Is incidental splenectomy during thoracoabdominal aortic aneurysm repair associated with reduced survival?

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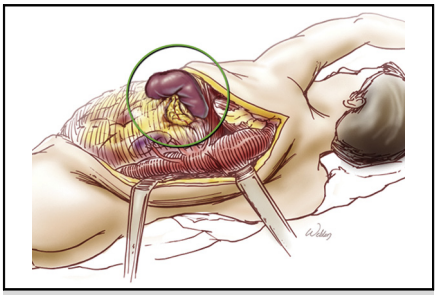
ABSTRACT

Objective: The effect of incidental splenectomy during thoracoabdominal aortic aneurysm repair is unknown. We hypothesized incidental splenectomy was associated with decreased late survival.

Methods: We studied 1056 thoracoabdominal aortic aneurysm repairs from 2006 to 2016. Exclusion criteria were age less than 18 years (n = 9), prior splenectomy (n = 2), and intraoperative death (n = 3). This left 1042 thoracoabdominal aortic aneurysm repairs for analysis (median age, 65 years; interquartile range, 56-72), including 221 (21%) that were reoperations. Multivariable modeling identified predictors of operative mortality in the total cohort. Moreover, to adjust for baseline differences, propensity score matching was performed to examine the frequency of these outcomes in the total cohort (n = 132 pairs) and the early survivors (n = 110 pairs). Late survival was estimated by the Kaplan–Meier method, and risk of late mortality was assessed by Cox proportional hazards regression.

Results: Incidental splenectomy was performed in 135 patients (13%), 36% of whom underwent reoperation. Operative mortality rates of the incidental splenectomy and nonincidental splenectomy groups were 16% versus 8% in both the overall study ($P = .005$) and the propensity score–matched ($P = .07$) cohorts. In multivariable analysis, incidental splenectomy independently predicted operative mortality (odds ratio, 2.2; 95% confidence interval, 1.21-3.94; $P = .008$). For early survivors, incidental splenectomy did not increase the risk of late mortality. Survival estimates of matched early survivors did not differ between the incidental splenectomy and nonincidental splenectomy groups ($P = .29$).

Conclusions: Incidental splenectomy during thoracoabdominal aortic aneurysm repair was associated with increased operative mortality but not reduced late survival. Splenic preservation is encouraged when feasible. (J Thorac Cardiovasc Surg 2020;160:641-52)



In thoracoabdominal aneurysm repair, adhesions or traction can cause splenic injury.

Central Message

Operative death was increased in patients who underwent IS during TAAA repair, but among the early survivors, late survival was not adversely affected.

Perspective

IS may be performed during TAAA repair because of dense adhesions from previous surgery or concern about postoperative hemorrhage. Patients undergoing reoperation are more likely to have an IS. Splenectomy at the time of TAAA repair is associated with increased operative mortality. However, IS does not seem to adversely affect late survival.

See Commentaries on pages 653 and 654.

Incidental splenectomy (IS) is defined as splenectomy performed not when the primary indication for surgery is splenic pathology, but for technical reasons to facilitate the primary operation or avoid splenic hemorrhage. Surgical reports regarding gastrointestinal (GI) malignancies

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Abbreviations and Acronyms
GI = gastrointestinal
IS = incidental splenectomy
PSM = propensity score matching
TAAA = thoracoabdominal aortic aneurysm

have shown unfavorable outcomes for IS. An esophagectomy series showed that IS was associated with increased operative mortality,[1] whereas reports of gastric,[2] pancreatic,[3] and colorectal[4] resections for malignancy demonstrated that IS was associated with decreased 5-year (midterm) survival.

Approximately 20% of all splenic procedures performed in the United States are necessitated by iatrogenic splenic injuries.[5] The risk of splenic injury has been described for colonoscopy,[6] liver resection,[7] liver transplantation,[8] nephrectomy,[9] and anterior thoracolumbar spine surgery using a thoracoabdominal incision.[10] IS risk factors include adhesions from previous operations, proximity of a primary GI tumor to the spleen, morbid obesity, advanced age, and left upper quadrant incisions.[11] The true incidence of IS may be difficult to assess accurately. Some researchers attribute this to the perception that IS is the surgeon's fault, observing that IS is not always recorded in operative notes and statistics.[12]

In the largest contemporary series of thoracoabdominal aortic aneurysm (TAAA) repairs, it was noted that 12% of patients underwent splenectomy.[13] Little is known about the outcomes of IS in patients undergoing TAAA repair. We hypothesized that IS is associated with decreased short-term and late patient survival.

MATERIALS AND METHODS

Study Enrollment and Patient Characteristics

Baylor College of Medicine's institutional review board approved our research protocol in 2006 (BCM H-18095). Most clinical data were collected prospectively, and informed consent was obtained whenever possible. A waiver of consent was approved for patients who were unable to provide consent.

Between January 2006 and January 2016, 1056 open TAAA repairs were performed by our single-practice service. For this study, we excluded patients aged less than 18 years (n = 9), patients who died intraoperatively (n = 3), and patients with a previous splenectomy (n = 2). The remaining 1042 repairs were analyzed. A total of 129 patients (12.4%) underwent IS at the time of TAAA repair. Of the 913 patients who did not undergo IS, 32 (3.5%) required reoperation for bleeding. Six (19%) of those patients were found to have splenic bleeding and subsequently underwent splenectomy; 4 had returned within 24 hours of the initial surgery, and 2 had returned between postoperative days 4 and 5. These 6 patients combined with the original 129 patients who underwent IS during the original TAAA repair constituted the IS group of 135 patients (13%).

Study Definitions and Follow-up

All data were collected using standard definitions, as recently reported.[13] Operative death was defined as death within 30 days of surgery or before final hospital discharge from any hospital. The composite end point "adverse event" comprised operative death or persistent (ie, present at hospital discharge) stroke, paraplegia, paraparesis, or renal failure necessitating dialysis.[14] "Life-altering complication" was defined as persistent stroke, paraplegia, paraparesis, or renal failure necessitating dialysis. Coronary artery disease was defined as any history of angina, myocardial infarction, percutaneous coronary intervention, or coronary artery bypass grafting. Cerebrovascular disease included any history of transient ischemic attack, stroke, carotid endarterectomy, or cerebral aneurysm. Pulmonary disease was defined as having a history of chronic obstructive pulmonary disease or asthma. Chronic kidney disease included an estimated glomerular filtrate rate less than 60 mL/min/1.73 m^2. Cerebral complication included stroke, transient ischemic attack, seizure, intracranial hemorrhage, or encephalopathy. Cardiac complication included any arrhythmias; new heart failure; myocardial infarction; implantation of a defibrillator, pacemaker, or intra-aortic balloon pump; or pericardial tamponade. Pulmonary complication consisted of acute respiratory distress syndrome, chylothorax, pleural effusion, atelectasis, pneumothorax needing intervention, respiratory failure (mechanical ventilation >72 hours), or tracheostomy. GI complications included GI bleeding, mesenteric ischemia, bowel obstruction, or pancreatitis. Reoperation was defined as an operation performed after any previous operation performed through an abdominal, thoracoabdominal, or left thoracotomy incision; it did not include prior median sternotomy. Prior distal aortic repair was any previous open or endovascular repair of the descending thoracic, thoracoabdominal, or abdominal aorta. At least 30 days of clinical follow-up data were available for 98.4% (937/952) of the early survivors (who comprised 99.1% [112/113] of the IS cases and 98.3% [825/839] of the non-IS cases); median follow-up time for these 937 patients was 3.8 years (interquartile range, 1.4-5.3 years). For patients without 30-day follow-up, complications were only captured if they presented before hospital discharge. Late survival indicated vital status after hospital discharge. To identify late deaths after repair, we used clinical or family correspondence, the Social Security Death Index, and internet obituary searches. Early cause of death was adjudicated by a senior investigator (S.A.L.) after research team review.

Surgical Techniques

A more complete description of our operative strategy has been described.[15] We routinely used moderate systemic heparinization (1.0 mg/kg), mild passive hypothermia (32°C-34°C), and cold renal perfusion (4°C) when feasible. For extensive TAAA repairs (Crawford extents I and II), we typically used left heart bypass, cerebrospinal fluid drainage, reattachment of intercostal or lumbar arteries, and selective visceral perfusion with isothermic blood. Before closure, a closed suction drain was placed in the splenic bed and removed after 48 to 72 hours. For reoperative repairs, we followed the same principles with careful adhesiolysis during exposure. During medial visceral rotation from left to right, the spleen was more vulnerable to traction and was carefully inspected at the start and conclusion of the aortic repair. Occasionally, small lacerations or capsular tears were treated with cautery and hemostatic agents to avoid splenectomy. If there was significant concern about bleeding from an injury, then a splenectomy was performed.

Statistical Analysis

Statistical analyses were performed with SAS version 9.4 (SAS Institute, Inc, Cary, NC), Stata version 14 (StataCorp, LLC, College Station, Tex), or IBM SPSS Statistics 24 (IBM Corp, Armonk, NY). Continuous variables are presented as mean ± standard deviation or median (interquartile range), and categoric variables are shown as number and percentage. Categoric data were compared by using the Pearson chi-square test, Fisher exact test, 2-sample independent *t* test, and nonparametric Wilcoxon rank-sum test, as appropriate.

TABLE 1. Preoperative characteristics of 1042 patients who underwent thoracoabdominal aortic aneurysm repair with or without splenectomy

Variable	Study cohort			
	All (n = 1042)	With splenectomy (n = 135)	Without splenectomy (n = 907)	*P* value
Median age, y	65 [56-72]	65 [55-70]	65 [56-72]	.8
Mean age, y	62.9 ± 13.0	63.1 ± 12.3	62.9 ± 13.0	.8
Male	675 (64.8)	78 (57.8)	597 (65.8)	.07
Genetic disorder	160 (15.4)	18 (13.3)	142 (15.7)	.5
Marfan syndrome	128 (12.3)	15 (11.1)	113 (12.5)	.7
Prior open distal aortic repair	189 (18.1)	43 (31.9)	146 (16.1)	<.001
Aortic aneurysm without dissection	576 (55.3)	80 (59.3)	496 (54.7)	.3
Aortic dissection	466 (44.7)	55 (40.7)	411 (45.3)	.3
Acute or subacute	42 (4.0)	5 (3.7)	37 (4.1)	.8
Chronic	424 (40.7)	50 (37.0)	374 (41.2)	.4
Hypertension	941 (90.3)	121 (89.6)	820 (90.4)	.8
Diabetes	122 (11.7)	10 (7.4)	112 (12.3)	.1
Coronary artery disease	352 (33.8)	55 (40.7)	297 (32.7)	.07
Cerebrovascular disease	186 (17.9)	23 (17.0)	163 (18.0)	.8
Peripheral vascular disease	353 (33.9)	42 (31.1)	311 (34.3)	.5
Chronic kidney disease	404 (38.8)	59 (43.7)	345 (38.0)	.2
Pulmonary disease (COPD or asthma)	336 (32.2)	54 (40.0)	282 (31.1)	.04
Symptomatic				
Acute	179 (17.2)	31 (23.0)	148 (16.3)	.06
Chronic	581 (55.8)	81 (60.0)	500 (55.1)	.3
Aortic rupture	61 (5.9)	10 (7.4)	51 (5.6)	.4

Values shown as n (%) or median [interquartile range]. *COPD*, Chronic obstructive pulmonary disease.

Multivariable logistic regression, overall cohort (n = 1042): Our primary analysis was to identify independent predictors of operative death after TAAA repair among our 1042 patients by comparing the 2 groups (IS vs non-IS), and we built multivariable logistic regression models by using clinically important variables with a univariate *P* value less than .1 in association with the outcomes of interest. We applied a backward selection method with a removal *P* value of .15 to select variables into the final logistic regression model. The following 18 preoperative and operative variables were included: age, sex, acute symptoms, hypertension, cerebrovascular disease, coronary artery disease, peripheral vascular disease, pulmonary disease, urgent or emergency status, aortic clamp time, renal or visceral stenting/bypass/endarterectomy, TAAA extent, left heart bypass, cold renal perfusion, cerebrospinal fluid drainage, reoperation, rupture, and chronic kidney disease. A variance inflation factor 10 or more was used to screen for multicollinearity. The model fit was assessed by the Hosmer–Lemeshow goodness-of-fit test and receiver operating characteristic curves (c-statistics).

Cox proportional hazards regression analysis, hospital survivors (n = 952): To assess risk factors for late mortality among early survivors, 8 variables (age, aortic dissection, coronary artery disease, chronic kidney disease, aortic rupture, reoperation, and life-altering complication) were identified for model entry after univariate analysis, and 1 variable (IS) was forcefully entered into the Cox regression model. The assumption of proportional hazards was assessed with scaled Schoenfeld residuals.

Propensity score matching (PSM) of the overall cohort (n = 1042) and early survivors (n = 952): With a sensitivity analysis, we analyzed the entire cohort (n = 1042) by performing 1-to-1 matching without replacement by propensity score, using the nearest neighbor method with a caliper of 0.25 standard deviation of the logit. The balance in baseline covariates of matched data was examined by using standardized differences. In the overall cohort, 132 pairs were matched. After excluding operative deaths, we also analyzed the 952 early survivors with a similar 1-to-1 PSM without replacement. In the cohort of early survivors, 110 pairs were matched.

Survival analysis of early survivors (n = 952) and matched survivors (n = 110): Kaplan–Meier analysis was used to estimate survival. Groups were compared by using the stratified log-rank test.

RESULTS

Preoperative Patient Characteristics

The preoperative characteristics of the IS and non-IS groups are presented in Table 1. In the overall cohort, the IS group had more patients with previous open distal aortic repair (31.9% vs 16.1%, $P < .001$) than the non-IS group. The IS group also had more patients with pulmonary disease (40.0% vs 31.1%, $P = .04$). After PSM, there were 132 pairs of patients with and without IS (Table 2); the IS and non-IS groups were comparable.

Operative Details

In the overall cohort, extent II TAAA repairs were less frequent in the IS group than in the non-IS group (24.4%

TABLE 2. Preoperative characteristics of 264 propensity-matched patients who underwent thoracoabdominal aortic aneurysm repair with or without splenectomy

Variable	All (n = 264)	Propensity-matched		
		With splenectomy (n = 132)	Without splenectomy (n = 132)	Standardized mean difference
Mean age, y	62.8 ± 13.0	63.2 ± 12.3	62.4 ± 13.7	.06
Male	146 (55.3)	76 (57.6)	70 (53.0)	.09
Hypertension	233 (88.3)	118 (89.4)	115 (87.1)	.07
Coronary artery disease	102 (38.6)	52 (39.4)	50 (37.9)	.03
Cerebrovascular disease	50 (18.9)	23 (17.4)	27 (20.5)	.08
Peripheral vascular disease	88 (33.3)	42 (31.8)	46 (34.8)	.06
Chronic kidney disease	115 (43.6)	57 (43.2)	58 (43.9)	.02
Pulmonary disease (COPD or asthma)	104 (39.4)	52 (39.4)	52 (39.4)	<.001
Acute symptoms	63 (23.9)	29 (22.0)	34 (25.8)	.09
Aortic rupture	18 (6.8)	10 (7.6)	8 (6.1)	.06

Values shown as n (%) or median [interquartile range]. *COPD*, Chronic obstructive pulmonary disease.

vs 33.4%, $P = .04$) (Table 3). The IS group also had more patients undergoing reoperation (36.3% vs 19.0%, $P < .001$) than the non-IS group. There was significantly more transfusion of all blood products in the IS group ($P < .001$). There was no significant difference in the rates of cold renal or selective visceral perfusion, or in the management of the renal or visceral vessels. After PSM, the IS and non-IS groups were comparable (Table 4).

Early Outcomes

The overall operative mortality rate was 8.8% for the study cohort (90/1027) and 12.2% for the PSM cohort (32/262) (Tables 5 and 6). In the univariate analysis, the IS group had higher rates of operative mortality (16.3% vs 7.5%, $P = .001$), adverse events (24.4% vs 14.9%, $P = .005$), renal failure with persistent dialysis (13.3% vs 6.5%, $P = .005$), and respiratory failure (39.3% vs 28.3%, $P = .01$) than the non-IS group. The IS group (9.7%) and non-IS group (8.0%, $P = .3$) had comparable rates of discharge with a life-altering complication. The IS group also had higher rates of GI complications (9.6% vs 3.0%, $P < .001$), septic complications (10.4% vs 2.9%, $P = .02$), and reoperation for bleeding (10.4% vs 2.9%, $P < .001$). For patients with IS, the operative mortality rate was 54% (7/13) for those with GI complications, 60% (9/15) for those with sepsis, and 36% (5/14) for those requiring reoperation for bleeding. After PSM, the operative mortality rate was higher for the IS group than for the non-IS group (15.9% vs 8.3%, $P = .07$), although this difference did not reach statistical significance. In addition, the matched IS group had higher rates of sepsis (11.4% vs 4.5%, $P = .046$), respiratory failure (39.4% vs 27.3%, $P = .04$), and tracheostomy (18.9% vs 9.8%, $P = .04$). The rate of discharge with life-altering complications was 9.9% in the IS group versus 14.9% in the non-IS group ($P = .3$) in the matched cohort. Of the 113 early survivors who underwent IS, 105 (93%) received triple vaccination against *Streptococcus pneumoniae, Haemophilus influenzae* type B, and *Neisseria meningitides* during the index hospitalization.

A multivariable analysis identified several independent risk factors of operative mortality (Table 7), one of which was IS (odds ratio, 2.22; $P = .008$). Additional risk factors included chronic kidney disease and Crawford extent II TAAA repair. Notably, reoperation was not found to be predictive of operative mortality.

Analysis of Early Mortality Cohort

To determine whether causes of death differed between the IS and non-IS groups, we examined the cohort of 90 patients who had operative or early deaths. We found that the IS group had higher incidences of bleeding requiring re-operation (22.7% vs 5.9%, $P = .02$) and GI complications (31.8 vs 11.8%, $P = .03$) than the non-IS group (Table E1). When the primary cause of death was analyzed for this early mortality cohort, no significant differences were found between the IS and non-IS groups (Table E2).

Late Outcomes

In the Kaplan–Meier analysis of the 952 early survivors, the 5-year survival estimate was 61.9% ± 5.2% for the IS group (n = 113) and 71.6% ± 1.9% for the non-IS group (n = 839) ($P = .085$, Figure 1). A PSM analysis of the early survivors yielded 110 matched pairs among hospital survivors (Table E3). In the Kaplan–Meier analysis of these 110 propensity-matched pairs, the 5-year survival estimates for the IS and non-IS groups were 63.1% ± 5.2% and 77.7% ± 4.7%, respectively ($P = .29$, Figure 2).

TABLE 3. Operative details of 1042 patients who underwent thoracoabdominal aortic aneurysm repair with or without splenectomy

Variable	Study cohort			
	All (n = 1042)	With splenectomy (n = 135)	Without splenectomy (n = 907)	*P* value
Urgency of operation				
Elective	795 (76.3)	94 (69.6)	701 (77.3)	.051
Urgent or emergency	247 (23.7)	41 (30.4)	206 (22.7)	.051
Extent of repair				
Extent I	257 (24.7)	32 (23.7)	225 (24.8)	.8
Extent II	336 (32.2)	33 (24.4)	303 (33.4)	.04
Extent III	201 (19.3)	32 (23.7)	169 (18.6)	.2
Extent IV	248 (23.8)	38 (28.1)	210 (23.2)	.2
Aortic repair details				
Reoperation	221 (21.2)	49 (36.3)	172 (19.0)	<.001
Aortic clamp time, min	54 [41-70]	55 [43-71]	54 [41-70]	.4
Celiac unprotected time, min	33 [25-43] (n = 1020)	38 [27-48] (n = 130)	33 [25-43] (n = 890)	.2
SMA unprotected time, min	33 [25-43] (n = 1033)	37 [27-47] (n = 133)	33 [25-43] (n = 900)	.3
Right renal unprotected time, min	33 [25-43] (n = 994)	35 [26-47] (n = 127)	33 [25-42] (n = 867)	.5
Left renal unprotected time, min	39 [27-51] (n = 996)	41 [28-55] (n = 129)	38 [27-51] (n = 867)	.2
Management of visceral/renal arteries				
Bypass graft	502 (48.2)	71 (52.6)	431 (47.5)	.3
Endarterectomy	334 (32.1)	45 (33.3)	289 (31.9)	.7
Stenting	136 (13.1)	18 (13.3)	118 (13.0)	.9
Endarterectomy, stenting, or bypass	619 (59.4)	85 (63.0)	534 (58.9)	.4
Adjuncts				
Cerebrospinal fluid drainage	821 (78.8)	102 (75.6)	719 (79.3)	.3
Left heart bypass	546 (52.4)	59 (43.7)	487 (53.7)	.03
Cold renal perfusion	816 (78.3)	114 (84.4)	702 (77.4)	.2
Selective perfusion of visceral arteries	257 (24.7)	28 (20.7)	229 (25.2)	.3
Transfusions				
Median packed red blood cells, units	2 [0-4]	3 [1-6]	2 [0-4]	<.0001
Mean packed red blood cells, units	2.7 ± 3.2	4.5 ± 4.8	2.4 ± 2.8	<.001
Median fresh-frozen plasma, units	2 [0-4]	4 [2-6]	2 [0-4]	<.0001
Mean fresh-frozen plasma, units	3.4 ± 16.2	9.0 ± 43.7	2.6 ± 3.6	<.001
Median platelets, units	8 [4-16]	8 [4-16]	8 [0-12]	<.0001
Mean platelets, units	8.5 ± 8.9	12.1 ± 11.3	8.0 ± 8.3	<.001

Values shown as n (%) or median [interquartile range]. *SMA*, Superior mesenteric artery.

In an adjusted analysis of the 952 early survivors, IS was not a risk factor for late mortality (Table 8). Chronic kidney disease and life-altering complications were the most significant predictors.

DISCUSSION

The major finding of this study is that the patients who had an IS during TAAA repair had an increased operative mortality rate (16.4% vs 7.6%, $P = .001$). Of note, the operative mortality rates of the IS and non-IS groups were similar in the overall cohort and in the propensity-matched cohorts (15.9% vs 8.3%); however, in the PSM analysis, the difference between the IS and non-IS groups was below the threshold for statistical significance ($P = .07$). This change in statistical significance was probably due to the smaller sample size and the associated decrease in statistical power. We also found that IS was associated with a higher incidence of septic and respiratory failure complications. However, in the patients who survived the TAAA repair, IS was not an independent predictor of late mortality. In Video 1, Dr Chatterjee further discusses the major findings of this study and its insights and implications.

Few reports of TAAA series have assessed the incidence of IS at the time of TAAA repair. In 2000, Eaton and colleagues[16] published a report on 17 incidental splenic injuries that occurred during the course of more than 3500 abdominal vascular operations and noted that 5% (5/107) of TAAA repairs required splenectomy. They found that TAAA repair and left renal artery revascularization procedures were associated with a 50-fold increase in IS compared with other abdominal vascular procedures.

TABLE 4. Operative details of 264 propensity-matched patients who underwent thoracoabdominal aortic aneurysm repair with or without splenectomy

Variable	Propensity-matched			
	All (n = 264)	With splenectomy (n = 132)	Without splenectomy (n = 132)	Standardized mean difference
Urgent/emergency status	78 (29.5)	39 (29.5)	39 (29.5)	<.001
Extent of repair				
Extent I	67 (25.4)	32 (24.2)	35 (26.5)	.05
Extent II	60 (22.7)	32 (24.2)	28 (21.2)	.07
Extent III	59 (22.3)	30 (22.7)	29 (22.0)	.02
Extent IV	78 (29.5)	38 (28.8)	40 (30.3)	.03
Aortic repair details				
Reoperation	87 (33.0)	46 (34.8)	41 (31.1)	.08
Aortic clamp time, min	59.4 ± 28.1	58.3 ± 24.5	60.4 ± 31.7	.08
Visceral/renal endarterectomy, stenting, or bypass	162 (61.4)	83 (62.9)	79 (59.8)	.06
Adjuncts				
Cerebrospinal fluid drainage	200 (75.8)	99 (75.0)	101 (76.5)	.04
Left heart bypass	117 (44.3)	58 (43.9)	59 (44.7)	.02
Cold renal perfusion	223 (84.5)	111 (84.1)	112 (84.8)	.02

Values shown as n (%) or median [interquartile range].

During the medial visceral rotation exposure of the thoracoabdominal aorta, the spleen is at risk of avulsion and retraction injury. Medial visceral rotation has been associated with an IS rate of up to 21% in elective and up to 60% for emergency procedures.[17] In patients undergoing retroperitoneal exposure of an abdominal aortic aneurysm,

TABLE 5. Early outcomes of 1042 patients who underwent thoracoabdominal aortic aneurysm repair with or without splenectomy

Variable	Study cohort			
	All (n = 1042)	With splenectomy (n = 135)	Without splenectomy (n = 907)	*P* value
Adverse event*	168 (16.3)	33 (24.4)	135 (15.1)	.005
Operative mortality†	90 (8.8)	22 (16.4)	68 (7.6)	.001
30-d mortality	56 (5.5)	15 (11.2)	41 (4.6)	.002
Cerebral complications	63 (6.0)	8 (5.9)	55 (6.1)	.95
Persistent stroke‡	24 (2.3)	2 (1.5)	22 (2.4)	.5
Spinal cord deficit	167 (16.0)	26 (19.3)	141 (15.5)	.3
Persistent paraplegia‡	41 (3.9)	9 (6.7)	32 (3.5)	.08
Persistent paraparesis‡	22 (2.1)	3 (2.2)	19 (2.1)	.9
Acute kidney injury (creatinine ≥2 mg/dL)	164 (15.7)	32 (23.7)	132 (14.6)	.006
Renal failure-transient dialysis	26 (2.5)	3 (2.2)	23 (2.5)	.8
Renal failure-dialysis at discharge‡	77 (7.4)	18 (13.3)	59 (6.5)	.005
Cardiac complication	335 (32.1)	52 (38.5)	283 (31.2)	.09
Pulmonary complication	426 (40.9)	65 (48.1)	361 (39.8)	.07
Respiratory failure	310 (29.8)	53 (39.3)	257 (28.3)	.01
Tracheostomy	143 (13.7)	26 (19.3)	117 (12.9)	.05
Reoperation for bleeding	40 (3.8)	14 (10.4)	26 (2.9)	<.001
GI complications	40 (3.8)	13 (9.6)	27 (3.0)	<.001
Sepsis	68 (6.5)	15 (11.1)	53 (5.8)	.02
Infection/thoracoabdominal wound	41 (3.9)	5 (3.7)	36 (4.0)	.9
Early survivors	952 (91.4)	113 (83.7)	839 (92.5)	.002
Median length of ICU stay, d	4 [3-8] (n = 937)	5 [3-9] (n = 112)	4 [3-8] (n = 825)	.5
Median length of overall hospital stay, d§	11 [8-19]	12 [9-26]	11 [8-18]	.4
Discharged with life-altering complication‖	78 (8.1)	11 (9.7)	67 (8.0)	.5

Values shown as n (%), median [interquartile range], or mean ± standard deviation. *GI*, Gastrointestinal; *ICU*, intensive care unit. *Defined as operative death or persistent (present at hospital discharge) stroke, paraplegia, paraparesis, or renal failure necessitating dialysis. †Included death before final hospital discharge or before 30 days if discharged. ‡Present at the time of hospital discharge or early death. §Overall hospital stay includes local hospital and discharge to long-term acute care hospital. ‖Defined as persistent (present at hospital discharge) stroke, paraplegia, paraparesis, or renal failure necessitating dialysis.

TABLE 6. Early outcomes of 264 propensity-matched patients who underwent thoracoabdominal aortic aneurysm repair with or without splenectomy

Variable	All (n = 264)	Propensity-matched		*P* value
		With splenectomy (n = 132)	Without splenectomy (n = 132)	
Adverse event*	61 (23.1)	32 (24.2)	29 (22.0)	.7
Operative mortality†	32 (12.2)	21 (15.9)	11 (8.3)	.07
30-d mortality	22 (8.4)	15 (11.4)	7 (5.3)	.1
Cerebral complications	7 (7.6)	8 (6.1)	12 (9.1)	.4
Persistent stroke‡	6 (2.2)	2 (1.5)	4 (3.0)	.4
Spinal cord deficit	48 (18.2)	25 (18.9)	23 (17.4)	.7
Persistent paraplegia‡	13 (4.9)	8 (6.1)	5 (3.8)	.4
Persistent paraparesis‡	5 (1.9)	3 (2.3)	2 (1.5)	.7
Acute kidney injury (creatinine ≥2 mg/dL)	58 (22.0)	30 (22.7)	28 (21.2)	.8
Renal failure-transient dialysis	4 (1.5)	3 (2.3)	1 (0.8)	.3
Renal failure-dialysis at discharge‡	37 (14.0)	18 (13.6)	19 (14.4)	.9
Cardiac complication	86 (32.6)	50 (37.9)	36 (27.3)	.06
Pulmonary complication	115 (43.6)	64 (48.5)	51 (38.6)	.1
Respiratory failure	88 (33.3)	52 (39.4)	36 (27.3)	.04
Tracheostomy	38 (14.4)	25 (18.9)	13 (9.8)	.04
Reoperation for bleeding	21 (8.0)	14 (10.6)	7 (5.3)	.1
GI complications	19 (7.2)	13 (9.8)	6 (4.5)	.1
Sepsis	21 (8.0)	15 (11.4)	6 (4.5)	.046
Infection/thoracoabdominal wound	10 (3.8)	4 (3.0)	6 (4.5)	.5
Early survivors	232 (88.5)	111 (84.7)	121 (92.4)	.07
Length of ICU stay, d	8.7 ± 10.7	9.7 ± 12.2	7.6 ± 9.2	.1
Length of hospital stay, d	22.0 ± 29.7	24.7 ± 37.0	19.2 ± 22.4	.2
Discharge with life-altering complication§	29 (12.5)	11 (9.9)	18 (14.9)	.3

Values shown as n (%) or mean ± standard deviation. *GI*, Gastrointestinal; *ICU*, intensive care unit. *Defined as operative death or persistent (present at hospital discharge) stroke, paraplegia, paraparesis, or renal failure necessitating dialysis. †Included death before final hospital discharge or before 30 days if discharged. ‡Present at the time of hospital discharge or early death. §Defined as persistent (present at hospital discharge) stroke, paraplegia, paraparesis, or renal failure necessitating dialysis.

the risk of IS has been reported to be 0.7%[18] to 1.0%,[19] and IS in these patients has been associated with a 4- to 5-fold increase in mortality.[18]

In our overall study cohort, the significant associations for IS were undergoing reoperation and having a history of open distal aortic surgery. The close association between IS and reoperation reflects the fact that these are more technically demanding surgical procedures. These associations are likely reflective of the development of dense adhesions after the previous repairs and the need to facilitate optimal visualization at the time of surgery. Two groups besides ours have recently published findings regarding reoperative TAAA repairs: The Cornell group (n = 69) reported no splenectomies,[20] and the University of Texas-Houston/Memorial Hermann group (n = 266) did not report on splenectomies.[21] A recent study from our group regarding 726 reoperative TAAA repairs showed an overall operative mortality rate of 8.1% and a splenectomy rate of 21%.[22] In 4 published series of reoperative TAAA, the operative mortality rates ranged from 8% to 23%.[20-23]

TABLE 7. Independent predictors of operative death (n = 90) after thoracoabdominal aortic aneurysm repair for 1042 patients

Variable	OR (CI)	*P* value
IS	2.22 (1.21-3.94)	.008
Chronic kidney disease	2.11 (1.29-3.51)	.003
Extent II TAAA	1.85 (1.09-3.11)	.02
Acute symptoms	1.70 (0.97-2.91)	.06
Reoperation	1.55 (0.91-2.59)	.1
Cerebrovascular disease	1.52 (0.88-2.54)	.1
Age at repair (increase per y)	1.07 (1.04-1.09)	<.001
Aortic clamp time (increase per min)	1.20 (1.01-1.03)	<.001
Cold renal perfusion	0.39 (0.23-0.67)	<.001

OR, Odds ratio; *CI*, confidence interval; *IS*, incidental splenectomy; *TAAA*, thoracoabdominal aortic aneurysm.

The spectrum of splenic injuries includes lacerations, avulsions, and subcapsular hematomas. An analysis of approximately 1 million colon resections found that the rate of splenic injury was 1% and that 85% of these injuries necessitated splenectomy.[24] Other studies have noted

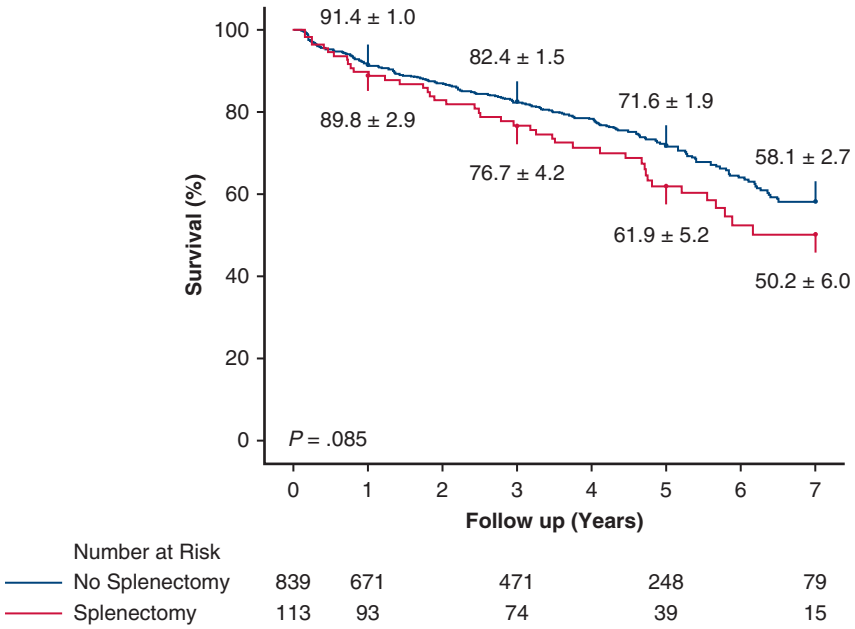


FIGURE 1. Kaplan–Meier analysis of the 952 early survivors of open thoracoabdominal aortic repair showed no significant difference ($P = .08$) in late survival between those with and without IS. At 5 years, the estimated survival was 61.9% ± 5.2% for those with IS and 71.6% ± 1.9% for those without.

that conservative management of such injuries with splenorrhaphy was unsuccessful in cases of abdominal vascular surgery[16] and that splenectomy was advised.[17] When deciding whether to preserve the spleen after a capsular tear, a surgeon must weigh the risk of catastrophic postoperative bleeding that could lead to hypotension, spinal cord ischemia, and death against postsplenectomy risks. Postsplenectomy bleeding can result from divided

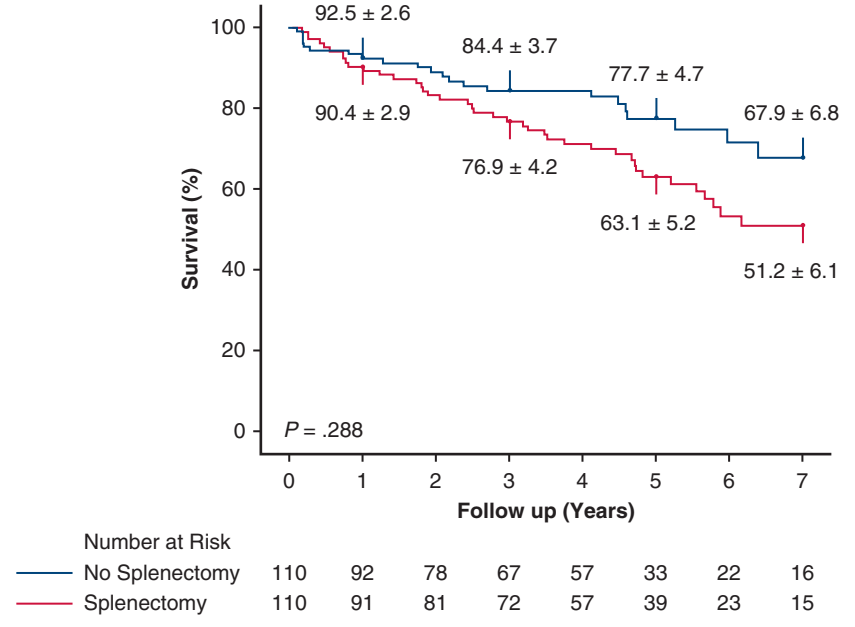


FIGURE 2. Kaplan–Meier analysis of the 110 propensity-matched pairs (Table E3) derived from the 952 early survivors after open TAAA repair showed no significant difference ($P = .29$) between those with and without IS. At 5 years, the estimated survival was 77.7 ± 4.7 for those with IS and 63.1 ± 5.2 for those without IS.

TABLE 8. Cox proportional hazards regression analysis of late death for the 952 early survivors of thoracoabdominal aortic aneurysm repair

Variables	HR (CI)	*P* value
Rupture	2.15 (1.33-3.48)	.002
Life-altering complication*	1.90 (1.30-2.79)	.001
Chronic kidney disease	1.62 (1.21-2.18)	.001
Coronary artery disease	1.52 (1.14-2.02)	.004
Aortic dissection	1.51 (1.08-2.11)	.02
Reoperation	1.35 (0.99-1.82)	.06
Age at repair (increase per y)	1.04 (1.03-1.06)	<.001
IS†	1.19 (0.83-1.72)	.3

HR, Hazard ratio; *CI*, confidence interval; *IS*, incidental splenectomy. *Life-altering complication refers to discharge with paraplegia, paraparesis, stroke, or renal failure necessitating dialysis. †IS did not qualify for the model and was forced in.

VIDEO 1. Dr Chatterjee discussing the clinical implications of this analysis and the association between IS and outcomes after TAAA repair. Video available at: https://www.jtcvs.org/article/S0022-5223(19)31757-X/fulltext.

adhesions, splenic or short gastric vessels, or the tail of the pancreas[25]; meticulous hemostasis after IS is paramount. In our study cohort, the overall rate of reoperation for bleeding was low (3.8%, n = 40) and compared favorably to the 5% rate seen in other large TAAA series.[26,27] Of the 6 patients who underwent splenectomy at the time of reoperation for bleeding, 2 (33%) died, 1 on postoperative day 4 and 1 on postoperative day 30. Moreover, within the early mortality cohort, bleeding and reoperation were more common in the IS group than in the non-IS group. These findings underscore that postoperative bleeding from a missed or mismanaged splenic injury carries a high risk of mortality.

It is notable that despite the greater operative mortality in the IS group, the incidence of life-altering complications (stroke, permanent paraplegia or paraparesis, dialysis) was comparable between the IS and non-IS groups in both the overall and matched cohorts. Compared with the non-IS group, the IS group had more septic complications during the perioperative period. Moreover, in the IS group, sepsis was associated with a 60% mortality rate. In our early mortality cohort, the incidence of infection and sepsis was comparable in the IS and non-IS groups. Other studies of IS after major abdominal vascular surgery[16] or liver transplantation[8] have reported higher infection rates in patients with IS. One study showed that the incidence of infection did not differ between patients who underwent elective as opposed to traumatic splenectomies.[28] We found no difference in the incidence of wound infections between the IS and non-IS groups, consistent with the observations of others.[28] Duke and colleagues[29] observed that the increase in sepsis after splenectomy was not due to the specific operation, but rather to an increase in transfusions. In our series, splenectomy was also associated with higher transfusion rates. We were vigilant about discontinuing vascular catheters early and about promptly administering antibiotics if infection was suspected. We did not compare the specific pathogens that caused infectious complications in the IS and non-IS groups to determine whether there was a difference. Moreover, the higher incidences of respiratory failure and GI complications in the IS group were notable in contributing to overall morbidity and mortality.

Triple vaccination after splenectomy is designed to reduce the risk of overwhelming postsplenectomy sepsis and is directed against *Streptococcus pneumoniae, Haemophilus influenzae* type B, and *Neisseria meningitidis*.[30] Our documented 93% administration rate of triple vaccination in the operative survivors compares favorably to the 90% rate reported for patients who underwent splenectomy for splenic trauma.[31] It is unknown whether the remaining patients received outpatient vaccinations afterward. The small number of patients who did not receive triple vaccination precluded meaningful analysis of this treatment's impact on survival. Given that approximately one-third of the IS cases were reoperations, patients with a history of open distal aortic surgery may be candidates for preoperative triple vaccination, similar to patients undergoing elective splenectomy.

Although open surgery is still the gold standard for TAAA repair, the development of branched and fenestrated endografts will offer some patients with TAAA the option of avoiding open repair.[32,33] Use of these technologies is especially attractive for patients undergoing reoperation and could reduce the risk of IS.

Study Limitations

First, our retrospective study was subject to the inherent limitations of evaluating associations, notably, the inability to determine whether there was a direct causal relationship between IS and mortality. Second, a sample size calculation suggested that 399 IS/non-IS pairs would be required to power the PSM analysis adequately to show a significant

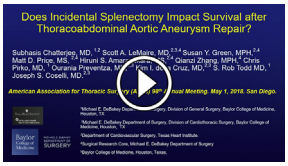
difference in operative mortality. That would be 3 times the number of pairs in our current PSM analysis of this large TAAA series. Thus, it is possible that with a larger number of matched pairs, we might have observed a statistically significant difference in operative mortality. Third, although guidelines advise that patients undergoing splenectomy receive thromboprophylaxis because of the increased venous thromboembolism risk,[34] we could not accurately determine the rates of guideline adherence or thrombotic complications. Likewise, we do not know if other postsplenectomy guidelines (eg, regarding antibiotics, annual influenza vaccination, and emergency antibiotic supply) were carried out consistently in the outpatient setting.[31] Fourth, we could not determine how often an iatrogenic splenic injury was managed without splenectomy without postoperative sequelae. Unfortunately, although we have used hemostatic agents to avoid splenectomy in selected cases, we were not able to identify such cases in our database. Fifth, for the analysis of early deaths, although a senior investigator adjudicated the causes of mortality through chart abstraction, assigning a primary cause in patients with multisystem organ failure was difficult. Sixth, even though the primary surgeon (J.S.C.) remained constant throughout this series, the experience level of the co-surgeon and other assistants varied, which may have affected the IS rates.

CONCLUSIONS

IS at the time of TAAA repair was predictive of operative mortality but not late survival. Although there was an associated increase in the rate of reoperation for patients with IS, it was not predictive of operative or late mortality. Reasonable efforts should be made to avoid IS.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://aats.blob.core.windows.net/media/18May01/28ABC%202.Aortic%20Endovascular/S85%20-%20Part%201/S85_7_webcast_033134485.mp4.



Conflict of Interest Statement

Dr Coselli participates in clinical trials with or consults for Terumo Aortic, Medtronic, and WL Gore, and receives royalties and grant support from Terumo Aortic. Dr LeMaire's work is supported, in part, by the Jimmy and Roberta Howell Professorship in Cardiovascular Surgery at Baylor College of Medicine, and he participates in clinical trials with or consults for Terumo Aortic, Baxter Healthcare, Medtronic, WL Gore, and CytoSorbents. Dr Preventza participates in clinical trials with or consults for Medtronic and WL Gore. All other authors have nothing to disclose with regard to commercial support.

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Key Words: aortic, thoracoabdominal aortic aneurysm

Discussion

Dr Edward P. Chen *(Atlanta, Ga)*. The issue of needing IS at the time of thoracoabdominal repair is certainly something that we at our own institution have dealt with, as I am sure others have as well, but as far as I am aware, this has never really been discussed formally. I appreciate your group presenting your results on this topic.

Were there cases in the nonsplenectomy group where the spleen was actually injured and ultimately repaired? What were some of the techniques used? If so, did you look at those patients as a subgroup and compare those with the splenectomy cases as a separate analysis?

Dr Subhasis Chatterjee *(Houston, Tex)*. Because the operative report itself typically just reports splenectomy or no splenectomy, it's difficult to ascertain whether there were subclinical splenic injuries successfully managed conservatively. I think this experience was largely driven by the fact that when you look at the 6 patients who had required reoperation for bleeding for spleen reasons, the mortality was 33%. I think there is an aggressive approach toward a splenectomy at our institution because the risk of a missed injury to the spleen can be catastrophic bleeding, hypotension, paraplegia, and death. Obviously, prevention is best.

Dr Chen. I noticed in the splenectomy group there was a smaller percentage of patients who had left heart bypass compared with the nonsplenectomy group, 44% versus 54%. Presumably the nonsplenectomy group had a somewhat more benign anatomy to allow for left heart bypass. Could you comment on the circulation management, other strategies that were used in the splenectomy group compared with the nonsplenectomy group.

Dr Chatterjee. That is an astute observation. That is a reflection of the extent of distribution within the reoperative cases, which was a major determinant in the need for splenectomy. If you look at the reoperative cases, approximately 30% of those cases were extent I's or II's, whereas approximately 70% of the nonreoperative cases were extent I's or II's. So consistent with the fact that extent I's and II's are more likely to undergo left heart bypass, the nonreoperative cases tended to have more left heart bypass because they were more likely to be extent I's and II's. So I think the left heart bypass number is a reflection of the fact that I's and II's are more common in the nonreoperative cases and, thus, less likely to be at risk for splenectomy.

Dr Chen. With respect to cases of previous open distal repairs, where a higher procedure was seen in the splenectomy group, were those isolated descendings or were those previous thoracoabdominals, for instance, an extent 1 that may have needed an extent 4, and subsequently did you have to redo the native visceral rotation to deal with the scar tissue as a risk factor for needing the spleen to be resected?

Dr Chatterjee. There were some patients with previous proximal open thoracoabdominal aortic repairs (extent I) who required completion of the distal thoracoabdominal aortic segment (extent IV); however, the more common finding in the reoperative setting was a patient with a previous abdominal aortic aneurysm repair who then had a completion of the proximal thoracoabdominal aortic segment (extent III repair). With respect to redoing the medial visceral rotation, that is certainly one of the technical risk factors along with traction injury for requiring splenectomy, those data are not exactly altogether clear.

Dr Chen. Great job.

Unidentified Speaker. I just rise to emphasize one of the points that you made in your conclusion, and that is, prevention of this, especially for type 2. It's a big operation, the surgeon has a lot of adrenaline and wants to get to the heart of the matter, and that's where the surgeon has to control himself, during the dissection of the splenic area, splenic structure, and the left collar to move them. I sometimes even break or go and take a glass of water to come back and just do this very carefully, and I have never had a splenic injury, but it can happen. I think it should be emphasized to just get yourself ready for this part, which is different, because a little move can rupture the spleen.

Dr Thoralf Sundt *(Boston, Mass)*. You were cautious in your conclusions, which is good. Your title suggests a little more aggressive conclusion, I think. Anytime that we look at a retrospective series, trying to distinguish between association and causation is a challenge. It seems to me if you want to make the argument that IS affects survival, which you didn't make in your conclusions but your title suggests, there needs to be some sort of mechanistic explanation. You demonstrated a lot of associations, for example, dialysis. Are you suggesting that there is a causal relationship between splenectomy and dialysis? Is splenectomy really a marker for a sicker group of patients and more difficult operations? I think that's really what one of Ed's questions was about.

Dr Chatterjee. That is an excellent point. For the article, we actually changed ''impact'' to ''associated,'' so the spirit of your question is certainly acknowledged.

I would say that approximately one-third of the splenectomy cases are reoperative cases; that certainly has a significant explanatory role. There is also a clear association between acuity of presentation and a higher likelihood of requiring a splenectomy. At the same time, we did find an independent association with respect to operative mortality with splenectomy itself in multivariable risk modeling, so I think the association is real.

Dr Sundt. I still think that when we talk about statistics, we need to keep in mind that an association is not causation, and then you really have to make an argument for a mechanism to somehow relate those 2.

Dr Eric Roselli *(Cleveland, Ohio)*. I was thinking the same thing. Any difference in infection rates at all?

Dr Sundt. That's an example of something where you can imagine a causal relationship.

Dr Chatterjee. We did see a higher incidence of GI complications and sepsis within the splenectomy group. We also saw that GI complications and sepsis in the splenectomy group had a 60% mortality, compared with the 40% mortality in the nonsplenectomy group. Again, those are just small numbers but there appears to be a difference.

Dr Roselli. And GI complications would include pancreatitis?

Dr Chatterjee. Yes, pancreatitis was a small number with the most common GI complication being small bowel obstruction but also GI bleeding, and most rare of all, mesenteric ischemia.

TABLE E1. Complications observed in the 90 patients who had early deaths after thoracoabdominal aortic aneurysm repair

Complication	With splenectomy (n = 22)	Without splenectomy (n = 68)	*P* value
Cardiac complications	16 (72.7)	52 (76.5)	.7
Pulmonary complications	20 (90.9)	60 (88.2)	.7
Cerebrovascular complications	6 (27.3)	22 (32.4)	.7
Spinal cord deficits	6 (27.3)	24 (35.3)	.5
Pneumonia	10 (45.5)	25 (36.8)	.9
Reoperation for bleeding	5 (22.7)	4 (5.9)	.02
GI complications	7 (31.8)	8 (11.8)	.03
Infection/sepsis	9 (40.9)	26 (38.2)	.8
Incisional wound infection	2 (9.1)	7 (10.3)	.9
Dialysis (any)	14 (63.6)	33 (48.5)	.2

Values shown as n (%). *GI*, Gastrointestinal.

TABLE E2. Primary cause of death for the 90 patients who had early deaths after thoracoabdominal aortic aneurysm repair

Cause of death	With splenectomy (n = 22)	Without splenectomy (n = 68)	*P* value
Neurologic complications	2 (8.7)	10 (14.7)	.5
Respiratory failure	4 (17.4)	10 (14.7)	.7
Renal failure	1 (4.4)	4 (5.9)	.8
GI complications	4 (17.4)	5 (7.4)	.1
Sepsis/multisystem organ failure	5 (22.8)	13 (19.1)	.7
Reoperation for bleeding	2 (8.7)	5 (7.4)	.8
Cardiac complications or cardiac arrest	2 (8.7)	13 (19.1)	.6
Unknown	2 (8.7)	8 (11.8)	.7

Values shown as n (%). *GI*, Gastrointestinal.

TABLE E3. Characteristics of 220 propensity-matched hospital survivors who underwent thoracoabdominal aortic aneurysm repair with or without splenectomy

Variable	All (n = 220)	With splenectomy (n = 110)	Without splenectomy (n = 110)	Standardized mean difference
Preoperative variables				
Age, y	63.0 ± 12.0	62.7 ± 12.3	63.3 ± 11.7	.05
Genetic disorder	29 (13.2)	15 (13.6)	14 (12.7)	.03
Prior open distal aortic repair	63 (28.6)	32 (29.1)	31 (28.2)	.02
Aortic dissection (acute or subacute)	7 (3.2)	4 (3.6)	3 (2.7)	.05
Acute symptoms	37 (16.8)	21 (19.1)	16 (14.5)	.1
Hypertension	196 (89.1)	97 (88.2)	99 (90.0)	.06
Coronary artery disease	86 (39.1)	44 (40.0)	42 (38.2)	.04
Cerebrovascular disease	34 (15.5)	18 (16.4)	16 (14.5)	.05
Chronic kidney disease	101 (45.9)	46 (41.8)	55 (50.0)	.2
Pulmonary disease (COPD or asthma)	83 (37.7)	43 (39.1)	40 (36.4)	.06
Operative variables				
Urgent or emergency	57 (25.9)	28 (25.5)	29 (26.4)	.02
Reoperation	77 (35.0)	37 (33.6)	40 (36.4)	.06
Extent of repair				
Extent I	59 (26.8)	29 (26.4)	30 (27.3)	.02
Extent II	55 (25.0)	26 (23.6)	29 (26.4)	.06
Extent III	45 (20.5)	23 (20.9)	22 (20.0)	.02
Early outcomes				*P* value
Adverse event*	18 (8.2)	11 (10.0)	7 (6.4)	.3
Cerebral complications	5 (2.3)	2 (1.8)	3 (2.7)	.7
Spinal cord deficit (temporary or persistent)	37 (16.8)	20 (18.2)	17 (15.5)	.6
Renal failure-dialysis at discharge	7 (3.2)	5 (4.5)	2 (1.8)	.6
Respiratory failure with tracheostomy	24 (10.9)	15 (13.6)	9 (8.2)	.2

Values shown as n (%) or median [interquartile range] or mean ± standard deviation. *COPD*, Chronic obstructive pulmonary disease. *Defined as operative death or persistent (present at hospital discharge) stroke, paraplegia, paraparesis, or renal failure necessitating dialysis.