites except in the supraceliac clamp, where TP had around double

Table 2. Operative Data

Variable	Infrarenal			Interrenal			Suprarenal			Supraceliac		
	RP	TP	p Value	RP	TP	p Value	RP	TP	p Value	RP	TP	p Value
Mean operative duration, h*	4.1	4.1	0.760	4.1	4.3	0.124	4.1	4.5	<0.001 [†]	4.5	4.9	0.013 [†]
Mean blood loss, L	1.6	1.7	0.266	1.7	1.8	0.403	1.9	1.9	0.926	2.3	2.8	0.011 [†]
Mean renal ischemia time, min [‡]	—	—	—	28.9	29.1	0.872	30.0	30.9	0.395	30.9	35.3	0.103
Renal bypass, n (%) [‡]	—	—	—	24 (5.9)	67 (6.0)	0.948	117 (11.5)	74 (5.01)	<0.001 [†]	79 (23.0)	13 (6.3)	<0.001 [†]
Cold perfusion, n (%) [‡]	—	—	—	44 (11.0)	97 (8.7)	0.182	167 (16.6)	134 (9.2)	<0.001 [†]	81 (23.9)	26 (12.8)	0.002 [†]

*Operative duration is defined as time from incision to closure.

[†]Statistically significant.[‡]Renal ischemia time, renal bypass, and cold perfusion were only collected for cases with interrenal cross-clamping or higher.

RP, retroperitoneal; TP, transperitoneal.

the rate of mortality (8.7% vs 4.4%, $p = 0.037$; Table 3). Patients requiring suprarenal clamping had a higher rate of 30-day mortality with the TP approach compared with the RP approach (4.9% vs 3.3%, $p = 0.04$) and a trend of higher mortality in the supraceliac group as well (8.3% vs 4.4%, $p = 0.06$). The only group with a significant difference in crude rates of postoperative dialysis was the infrarenal group, with RP at 2.6% vs TP at 1.5% ($p = 0.032$). Regarding bowel ischemia, the TP approach had higher rates compared with the RP approach in the interrenal (5.4% vs 2.2%, $p = 0.008$) and the suprarenal groups (5.1% vs 3.2%, $p = 0.019$). A trend of higher MI with TP compared with RP was evident in the interrenal group (5.6% vs 3.2%, $p = 0.051$); nevertheless, there was no statistically significant difference between both approaches in rates of MI, return to operating room, PLOS, and PLICU regardless of the clamp site ($p > 0.05$). Figure 1 shows the total number of open AAAs performed each year in our study, and Figure 2 illustrates the proportion of RP and TP exposures performed each year. The proportion of RP exposure usage is consistently lower than TP throughout the study period, with insignificant differences in the percentage of RP repairs performed over time according to the trend analysis we performed (30.6% in 2012; 29.3% in 2018; 30.0% in 2024, $p > 0.05$).

Multivariate analysis

After adjusting for potential confounders, the RP approach was associated with overall 74% higher odds of postoperative dialysis compared with TP (adjusted odds ratio [aOR] 1.74, 95% CI 1.07 to 2.83, $p = 0.025$; Table 4). In the interrenal group, on the other hand, the RP approach was associated with a 60% reduced risk of bowel ischemia (aOR 0.40, 95% CI 0.20 to 0.80, $p = 0.009$) and a trend of lower odds of MI (aOR 0.55, 95% CI 0.28 to 1.09, $p = 0.085$). However, no significant differences were found with regard to survival or need for dialysis postoperatively ($p > 0.05$). In contrast, AAA repairs done through the RP approach in patients requiring suprarenal clamping were associated with half the odds of 30-day mortality (aOR 0.48, 95% CI 0.30 to 0.79, $p = 0.004$) and bowel ischemia (aOR 0.52, 95% CI 0.32 to 0.85, $p = 0.009$). Additionally, there was also >30% reduction in odds of postoperative dialysis (aOR 0.66, 95% CI 0.44 to 0.99, $p = 0.048$) and in-hospital death (aOR 0.64, 95% CI 0.41 to 0.99, $p = 0.049$). Similarly, in the supraceliac clamp group, the RP approach was found to be associated with >60% reduction in odds of mortality whether in-hospital (aOR 0.35, 95% CI 0.16 to 0.80, $p = 0.013$) or within the first 30 days (aOR 0.41, 95% CI 0.17 to 0.98, $p = 0.046$).

Table 3. Univariate Analysis of Retroperitoneal vs Transperitoneal Open Abdominal Aortic Aneurysm Repair Stratified by Aortic Cross-Clamp Site

Variable	Infrarenal			Interrenal			Suprarenal			Supraceliac		
	RP	TP	p Value	RP	TP	p Value	RP	TP	p Value	RP	TP	p Value
Total	746 (17.47)	3,524 (82.53)	—	409 (26.71)	1,122 (73.29)	—	1,015 (40.73)	1,477 (59.27)	—	343 (62.48)	206 (37.52)	—
In-hospital mortality	17 (2.28)	91 (2.58)	0.632	15 (3.67)	39 (3.48)	0.857	38 (3.74)	68 (4.60)	0.296	18 (4.37)	18 (8.74)	0.037*
30-d mortality	19 (2.55)	89 (2.53)	0.973	14 (3.42)	39 (3.48)	0.960	33 (3.25)	73 (4.94)	0.040*	15 (4.37)	17 (8.25)	0.060
Dialysis	19 (2.55)	51 (1.45)	0.032*	13 (3.18)	34 (3.04)	0.888	38 (3.74)	69 (4.67)	0.260	14 (4.13)	13 (6.34)	0.250
Bowel ischemia	13 (1.74)	107 (3.04)	0.052	9 (2.20)	60 (5.36)	0.008*	32 (3.15)	75 (5.08)	0.019*	16 (4.72)	14 (6.83)	0.296
MI*	32 (4.29)	171 (4.86)	0.509	13 (3.18)	63 (5.63)	0.051	49 (4.83)	80 (5.42)	0.512	19 (5.60)	13 (6.34)	0.723
RTOR	56 (7.51)	232 (6.59)	0.362	27 (6.60)	83 (7.40)	0.591	86 (8.47)	148 (10.03)	0.191	47 (13.86)	31 (15.12)	0.685
PLOS	232 (31.10)	1,186 (33.65)	0.178	149 (36.43)	434 (38.68)	0.422	422 (41.58)	626 (42.38)	0.688	196 (57.14)	110 (53.40)	0.392
PLICU	145 (19.46)	646 (18.37)	0.485	91 (22.36)	279 (24.91)	0.303	293 (28.87)	439 (27.74)	0.637	135 (39.94)	82 (40.39)	0.917

Data presented as n (%).

*Statistically significant.

PLICU, prolonged length of ICU stay >4 d; PLOS, prolonged length of hospital stay >7 d; RP, retroperitoneal; RTOR, return to operating room; TP, transperitoneal.

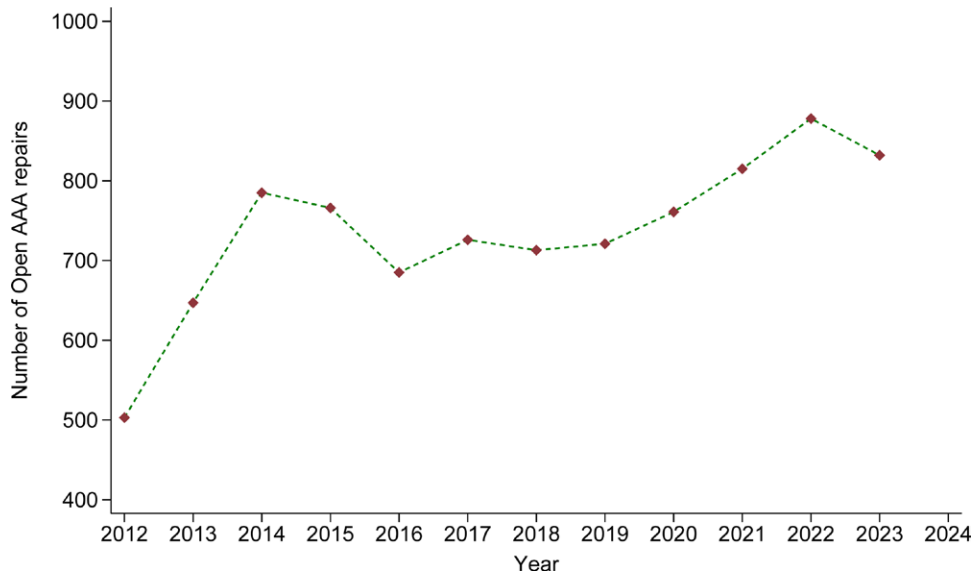


Figure 1. Number of AAA repairs performed each year. AAA, abdominal aortic aneurysm.

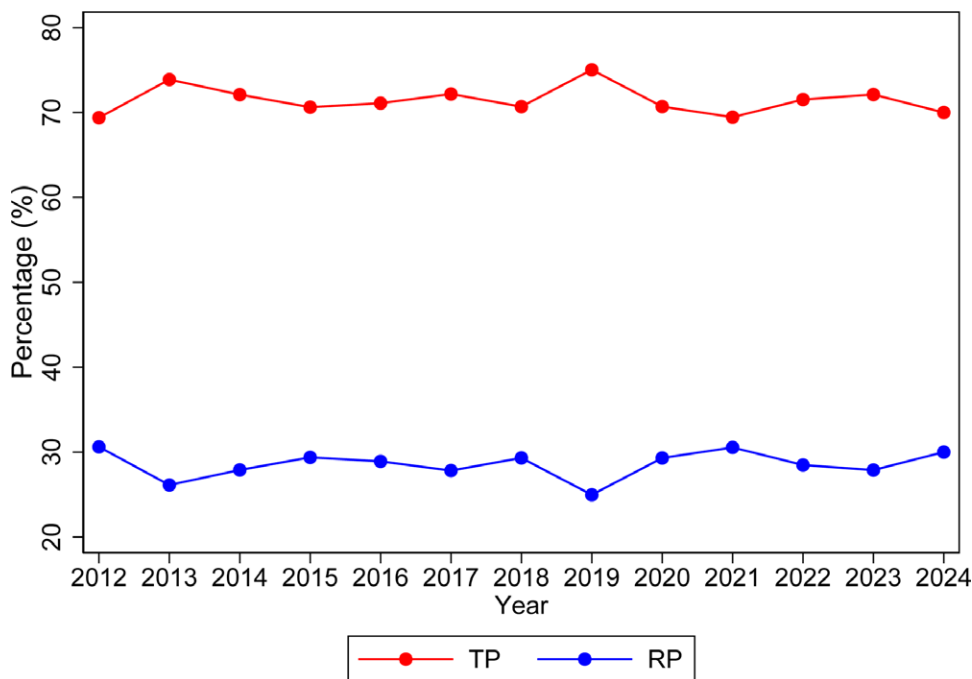


Figure 2. Proportion of RP and TP exposures performed each year. RP, retroperitoneal; TP, transperitoneal.

compared with the TP approach. The risk of respiratory complications was similar in both exposure techniques in the infrarenal group (8.85% vs 7.67%; aOR 1.06, 95% CI 0.63 to 1.77, $p = 0.827$). Finally, similar to univariate analysis, there were no statistically significant differences in outcomes of RP vs TP approach in odds of MI, return to operating room, PLOS, and PLICU regardless of the location of the aortic cross-clamp ($p > 0.05$).

DISCUSSION

This study examined postoperative outcomes of 8,842 patients undergoing elective infrarenal AAA repair via either the RP or TP approach, stratified by clamp site. Among patients undergoing infrarenal cross-clamping, the RP approach was associated with substantially higher odds of dialysis. In contrast, the RP approach was associated with the greatest reduction in adverse outcomes for

Table 4. Multivariate Analysis of Retroperitoneal vs Transperitoneal Open Abdominal Aortic Aneurysm Repair Stratified by Aortic Cross-Clamp Site

Variable	Infrarenal			Interrenal			Suprarenal			Supraceliac		
	aOR	95% CI	p Value	aOR	95% CI	p Value	aOR	95% CI	p Value	aOR	95% CI	p Value
In-hospital mortality	0.85	0.47–1.52	0.572	1.03	0.58–1.83	0.922	0.64	0.41–0.99	0.049*	0.35	0.16–0.80	0.013*
30-d mortality	1.07	0.60–1.90	0.824	0.98	0.51–1.88	0.953	0.48	0.30–0.79	0.004*	0.41	0.17–0.98	0.046*
Dialysis	1.74	1.07–2.83	0.025*	1.08	0.56–2.08	0.821	0.66	0.44–0.99	0.048*	0.75	0.33–1.72	0.500
Bowel ischemia	0.56	0.28–1.15	0.114	0.40	0.20–0.80	0.009*	0.52	0.32–0.85	0.009*	0.62	0.30–1.28	0.200
MI	0.92	0.52–1.64	0.785	0.55	0.28–1.09	0.085	0.91	0.57–1.47	0.702	0.86	0.40–1.84	0.702
RTOR	1.14	0.85–1.53	0.390	0.86	0.53–1.39	0.532	0.83	0.64–1.07	0.151	0.82	0.50–1.37	0.455
PLOS	0.93	0.78–1.10	0.386	0.92	0.72–1.18	0.535	0.92	0.74–1.14	0.432	1.01	0.67–1.52	0.971
PLICU	0.99	0.76–1.29	0.922	0.83	0.59–1.17	0.291	0.94	0.70–1.27	0.706	0.98	0.64–1.52	0.934

*Statistically significant.

aOR, adjusted odds ratio; PLICU, prolonged length of ICU stay >4 d; PLOS, prolonged length of hospital stay >7 d; RP, retroperitoneal; RTOR, return to operating room; TP, transperitoneal.

patients with suprarenal clamps, as they experienced lower odds of dialysis, bowel ischemia, and 30-day mortality. When examining supraceliac clamp site, this study found RP to be associated with lower in-hospital and 30-day mortality. However, there was no mortality benefit after RP access for patients undergoing interrenal clamping, although they did experience a substantial 60% decreased odds of bowel ischemia. The RP approach was associated with dramatically decreased odds of mortality for suprarenal and supraceliac clamp sites and maintained lower rates of key adverse outcomes across clamp locations, with the exception of dialysis among infrarenal clamping. These results suggest that there is a benefit in using the RP over TP approach for the open treatment of infrarenal aortic aneurysms in cases where a proximal clamp location is necessary.

Open repair via either RP or TP approaches is less common than endovascular management in the current endovascular era; however, it is associated with better long-term outcomes.^{1–6} The location of aortic cross-clamping has been clearly demonstrated to mediate key adverse outcomes after open repair, with suprarenal clamping being associated with an increased risk of renal complications and supraceliac clamp site is associated with increased cardiac morbidity.¹³ However, our study is the first to demonstrate an interaction between the cross-clamp level and operative approach, where we were able to show that outcomes of either exposure technique were affected by the clamp site.

The TP approach for AAA repair is a standard vascular procedure, predating the RP approach by nearly 30 years.¹⁴ However, since the posterolateral incision was adopted for RP access in 1980, this approach has been increasingly used for the repair of complex aneurysms in higher-risk patients, as it results in less blood loss, a more

stable core body temperature, and quicker return of bowel function.^{2,14,15} The RP approach offers better visualization of the suprarenal aorta, with the additional benefit of leaving the peritoneum undisturbed.¹⁴ Previous studies examining the results of TP AAA repair have identified pulmonary complications as the most significant factor contributing to adverse events and prolonged hospital stays.^{16,17} However, after adjusting for confounders, our study found no difference in hospital stay or ICU stay between approaches. Additionally, the TP approach is associated with greater postoperative pain, which can limit ventilation and predispose patients to respiratory complications.^{16,18,19} The elevated postoperative opioid use necessary to control pain can also cause respiratory depression leading to alveolar collapse and pneumonia.^{18,20} The RP approach, on the other hand, avoids disturbing the peritoneal cavity and transecting the rectus abdominus, precluding these complications. Therefore, even among patients with complex pararenal aneurysms, the RP approach has demonstrated more favorable outcomes, namely decreased systemic inflammation; lower multiple organ dysfunction scores; and rates of renal, pulmonary, and gastrointestinal complications, along with shorter hospital stays.^{15,16,21,22}

However, both RP and TP approaches provide access to all clamp sites, and indications for one approach over the other given a particular clamp site are unclear.^{16,21,22} Not all infrarenal AAAs are amenable to infrarenal clamping commonly due to a hostile infrarenal aortic neck, extension of the aneurysm into the level of the renal arteries, or concomitant renal artery stenosis requiring concomitant revascularization.^{11,12} Therefore, open surgical treatment of infrarenal AAAs may necessitate suprarenal or even supraceliac clamp sites, depending on certain anatomical factors.

In our analysis, the RP approach was associated with significantly lower rates of in-hospital and 30-day mortality, as well as dialysis and bowel ischemia, than TP for suprarenal clamp sites. Suprarenal clamping is well known to be associated with greater risk of dialysis due to extended periods of reduced renal blood flow.²³ Although exposure of the proximal abdominal aorta allows visualization and clamping at the level of renal and visceral arteries to be performed, the RP approach is preferred for its more expansive exposure and easier visualization of the abdominal aorta at this site.¹⁰ One single-center prospective study showed that the TP approach with suprarenal clamping resulted in longer clamp times and significantly greater blood loss than the RP approach.¹⁰

Previous literature has demonstrated that RP approaches to AAA repair are associated with significantly lower rates of perioperative mortality; however, our study only found that to hold true among patients undergoing suprarenal and supraceliac clamping.¹⁶ The aorta above the level of the renal arteries, as previously mentioned, is more easily visualized via an RP approach than a TP approach; hence, many are proponents of RP access for this very reason.^{10,14,22} Similarly, in our study, the proportion of patients who underwent AAA repair through the RP approach increases the more proximal the clamp site is (RP infrarenal 17.47%, interrenal 26.71%, suprarenal 40.73%, and supraceliac 62.48%). Although other prospective work has found equivocal use of both approaches for proximal clamp sites, this is mainly due to surgeon preference in the absence of clear indications.²⁴

Supraceliac clamping is indicated in the case of rupture, significant inflammation, concomitant renal or mesenteric revascularization, or juxtarenal aneurysm repair.¹¹ The significantly lower rates of in-hospital and 30-day mortality associated with the RP approach are likely owing to its association with lower rates of postoperative complications. Although the present study found that an RP approach was associated with significantly lower mortality risk for supraceliac and suprarenal clamping, it had no association with interrenal clamping mortality. Interrenal clamping has been demonstrated to carry an even higher risk of bowel and kidney ischemia than suprarenal or supraceliac clamp locations; however, the reason behind that was due to concomitant longer visceral ischemia times reported in one of the studies.²⁵ Our study, on the other hand, found no difference in RP vs TP at interrenal cross-clamp location except for lower odds of bowel ischemia. Additionally, distal infrarenal cross-clamp patients experienced no mortality benefit via the RP approach but higher odds of dialysis, a complication typically avoided in this clamp location.¹³ Reasons behind the higher risk of renal complications with RP exposure in the infrarenal group

are unclear and have not been explained by other studies in the literature. Nevertheless, the advantage of the RP approach therefore appears to manifest at higher clamp levels.

The optimal cross-clamp site for any given aneurysm is typically determined during preoperative planning based on CT scans. However, the use of RP vs TP exposures is surgeon dependent. This study indicates that the RP approach may be superior for suprarenal clamping. Aneurysms requiring suprarenal clamp sites are typically more complicated; therefore, the results of this study indicate that more complex aneurysms requiring suprarenal clamping may be associated with fewer adverse outcomes and lower mortality if done via the RP approach. However, there has been a trend of a decrease in the proportion of open AAA repairs done via the RP approach since 2015.⁶ This is despite the ever-increasing evidence that the RP approach holds an overall survival benefit.²⁻⁶ The TP approach is considered more straightforward and arguably easier to learn, and therefore, it is more accessible for vascular surgeons predominately familiar with endovascular techniques. Due to its higher complexity, the RP approach is more commonly performed in high-volume centers, where surgeons have greater exposure to open cases and opportunities for learning this technique. However, the overall decrease in RP use and its localization to fewer centers are seen to represent a loss of expertise in the field of vascular surgery.⁶ However, our study clearly demonstrates that patients with proximal clamp sites experience benefits in survival, renal function, and bowel ischemia after intervention through the RP approach compared with TP, and therefore, this method should be of focus in training. Vascular surgeons must maintain the ability to repair AAAs via either the TP or RP approach, as indicated by patient-specific anatomy, and not be limited by familiarity to ensure optimal outcomes.

Limitations

This study has several limitations. First, being of a retrospective design and nonrandomized in nature makes it liable for selection bias. The presence of unmeasured confounders, such as the physician's or patient's preference, the physician's technical skills regardless of case volume, and center-level policies, might impact the procedure choice and contribute to this selection bias. In addition, data regarding any unplanned change in the cross-clamp location to a more proximal level are also not provided by the dataset. However, we attempted to adjust for all other potential measurable confounders reported in the dataset, and observations were clustered in each center to reduce the bias from unmeasurable hospital-level factors

and to account for intergroup correlations. Our patient population was derived from self-reported data, which are vulnerable to human and coding errors during data entry. However, data validation is accomplished by comparing data entered in the VQI registry with claims data provided by the participating center on an annual basis, ameliorating any inconsistencies if found.

CONCLUSIONS

In this large multi-institutional retrospective study, outcomes of open AAA repair approaches (RP vs TP) were found to be modified by aortic cross-clamping site. RP was associated with lower risk of bowel ischemia in cases requiring clamping above 1 or both renal arteries compared with AAA repairs done via TP exposure. Similarly, compared with the TP approach, the RP group was associated with a reduced need for dialysis if a suprarenal clamping was required, as well as better postoperative survival with suprarenal or supraceliac aortic clamping. In contrast, TP approach had lower risk of renal complications in cases restricted to infrarenal clamping. Therefore, the RP approach is preferred over TP in open AAA repairs requiring clamping above the renal arteries. Training programs should focus on training future vascular surgeons to be comfortable performing AAA repairs via either approach, as indicated by patient-specific anatomy.

Author Contributions

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Invited Commentary

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Sir Astley Cooper, a British surgeon and anatomist, was first to suggest the retroperitoneal (RP) approach to the abdominal aorta in 1817. The first successful open infrarenal aortic aneurysm repair was performed by Charles Dubost, a French surgeon, in 1951. He used a homograft, because prosthetic grafts had not been invented yet, and the repair was completed through the left RP approach.¹ Since that time, there have been many innovations in aortic surgery, both in open and endovascular techniques. The advantages of the left RP approach to open aortic surgery are clear in the following cases: juxta or suprarenal aneurysms, inflammatory aneurysms, presence of a horseshoe kidney, and the existence of a hostile abdomen. In addition, redo and complex aortic operation are best performed through the RP approach.² Most surgeons are quite familiar and comfortable with the transabdominal approach. The latter is favored in thin patients with no abdominal scarring and allows unhindered access to the right iliac vessels when a bifurcated graft is needed.

Several randomized trials failed to show a survival advantage with the RP approach.³ However, patients who had

an RP approach showed a tendency for decreased ICU and hospital stay. In 1 randomized trial that included patients with aneurysm and aortic occlusive disease, whereas there was no survival advantage of 1 technique over the other, there were significantly lower hospital costs and complications associated with the RP approach. This can likely be attributed to a slightly faster recovery compared with the transabdominal approach.^{2,3}

In this article, the authors review the Vascular Quality Initiative database spanning 12 years, ending in 2024, and included more than 8,800 patients in their analysis. There were 2,513 patients (28.4%) who received the RP approach. They made an important observation that as the need from proximal clamping increased, the proportion of RP patients also increased, from 17% in infrarenal, 27% intrarenal, 41% suprarenal, and 62% supraceliac. Additionally, they observed a significantly higher number of patients in the RP group requiring renal bypass or cold perfusion when suprarenal or supraceliac clamping was performed. They also observed that there were fewer patients in the transperitoneal (TP) infrarenal clamp group that required dialysis. On the other hand, bowel ischemia was more frequent if clamping higher than the renals was required in the TP group. There was no survival advantage of 1 approach over the other.

This large review of cases confirms the findings of many other studies and a Cochrane review that there is no survival advantage for 1 technique over the other.^{3,4} However, certain patient-specific or anatomical features favor the use of the RP approach, particularly when the suprarenal aorta needs to be exposed for proximal control.^{5,6} The RP approach can be extended more proximally quite easily. Open thoracoabdominal aortic operation uses essentially an RP approach; the question becomes how high of a thoracotomy is needed. The advantages of the RP approach include the avoidance of intra-abdominal contents and ready access to the proximal aorta. Perhaps the avoidance of retraction of abdominal contents helps decrease postoperative ileus and reduces insensible fluid losses from the exposed bowel surfaces and lessens fluid shifts. Patients who had an RP approach tend to have a faster return of bowel function, and perhaps less significant abdominal pain that could interfere with proper pulmonary toilet. Many authors have also observed less blood loss with RP approach and lower incidence of pneumonia.³ Also, access to all the visceral vessels (except the right renal) is easier. The disadvantages of the RP approach are that contemporary surgeons are less familiar with it because open aortic operation in the US has decreased overall with the shift of >80% of cases to endovascular repair. Because the patient is positioned in the right lateral decubitus, access to the right renal artery and the right iliac vessels is technically more difficult, if direct repair is needed.