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Splenectomy versus angioembolization for severe splenic injuries in a national trauma registry: To save, or not to save, the spleen, that is the question

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ABSTRACT

Background: The use of angioembolization as a first approach for treating severe, blunt splenic injuries has increased recently, yet evidence showing its superiority to immediate splenectomy is lacking. We compared the prognosis of angioembolization versus splenectomy in patients presenting hemodynamically unstable with high-grade, image-confirmed, blunt splenic injuries in a nationally representative dataset.
Methods: We queried the 2017–2022 Trauma Quality Improvement Program database for adults with blunt splenic injury abbreviated injury scale = 4–5, with arrival systolic blood pressure <90 mm Hg, and treated with either angioembolization or splenectomy <6 hours of arrival after a computed tomography scan. Entropy balancing was used to adjust for confounders.
Results: Of 1,360 patients, 328 (24.1%) underwent angioembolization and 1,032 (75.9%) splenectomy. Treatment with angioembolization first was more likely in recent years, in level 1 trauma centers, for less severe spleen injuries, in the absence of head injuries. Angioembolization and splenectomy had similar entropy balancing–adjusted survival (entropy balancing hazard ratio = 1.02; 95% confidence interval: 0.97–1.07, P = .49). One-fifth of those with angioembolization first required rescue splenectomy <6 hours, mostly those with spleen injury grade 5 and additional abdominal injuries. Although this resulted in worse survival (hazard ratio: 1.12; 95% confidence Interval: 0.99–1.26) than successful angioembolization, the survival was not significantly worse than those treated with splenectomy first (entropy balancing hazard ratio: 1.07; 95% confidence Interval: 0.96–1.20).
Conclusion: Angioembolization was associated with similar survival to splenectomy first for patients arriving hypotensive with severe, image-confirmed blunt splenic injuries, suggesting that it was an appropriate treatment decision. Although survival was worse after failed angioembolization than after successful angioembolization, it was not worse than splenectomy first, suggesting that the attempt to preserve the spleen was justified.

Introduction

The spleen remains one of the most frequently injured abdominal organs, and splenic injuries continue to be a major source of trauma burden.[1,2] Although splenectomy remains the most definitive treatment of splenic hemorrhage, the treatment paradigm has shifted in recent years toward selective nonoperative management (NOM).[1,3–6] Traditionally, NOM was reserved for low-grade injuries in hemodynamically stable patients.[6,7] However, now select patients with higher-grade injuries presenting with hemodynamic instability, but able to undergo computerized tomography (CT) scanning, can undergo angioembolization (AE) as the initial approach.[8–12] Even patients with penetrating injuries (most commonly managed operatively) may be safely managed non-operatively if appropriately selected.[13,14]

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AE has emerged as a major component of NOM of severe splenic trauma over the past 2 decades.[5,15–18] Recent studies have suggested that AE is particularly useful for high-grade lesions or those with a contrast "blush" (indicative of active extravasation) on CT scan.[16–19] AE may also be effective in select hemodynamically unstable patients, though high-quality evidence guiding this practice is scarce.[10–12] There are certainly benefits to hemorrhage control by endovascular means, including splenic salvage and avoiding the morbidity of a laparotomy.[20–23] However, this treatment strategy requires adequate resources and carries its own risks and complications. Aside from continued hemorrhage and the need for "rescue" splenectomy, splenic infarction and abscess, groin hematoma and infection, coil migration, and reactive pleural effusions have been reported as complications of splenic AE.[1,24–26]

Despite its increasing use, there are inconsistent data on the benefit of AE.[27–30] Even less clear is the role of AE specifically in the initial treatment of patients presenting with high-grade injuries and hemorrhagic shock but able to undergo CT scanning. In the absence of a randomized controlled trial (RCT), investigating this topic requires a large sample size and well-matched groups with extensive control for confounders. Therefore, the aim of this study was to use a nationally representative dataset built over recent years, to document the increasing use of AE, and to compare upfront AE with splenectomy for the treatment of patients with image-confirmed high-grade, splenic injuries who present with hypotension. We hypothesized that AE as the initial approach would be associated with better outcomes than splenectomy in these patients.

Methods

Study design and setting

We queried the American College of Surgeons Trauma Quality Improvement Program (TQIP) national dataset to compare patient characteristics and outcomes of those who underwent upfront AE versus splenectomy for those arriving hemodynamically unstable, but who underwent CT scanning, with high-grade, blunt splenic injuries from 2017 to 2022. This is an observational cohort study using TQIP data, which includes voluntarily collected data from over 900 facilities nationwide. The STrengthening the Reporting of OBservational Studies in Epidemiology (STROBE) checklist was used to ensure abidance to the Enhancing the QUAlity and Transparency Of Health Research (EQUATOR) guidelines for reporting observational studies (Supplementary Table S1).

Inclusion and exclusion criteria

We queried the 2017–2022 TQIP database for patients aged $\geq$16 years with severe, blunt splenic injury (Abbreviated Injury Scale [AIS] for the spleen = 4 or 5), hypotension on arrival (emergency department systolic blood pressure [SBP] <90 mm Hg), and treatment with either AE or splenectomy within 6 hours of arrival after undergoing a CT scan. The CT scan inclusion criterion ensured that all included patients had the option for AE. Splenectomy was defined by International Classification of Diseases, Tenth Revision (ICD-10) codes (075P0ZZ, 07BP0ZZ, and 07TP0ZZ), whereas AE was defined by the TQIP variables related to AE of spleen and aorta, the latter included to capture proximal splenic AE. Patients were categorized based on the initial treatment strategy to AE or splenectomy. Patients with Injury Severity Score (ISS) = 75 were excluded as these are considered nonsurvivable injuries. In addition, all patients who were transferred from another facility or who had missing data regarding the timing of angiography, surgical procedure, or CT were excluded.

Outcome measures and variables of interest

Our primary outcome measure was survival to hospital discharge or up to 28 days in-hospital. Secondary outcomes included 28-day intensive care unit–free days (IFD) and ventilator-free days (VFD). We reviewed demographic and injury characteristics as well as both prehospital and early hospital clinical data. Traumatic brain injury (TBI) was defined as AIS head >2. Isolated spleen injury was defined as AIS of all other body regions as well as nonspleen abdominal organs <3. The incidence and outcomes of post-AE rescue splenectomy (splenectomy performed after initial AE at any time during the hospitalization) were also evaluated. In addition, year of admission, institution characteristics (hospital size and trauma center level), and volume of AE and splenectomy procedures performed by each institution were included.

Statistical analyses

All statistical analyses were performed using SAS 9.4 (SAS Institute, Inc, Cary, NC). All tests were 2-tailed with significance declared at $P < .05$. Numerical data are presented with median and interquartile range (IQR). Categorical data are presented with frequency and percentage. The Wilcoxon Mann-Whitney, χ^2, and Fisher exact tests were used for the unadjusted analyses comparing the AE and splenectomy groups as well as comparing patients with successful versus failed upfront AE and failed upfront AE versus splenectomy first. Correlation between time to first treatment and patient acuity was conducted with the Spearman nonparametric correlation test.

Confounders were chosen based on bivariate association with the outcome with $P < .10$ and missing in <15% of the observations. Missing data when <15% were treated with listwise deletion. To control for confounding, we used entropy balancing (EB), which entailed weighting sample units to the variables' first moments (mean or proportion) with a maximal tolerance difference of 0.015, so a high degree of covariate balance could be achieved with as large of an effective sample size as possible.[31] The survival of the balanced groups was compared with Cox proportional hazards models with sandwich variance estimates and robust standard errors to account for intrafacility clustering, and the hazard ratio (HR) and its 95% confidence interval (95% CI) were calculated. IFD and VFD were compared between balanced AE and splenectomy groups using the *t* tests with Satterthwaite correction if significant heteroscedasticity was detected. EB was used to balance the groups regarding the initial therapeutic approach (AE versus splenectomy); thus the comparison between successful AE and failed AE was not EB adjusted as these patients were subjected to the same initial therapy. Trends over time were tested using the Cochran-Armitage trend test or by including an interaction between treatment choice and year in the EB weighted survival models. A sensitivity analysis was performed using propensity score matching (PSM) 1:1 case-control ratio, based on the same variables used for EB, using the greedy method and caliper 0.15, without replacement.

Results

Population characteristics, time trends, and facility variation

Overall, 1,360 patients with splenic injury and hypotension on arrival, first management within 6 hours of hospital arrival after a CT scan, and no exclusion criteria in 448 facilities across the United States (Figure 1) were included in the study. Of these, 329 patients (24.1%) were selected to be treated initially with AE, whereas

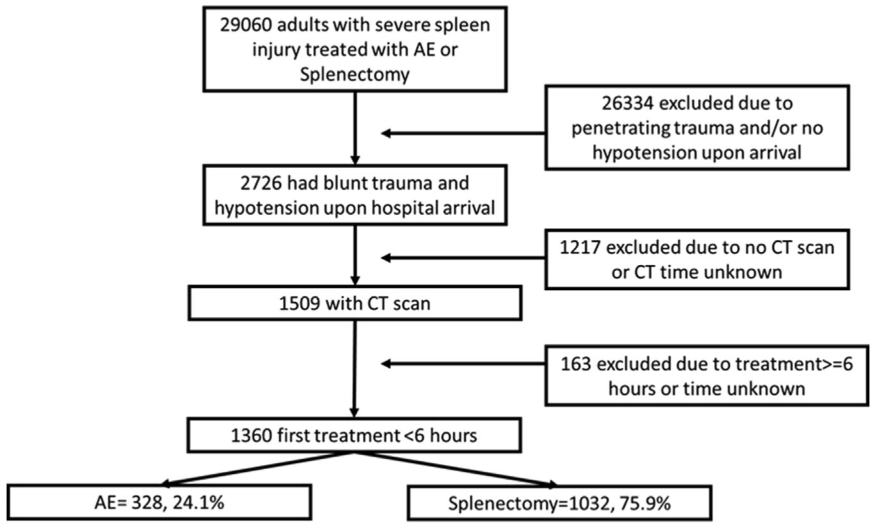

Figure 1. CONSORT-like study flow diagram. *AE*, angioembolization; *CT*, computed tomography.

upfront splenectomy was chosen for 1,032 (75.9%). The proportions of patients treated with AE upfront increased significantly over the study period, varying from 18.7% in 2017 to 31.8% in 2022 (Cochran-Armitage trend test, $P = .001$), albeit in the EB-adjusted analysis this trend was not significant ($P = .99$), suggesting that patient selection remained similar. AE was the initial approach in 185 (41.3%) of the facilities, with most facilities (83.2%) only contributing 1 or 2 AE cases to the sample.

Although the AE and splenectomy groups were similar in several ways (Table I), patients who underwent upfront AE tended to be marginally older, were more likely to be admitted in more recent years to a level 1 trauma center, and presented with more severe (AIS = 5) spleen injuries, with other abdominal injuries, and with TBI. As expected, they were significantly more likely to undergo AE of other organs (liver, kidney, and pelvis). Patients who underwent AE first took longer to receive their treatment than patients who underwent splenectomy took to reach the operating room (OR) (148.5 vs 99.0 minutes), possibly due to the lower acuity of patients selected for upfront AE. A total of 7 patients underwent a second AE, of whom 2 eventually required a rescue splenectomy (2 died); none of those with successful second AE died. The median timing of the second AE was 2 hours after admission (IQR: 1.6–189.3, range 1.5–247.7), with 57% of them being performed 6 hours after admission.

Outcomes

Upfront AE was associated with significantly lower unadjusted in-hospital mortality and fewer VFD and IFD (Table I). The EB-adjusted analysis using weights based on year of admission, age, prehospital cardiac arrest, spleen AIS, TBI, ISS, chest max AIS, nonspleen abdominal max AIS, extremity max AIS, arrival heart rate and arrival Glasgow Coma Scale (GCS), trauma center level, and hospital size resulted in well-balanced groups with minimal loss of sample (EB-AE group $n = 309$; 94.2% of the original AE group; EB-splenectomy group $n = 960$, 93.0% of the original splenectomy group). Supplementary Table S2 presents the EB diagnostics showing covariates before and after EB weighting and the unadjusted and EB-adjusted survival. In EB risk-adjusted survival analysis, patients treated initially with splenectomy versus AE had similar survival (Figure 2, HR = 1.02; 95% CI: 0.97–1.07, $P = .49$). After EB risk adjustment, compared with the splenectomy group, AE was associated with significantly greater IFD (22 [range: 11–24] days vs 20 [range: 4–25] days, $P = .045$), but the difference in VFD did not reach significance (26 [range: 18–28] days vs 25 [range: 16–28] days, $P = .24$).

Stratifying the EB-adjusted analysis by spleen AIS confirmed a similar HR for splenectomy compared with AE for both patients with spleen AIS = 4 (EB weighted HR = 1.05; 95% CI: 0.99–1.12, $P = .10$) and those with spleen AIS = 5 (EB HR: 0.97; 95% CI: 0.90–1.05, $P = .52$). Stratification by whether the admitting facility was a level 1 trauma center (versus not level 1) did not alter the significant survival benefit of AE over splenectomy (level 1: EB HR: 0.99; 95% CI: 0.92–1.06, $P = .74$ vs not level 1: EB HR: 1.06; 95% CI: 0.99–1.13, $P = .09$). An interaction between year of admission and initial therapeutic approach was not significant ($P = .99$), suggesting that the survival after AE versus splenectomy first did not change from 2017 to 2022.

The sensitivity analysis using PSM resulted in 295 well-matched pairs for a total of 590 patients (Supplementary Figure S1). Similar to EB weighting, the Cox proportional hazards model of the PSM matched groups also found similar survival after splenectomy first versus AE (PSM HR: 1.02; 95% CI: 0.96–1.08, $P = .53$). A comparison between matched and unmatched patients (Supplementary Figure S1) highlights the patients for whom AE and splenectomy first resulted in similar prognosis. In brief, matched patients were more likely to (1) be admitted in more recent years to a large, level 1 trauma center, (2) be older (although there is confounding between age and injury severity), (3) have less severe spleen and nonspleen abdominal injuries, and (4) have higher SBP, lower heart rate, and higher GCS on admission.

Rescue splenectomy

Of the 328 patients initially treated with AE, one-fifth (66, 20.1%) required splenectomy within 6 hours after admission. Compared with patients successfully treated with AE (Table II), patients who failed the initial AE attempt were more likely to have a more severe splenic injury and injuries of other abdominal organs. They also arrived at the angiography suite faster than patients successfully treated with AE, suggesting higher acuity. No other characteristics of patients nor of facilities differed between the 2 groups. Rescue splenectomy, as expected, was associated with more blood products transfused in the first 4 hours after admission.

Table I
Characteristics and outcomes of patients with blunt, CT-confirmed severe splenic injuries presenting with hypotension and treated initially with angioembolization (AE) versus splenectomy[*]

Variables	Total (N = 1,360)	AE first (n = 328, 24.1%)	Splenectomy first (n = 1,032, 75.9%)	P value
Admission year				.01
2017	192 (14.1)	36 (11.0)	156 (15.1)	
2018	161 (11.8)	36 (11.0)	125 (12.1)	
2019	190 (14.0)	43 (13.1)	147 (14.2)	
2020	258 (19.0)	53 (16.2)	205 (19.9)	
2021	257 (18.9)	64 (19.5)	193 (18.7)	
2022	302 (22.2)	96 (29.3)	206 (20.0)	
Male sex	889 (65.4)	216 (65.9)	673 (65.2)	.83
Age, yr	42.0 (28.0–59.0)	45.0 (29.5–59.0)	41.0 (28.0–58.0)	.07
Documented White non-Latinx race and ethnicity	948 (69.7)	230 (70.1)	718 (69.6)	.85
Health insurance coverage				.70
Medicaid	Medicaid	273 (20.1)	60 (18.3)	
Medicare	Medicare	183 (13.5)	50 (15.2)	
Other	Other	129 (9.5)	28 (8.5)	
Private	Private	611 (44.9)	150 (45.7)	
Uninsured	Uninsured	164 (12.1)	40 (12.2)	
Documented comorbidity	225 (16.5)	47 (14.3)	178 (17.2)	.21
Injury severity				
Isolated spleen injury	270 (19.9)	69 (21.0)	201 (19.5)	.54
AIS spleen				<.0001
4	595 (43.8)	184 (56.1)	411 (39.8)	
5	765 (56.3)	144 (43.9)	621 (60.2)	
Traumatic brain injury	320 (23.5)	61 (18.6)	259 (25.1)	.02
Injury Severity Score	36.0 (29.0–45.0)	34.0 (29.0–43.0)	38.0 (29.0–45.0)	.0004
Head max AIS	0.0 (0.0–2.0)	0.0 (0.0–2.0)	0.0 (0.0–3.0)	.01
Neck max AIS	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	.51
Chest max AIS	3.0 (2.0–3.0)	3.0 (2.0–3.0)	3.0 (2.0–3.0)	.04
Nonspleen abdominal max AIS	2.0 (0.0–3.0)	1.0 (0.0–3.0)	2.0 (0.0–3.0)	.04
Extremity max AIS	2.0 (1.0–3.0)	2.0 (1.0–3.0)	2.0 (0.0–3.0)	.08
Spine max AIS	0.0 (0.0–2.0)	0.0 (0.0–2.0)	0.0 (0.0–2.0)	.76
Prehospital SBP, mm Hg	98.0 (80.0–120.0)	97.0 (78.0–117.0)	98.0 (80.0–121.0)	.38
Number missing	776 (57.1)	211 (64.3)	565 (54.7)	
Prehospital heart rate, bpm	100.0 (82.0–123.0)	100.0 (80.0–122.0)	102.0 (82.0–124.0)	.42
Number missing	737 (54.2)	203 (61.9)	534 (51.7)	
Prehospital Glasgow Coma Scale	14.0 (9.0–15.0)	15.0 (12.0–15.0)	14.0 (8.0–15.0)	.002
Number missing	742 (54.6)	205 (62.5)	537 (52.0)	
Prehospital cardiac arrest	45 (3.3)	16 (4.9)	29 (2.8)	.07
Number missing	12 (0.9)	1 (0.3)	11 (1.1)	
ED SBP, mm Hg	78.0 (70.0–84.0)	80.0 (70.0–84.0)	78.0 (70.0–83.0)	.36
ED heart rate, bpm	105.0 (84.0–125.0)	101.0 (81.0–122.0)	106.0 (85.0–126.0)	.07
ED temperature, °C	36.4 (36.0–36.7)	36.4 (36.1–36.7)	36.3 (35.9–36.6)	.0003
Number missing	324 (23.8)	69 (21.0)	255 (24.7)	
ED respiratory rate, rpm	20.0 (17.0–25.0)	20.0 (17.0–25.0)	20.0 (17.0–25.0)	.63
Number missing	76 (5.6)	10 (3.0)	66 (6.4)	
ED Glasgow Coma Scale	14.0 (6.0–15.0)	15.0 (11.0–15.0)	14.0 (5.0–15.0)	.0007
Number missing	44 (3.2)	9 (2.7)	35 (3.4)	
Outcomes				
Death	222 (16.3)	40 (12.2)	182 (17.6)	.02
ICU days	5.0 (3.0–12.0)	5.0 (3.0–10.0)	6.0 (3.0–13.0)	.53
ICU-free days	20.0 (4.0–24.0)	22.0 (11.0–24.0)	19.0 (1.0–24.0)	.004
Ventilation days	2.0 (0.0–6.0)	2.0 (0.0–5.5)	2.0 (0.0–7.0)	.0003
VFD	25.0 (12.0–28.0)	26.0 (17.5–28.0)	24.0 (10.0–28.0)	<.0001
Complications during hospitalization	141 (10.4)	27 (8.2)	114 (11.0)	.14
CLABSI	2 (0.1)	1 (0.3)	1 (0.1)	.39
Deep SSI	8 (0.6)	1 (0.3)	7 (0.7)	.44
DVT	70 (5.1)	14 (4.3)	56 (5.4)	.41
Alcohol withdrawal	15 (1.1)	1 (0.3)	14 (1.4)	.11
Cardiac arrest	89 (6.5)	13 (4.0)	76 (7.4)	.03
CAUTI	18 (1.3)	4 (1.2)	14 (1.4)	.85
Pulmonary embolism	24 (1.8)	6 (1.8)	18 (1.7)	.92
Extremity compartment syndrome	1 (0.1)	–	1 (0.1)	.57
Unplanned intubation	72 (5.3)	21 (6.4)	51 (4.9)	.30
Acute kidney injury	64 (4.7)	14 (4.3)	50 (4.8)	.67
Myocardial infarction	6 (0.4)	2 (0.6)	4 (0.4)	.60
Organ space SSI	12 (0.9)	2 (0.6)	10 (1.0)	.54
Osteomyelitis	2 (0.1)	–	2 (0.2)	.42
Acute lung injury	34 (2.5)	3 (0.9)	31 (3.0)	.03
Unplanned return to OR	87 (6.4)	21 (6.4)	66 (6.4)	1.00
Sepsis	24 (1.8)	5 (1.5)	19 (1.8)	.70
Stroke CVA	20 (1.5)	7 (2.1)	13 (1.3)	.25
Superficial incision SSI	6 (0.4)	–	6 (0.6)	.17

(*continued on next page*)

Table I (*continued*)

Variables	Total (N = 1,360)	AE first (n = 328, 24.1%)	Splenectomy first (n = 1,032, 75.9%)	P value
Pressure ulcer	41 (3.0)	14 (4.3)	27 (2.6)	.13
Unplanned admission to ICU	47 (3.5)	14 (4.3)	33 (3.2)	.35
Pneumonia	67 (4.9)	13 (4.0)	54 (5.2)	.35
Angioembolization				
Liver	25 (1.8)	16 (4.9)	9 (0.9)	<.0001
Kidney	19 (1.4)	11 (3.4)	8 (0.8)	.0005
Pelvis	43 (3.2)	20 (6.1)	23 (2.2)	.0005
Retroperitoneal	1 (0.1)		1 (0.1)	.57
Facility characteristics				
Trauma center level 1	642 (47.2)	189 (57.6)	453 (43.9)	<.0001
Hospital size (number of beds)				.001
≤200	95 (7.0)	15 (4.6)	80 (7.8)	
201–400	388 (28.5)	75 (22.9)	313 (30.3)	
401–600	370 (27.2)	90 (27.4)	280 (27.1)	
>600	507 (37.3)	148 (45.1)	359 (34.8)	
Minutes to the first treatment	110.0 (76.2–159.5)	148.5 (116.0–196.2)	99.0 (72.5–138.6)	<.0001
Transfusions in the first 4 hr				
Red blood cells units	4.0 (1.0–7.0)	2.0 (1.0–5.0)	4.0 (1.0–8.0)	<.0001
Number missing	189 (13.9)	20 (6.1)	169 (16.4)	
Plasma units	2.0 (0.0–5.0)	1.0 (0.0–3.0)	2.0 (0.0–6.0)	<.0001
Number missing	244 (17.9)	34 (10.4)	210 (20.3)	
Platelets units	0.0 (0.0–1.0)	0.0 (0.0–1.0)	0.0 (0.0–1.0)	<.0001
Number missing	269 (19.8)	39 (11.9)	230 (22.3)	
Cryoprecipitate units	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	.001
Number missing	317 (23.3)	49 (14.9)	268 (26.0)	

AIS, Abbreviated Injury Scale; *bpm*, beats per minute; *CAUTI*, catheter-associated urinary tract infection; *CLABSI*, central line–associated blood stream infection; *CT*, computed tomography; *CVA*, cerebrovascular accident; *DVT*, deep venous thrombosis; *ED*, emergency department; *ICU*, intensive care unit; *OR*, operating room; *rpm*, respirations per minute; *SBP*, systolic blood pressure; *SSI*, surgical site infection; *TBI*, traumatic brain injury; *VFD*, ventilation-free days.

* Numerical variables are presented as median (interquartile range) and categorical variables as n (%).

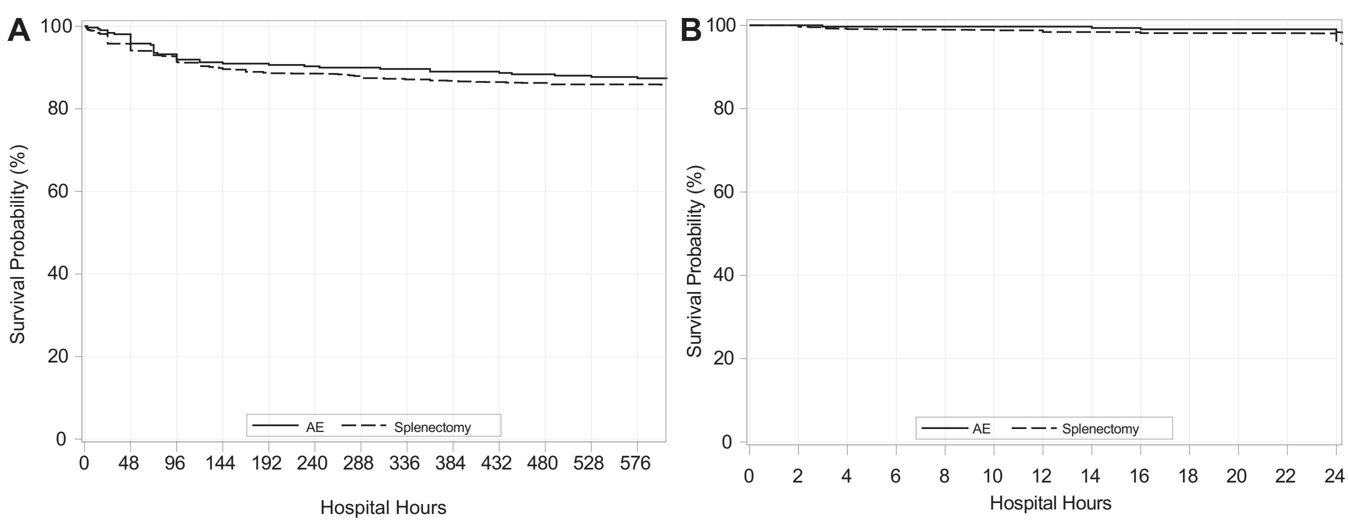

Figure 2. EB-adjusted survival curves for AE versus splenectomy: (A) survival up to 28 days (628 hours) and (B) survival up to 24 hours (EB hazard ratio: 1.02; 95% confidence interval: 0.97–1.07). *AE*, angioembolization; *EB*, entropy balancing.

Failed AE versus successful AE was associated with lower survival, although this difference did not reach significance (HR: 1.12; 95% CI: 0.99–1.26, $P = .07$), and significantly fewer IFD and VFD ($P = .001$ and $P = .0009$) as shown in Table II. Compared with successful AE, failed AE were more likely to develop complications during their hospital course, including acute kidney injury and respiratory failure. The incidence of TQIP-documented infections (pneumonia, central line–associated bloodstream infection, catheter-associated urinary tract infection, sepsis, and surgical site infections) was not significantly different between the groups. The proportion of failed AE diminished, albeit not significantly, over the study period from 30.6% in 2017 to 15.6% in 2022 (Cochran-Armitage trend test $P = .15$), despite a significant increase in the proportion of patients with spleen AIS = 5 who underwent upfront AE during the same period (from 27.8% in 2017 to 47.96% in 2022, Cochran-Armitage trend test $P = .02$), suggesting an improvement in AE performance and/or patient selection.

Patient characteristics and outcomes of failed AE with rescue splenectomy were also compared with the group who underwent splenectomy as the first approach (Table III). The failed AE patients were significantly less likely to have TBI and have had prehospital cardiac arrest. No other baseline differences were observed.

Table II
Characteristics and outcomes of patients treated with upfront angioembolization (AE) who were successfully treated versus those who failed AE and required rescue splenectomy*

Variables	Successful AE ($n = 262$)	Failed AE splenectomy ($n = 66$, 20.1%)	P value
Admission year			.50
2017	25 (9.5)	11 (16.7)	
2018	30 (11.5)	6 (9.1)	
2019	33 (12.6)	10 (15.2)	
2020	43 (16.4)	10 (15.2)	
2021	50 (19.1)	14 (21.2)	
2022	81 (30.9)	15 (22.7)	
AIS spleen			<.0001
4	162 (61.8)	22 (33.3)	
5	100 (38.2)	44 (66.7)	
Male sex	176 (67.2)	40 (60.6)	.31
Age, yr	45.0 (29.0–59.0)	45.0 (30.0–61.0)	.84
Documented White non-Latinx race/ethnicity	184 (70.2)	46 (69.7)	.93
Insurance coverage			.80
Medicaid	48 (18.3)	12 (18.2)	
Medicare	40 (15.3)	10 (15.2)	
Other	23 (8.8)	5 (7.6)	
Private	122 (46.6)	28 (42.4)	
Uninsured	29 (11.1)	11 (16.7)	
Documented comorbidity	36 (13.7)	11 (16.7)	.54
Injury severity			
Isolated spleen injury	36 (13.7)	11 (16.7)	.71
Traumatic brain injury	54 (20.6)	7 (10.6)	.06
Injury Severity Score	34.0 (27.0–42.0)	38.0 (30.0–45.0)	.049
Head max AIS	0.0 (0.0–2.0)	0.0 (0.0–2.0)	.18
Chest max AIS	3.0 (2.0–3.0)	3.0 (2.0–4.0)	.29
Non spleen abdominal AIS	1.0 (0.0–3.0)	2.0 (0.0–4.0)	.02
Extremity max AIS	2.0 (1.0–3.0)	2.0 (1.0–3.0)	.14
Spine max AIS	0.0 (0.0–2.0)	0.0 (0.0–2.0)	.60
Prehospital SBP, mm Hg	100.0 (80.5–117.0)	80.0 (71.0–115.0)	.26
Number missing	170 (64.9)	41 (62.1)	
Prehospital heart rate (bpm)	98.0 (78.0–120.0)	113.0 (87.0–126.0)	.16
Number missing	164 (62.6)	39 (59.1)	
Prehospital respiratory rate, rpm	18.0 (16.0–22.0)	19.0 (16.0–24.0)	.86
Number missing	165 (63.0)	40 (60.6)	
Prehospital GCS	15.0 (12.0–15.0)	14.0 (13.0–15.0)	.38
Number missing	165 (63.0)	40 (60.6)	
Prehospital cardiac arrest	9 (3.4)	7 (10.6)	.02
Number missing	1 (0.4)		
ED SBP, mm Hg	80.0 (70.0–84.0)	80.0 (67.5–84.5)	.99
ED heart rate, bpm	101.0 (80.5–122.0)	105.0 (81.0–119.0)	.66
ED respiratory rate, rpm	20.0 (17.0–25.0)	21.0 (18.0–24.0)	.65
Number missing	7 (2.7)	3 (4.5)	
ED temperature, °C	36.4 (36.1–36.8)	36.3 (36.0–36.7)	.18
Number missing	45 (17.2)	24 (36.4)	
ED GCS	15.0 (12.0–15.0)	14.0 (9.0–15.0)	.30
Number missing	8 (3.1)	1 (1.5)	
Outcomes			
Mortality	27 (10.3)	13 (19.7)	.04
ICU days	5.0 (3.0–10.0)	6.0 (4.0–13.0)	.08
ICU-free days	22.5 (13.0–25.0)	20.0 (1.0–23.0)	.001
Ventilation days	1.0 (0.0–5.0)	3.0 (1.0–7.0)	.003
VFD	26.5 (21.0–28.0)	24.0 (6.0–27.0)	.0009
Complications during hospitalization	18 (6.9)	9 (13.6)	.07
CLABSI	1 (0.4)		.61
Deep SSI	1 (0.4)		.61
DVT	12 (4.6)	2 (3.0)	.58
Alcohol withdrawal	1 (0.4)		.61
Cardiac arrest	9 (3.4)	4 (6.1)	.33
CAUTI	4 (1.5)		.31
Pulmonary embolism	5 (1.9)	1 (1.5)	.83
Extremity compartment syndrome	0	0	
Unplanned intubation	17 (6.5)	4 (6.1)	.90
Acute kidney injury	7 (2.7)	7 (10.6)	.004
Myocardial infarction	2 (0.8)		.48
Organ space SSI	1 (0.4)	1 (1.5)	.29
Acute lung injury	1 (0.4)	2 (3.0)	.04
Unplanned return to OR	10 (3.8)	11 (16.7)	.0001
Sepsis	4 (1.5)	1 (1.5)	.99
Stroke	4 (1.5)	3 (4.5)	.13
Pressure ulcer	11 (4.2)	3 (4.5)	.90

(*continued on next page*)

Table II (*continued*)

Variables	Successful AE ($n = 262$)	Failed AE splenectomy ($n = 66$, 20.1%)	*P* value
Unplanned admission to ICU	13 (5.0)	1 (1.5)	.22
Pneumonia	12 (4.6)	1 (1.5)	.25
Angioembolization			
Liver	8 (3.1)	8 (12.1)	.002
Kidney	6 (2.3)	5 (7.6)	.03
Pelvis	16 (6.1)	4 (6.1)	.99
Retroperitoneal	0	0	
Facility characteristics			
Trauma center level 1	147 (56.1)	42 (63.6)	.27
Hospital size (beds)			.73
≤200	11 (4.2)	4 (6.1)	
201–400	63 (24.0)	12 (18.2)	
401–600	71 (27.1)	19 (28.8)	
>600	117 (44.7)	31 (47.0)	
Minutes to first treatment	152.4 (120.0–201.0)	127.5 (87.0–180.0)	.005
Transfusions in the first 4 hr after admission			
RBC units	2.0 (1.0–4.0)	4.0 (1.0–10.0)	.001
Number missing	19 (7.3)	1 (1.5)	
Plasma units	0.0 (0.0–3.0)	2.0 (0.0–8.0)	.001
Number missing	31 (11.8)	3 (4.5)	
Platelet units	0.0 (0.0–0.0)	0.0 (0.0–1.0)	<.0001
Number missing	35 (13.4)	4 (6.1)	
Cryoprecipitate units	0.0 (0.0–0.0)	0.0 (0.0–0.0)	.11
Number missing	41 (15.6)	8 (12.1)	

AIS, Abbreviated Injury Scale; *bpm*, beats per minute; *CAUTI*, catheter-associated urinary tract infection; *CLABSI*, central line–associated blood stream infection; *DVT*, deep venous thrombosis; *ED*, emergency department; *GCS*, Glasgow Coma Scale; *ICU*, intensive care unit; *OR*, operating room; *RBC*, red blood cell; *rpm*, respirations per minute; *SBP*, systolic blood pressure; *SSI*, surgical site infection; *TBI*, traumatic brain injury; *VFD*, ventilation-free days.

* Values for all continuous variables are the median (interquartile range) and categorical variables as *n* (%).

Survival of failed AE was not significantly different from the survival of splenectomy first (EB-adjusted HR: 1.07, 95% CI: 0.96–1.20, $P = .23$), as illustrated in Figure 3. There were no differences in VFD or IFD after EB adjustment ($P = .12$ and $P = .17$). Patients for whom AE failed were significantly more likely to develop acute kidney injury (10.6% vs 4.8%, $P = .04$) and have a stroke (4.5% vs 1.3%, $P = .03$) during hospitalization.

Discussion

Using a large, nationally representative dataset over recent years, we found that, compared with splenectomy, AE as the initial treatment for high-grade, blunt splenic injuries in patients presenting with hypotension who underwent CT scanning was associated with similar risk-adjusted outcomes. This suggests that trauma surgeons are appropriately selecting the patients who can benefit from attempted upfront AE. Although further refining the indication of AE in this population would require an RCT, our findings indicate that patients with spleen injury AIS = 5 (versus AIS = 4) and other abdominal injuries represent a group for whom failed upfront AE is more likely. Earlier reports on predictors of failed NOM or AE are consistent with our observations that failed NOM/AE results in higher health care utilization than successful AE.[32,33] Notably though, in our study, the patients for whom splenectomy was delayed by AE did not have higher morbidity or mortality than those for whom splenectomy was the initial therapeutic choice, suggesting that the attempt to salvage the spleen did not worsen the outcome.

Our findings expand the accepted use of AE, which was traditionally reserved for hemodynamically stable patients or those with relatively low degrees of hemorrhagic shock.[6,7] Indeed, although there is consensus that hemodynamically stable patients should be treated with NOM/AE and hemodynamically unstable patients unresponsive to resuscitation ("nonresponders") should be taken to the OR, best management of the "grey zone" patients or "transient responders" remains unclear.[6,7,10,12] Our data indicate that some of these patients are appropriate for AE, whereas others should undergo splenectomy, and the discrepancy between the univariate and risk-adjusted outcome analyses highlights that patients selected to undergo AE initially are generally less critically ill.

In addition to being less severely injured, patients selected for AE tended to be older, although there is confounding between age and injury severity. In their 2008 single-center study comparing patients with blunt splenic injury and a CT scan before either OR or AE, Wei et al[34] also found that patients treated with AE were older. Although this may seem counterintuitive based on the multiple prior studies reporting increased failure rates of NOM/AE with increased age, the addition of AE has likely attenuated the effect of older age.[32,33,35] In addition, we found that patients selected for upfront AE had lower rates of TBI. This may reflect the concern that any ongoing bleeding and hypotension from failed NOM/AE could contribute to secondary brain injury, but it demonstrates that the presence of TBI contributes to the medical decision-making process of performing splenectomy rather than AE.[1,36]

If a patient can be effectively treated with AE and avoid a splenectomy, it seems reasonable to attempt this minimally invasive, spleen-preserving approach to hemorrhage control. Aside from the morbidity of a laparotomy and the risk of complications with major open abdominal surgery (ileus, pulmonary complications, surgical site infection, intraperitoneal adhesions, and incisional hernia), splenectomy carries additional risks (risk of infections, and injury to the stomach and pancreas) that may be avoided with AE.[20,34] For example, there have been reports that splenectomy is an independent risk factor for early infectious complications after splenic trauma, and spleen-preserving techniques should be attempted if feasible.[20] Of course, AE also carries risk, including vascular injuries, splenic infarction, splenic abscess, and contrast-related complications.[1,24,26] These risks should be weighed with the risk of ongoing bleeding and delayed hemorrhage control. As we report here, one-fifth of patients initially chosen for AE ultimately required splenectomy, and these patients had worse unadjusted and adjusted survival compared with those treated successfully with AE. This compares to a 23% rescue splenectomy rate reported by Velmahos et al[3] when considering all patients with splenic trauma treated

Table III
Characteristics and outcomes of patients who failed AE and required rescue splenectomy and those submitted to upfront splenectomy*

Variables	Splenectomy first (n = 1,032)	Failed AE (n = 66)	P value
Admission year			.88
2017	156 (15.1)	11 (16.7)	
2018	125 (12.1)	6 (9.1)	
2019	147 (14.2)	10 (15.2)	
2020	205 (19.9)	10 (15.2)	
2021	193 (18.7)	14 (21.2)	
2022	206 (20.0)	15 (22.7)	
AIS spleen			.29
4	411 (39.8)	22 (33.3)	
5	621 (60.2)	44 (66.7)	
Male sex	673 (65.2)	40 (60.6)	.45
Age, yr	41.0 (28.0–58.0)	45.0 (30.0–61.0)	.31
Documented White non-Latinx race and ethnicity	718 (69.6)	46 (69.7)	.98
Insurance coverage			.75
Medicaid	213 (20.6)	12 (18.2)	
Medicare	133 (12.9)	10 (15.2)	
Other	101 (9.8)	5 (7.6)	
Private	461 (44.7)	28 (42.4)	
Uninsured	124 (12.0)	11 (16.7)	
Comorbidity	178 (17.2)	11 (16.7)	.90
Injury severity			
Isolated spleen injury	178 (17.2)	11 (16.7)	.52
Traumatic brain injury	259 (25.1)	7 (10.6)	.008
Injury Severity Score	38.0 (29.0–45.0)	38.0 (30.0–45.0)	.80
Head max AIS	0.0 (0.0–3.0)	0.0 (0.0–2.0)	.02
Chest max AIS	3.0 (2.0–3.0)	3.0 (2.0–4.0)	.95
Non spleen abdominal max AIS	2.0 (0.0–3.0)	2.0 (0.0–4.0)	.30
Extremity max AIS	2.0 (0.0–3.0)	2.0 (1.0–3.0)	.71
Spine max AIS	0.0 (0.0–2.0)	0.0 (0.0–2.0)	.55
Prehospital SBP, mm Hg	98.0 (80.0–121.0)	80.0 (71.0–115.0)	.12
Number missing	98.0 (80.0–121.0)	80.0 (71.0–115.0)	
Prehospital heart rate, bpm	102.0 (82.0–124.0)	113.0 (87.0–126.0)	.41
Number missing	534 (51.7)	39 (59.1)	
Prehospital GCS	14.0 (8.0–15.0)	14.0 (13.0–15.0)	.39
Number missing	537 (52.0)	40 (60.6)	
Prehospital cardiac arrest	29 (2.8)	7 (10.6)	.0006
Number missing	11 (1.1)	–	
ED SBP, mm Hg	78.0 (70.0–83.0)	80.0 (67.5–84.5)	.64
ED heart rate, bpm	106.0 (85.0–126.0)	105.0 (81.0–119.0)	.53
ED temperature, °C	36.3 (35.9–36.6)	36.3 (36.0–36.7)	.61
Number missing	255 (24.7)	24 (36.4)	
ED respiratory rate, rpm	20.0 (17.0–25.0)	21.0 (18.0–24.0)	.56
Number missing	66 (6.4)	3 (4.5)	
ED GCS	14.0 (5.0–15.0)	14.0 (9.0–15.0)	.42
Number missing	35 (3.4)	1 (1.5)	
Outcomes			
Mortality	182 (17.6)	13 (19.7)	.67
ICU days	6.0 (3.0–13.0)	6.0 (4.0–13.0)	.33
ICU-free days	19.0 (1.0–24.0)	20.0 (1.0–23.0)	.30
Ventilation days	2.0 (0.0–7.0)	3.0 (1.0–7.0)	.43
VFD	24.0 (10.0–28.0)	24.0 (6.0–27.0)	.56
Complications during hospitalization	114 (11.0)	9 (13.6)	.52
CLABSI	1 (0.1)	–	.80
Deep SSI	7 (0.7)	–	.50
DVT	56 (5.4)	2 (3.0)	.40
Alcohol withdrawal	14 (1.4)	–	.34
Cardiac arrest	76 (7.4)	4 (6.1)	.69
CAUTI	14 (1.4)	–	.34
Pulmonary embolism	18 (1.7)	1 (1.5)	.89
Extremity compartment syndrome	1 (0.1)		.80
Unplanned intubation	51 (4.9)	4 (6.1)	.69
Acute kidney injury	50 (4.8)	7 (10.6)	.04
Myocardial infarction	4 (0.4)	–	.61
Organ space SSI	10 (1.0)	1 (1.5)	.67
Osteomyelitis	2 (0.2)	–	.72
Acute lung injury	31 (3.0)	2 (3.0)	.99
Unplanned return to OR	66 (6.4)	11 (16.7)	.001
Sepsis	19 (1.8)	1 (1.5)	.85
Stroke	13 (1.3)	3 (4.5)	.03
Superficial SSI	6 (0.6)		.53
Pressure ulcer	27 (2.6)	3 (4.5)	.35
Unplanned ICU	33 (3.2)	1 (1.5)	.44

(*continued on next page*)

Table III (*continued*)

Variables	Splenectomy first (n = 1,032)	Failed AE (n = 66)	*P* value
Pneumonia	54 (5.2)	1 (1.5)	.18
Angioembolization			
Liver	9 (0.9)	8 (12.1)	<.0001
Kidney	8 (0.8)	5 (7.6)	<.0001
Pelvis	23 (2.2)	4 (6.1)	.05
Retroperitoneal	1 (0.1)	–	.80
Facility characteristics			
Trauma center level 1	453 (43.9)	42 (63.6)	.002
Hospital size (beds)			.11
≤200	80 (7.8)	4 (6.1)	
201–400	313 (30.3)	12 (18.2)	
401–600	280 (27.1)	19 (28.8)	
>600	359 (34.8)	31 (47.0)	
Minutes to first treatment	99.0 (72.5–138.6)	127.5 (87.0–180.0)	.004
Transfusions in the first 4 hr after admission			
RBC units	4.0 (1.0–8.0)	4.0 (1.0–10.0)	.55
Number missing	169 (16.4)	1 (1.5)	
Plasma units	2.0 (0.0–6.0)	2.0 (0.0–8.0)	.98
Number missing	210 (20.3)	3 (4.5)	
Platelet units	0.0 (0.0–1.0)	0.0 (0.0–1.0)	.72
Number missing	230 (22.3)	4 (6.1)	
Cryoprecipitate units	0.0 (0.0–0.0)	0.0 (0.0–0.0)	.52
Number missing	268 (26.0)	8 (12.1)	

AE, angioembolization; *AIS*, Abbreviated Injury Scale; *bpm*, beats per minute; *CAUTI*, catheter-associated urinary tract infection; *CLABSI*, central line–associated blood stream infection; *DVT*, deep venous thrombosis; *ED*, emergency department; *GCS*, Glasgow Coma Scale; *ICU*, intensive care unit; *OR*, operating room; rpm, respirations per minute; *RBC*, red blood cell; *SBP*, systolic blood pressure; *SSI*, surgical site infection; *TBI*, traumatic brain injury; *VFD*, ventilation-free days.

* Values for all numeric variables are the median (interquartile range) and categorical variables as n (%).

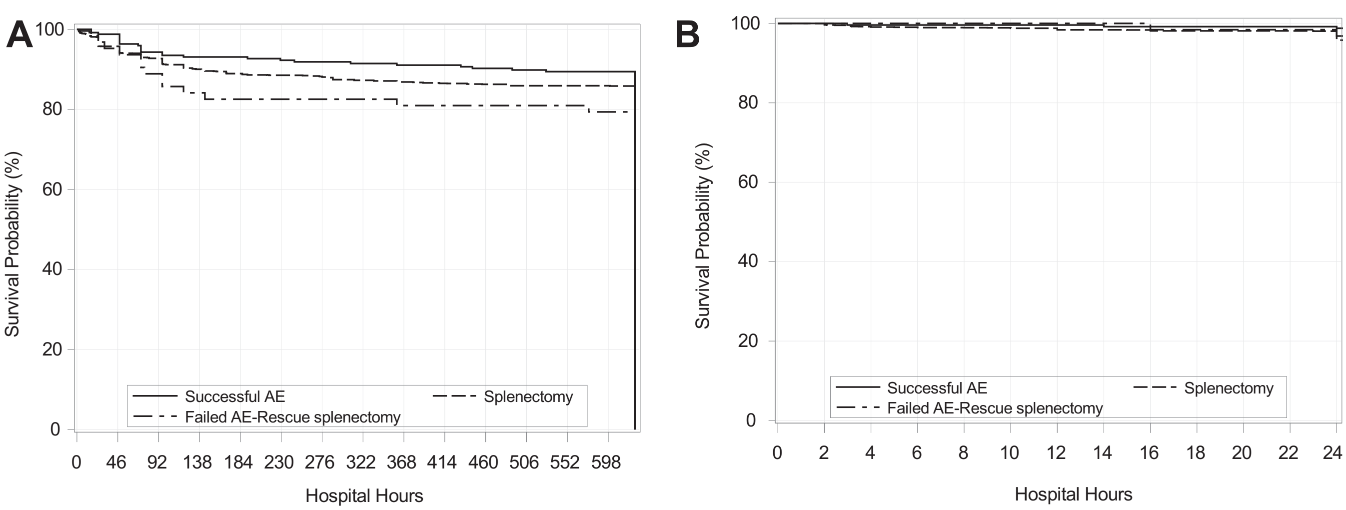

Figure 3. EB-adjusted survival curves of successful AE, failed AE splenectomy, and splenectomy first: (A) survival up to 28 days (628 hours) and (B) survival up to 24 hours (EB hazard ratio failed AE splenectomy versus successful AE: 1.12, 95% CI: 0.99–1.26; failed AE splenectomy versus splenectomy first: 1.07, 95% CI: 0.96–1.20). *AE*, angioembolization; *CI*, confidence interval; *EB*, entropy balancing.

initially with NOM/AE and a 4% rescue splenectomy rate reported by Gaarder et al[37] after implementing a protocol of pre-emptive AE for all grade III–V injuries. Neither of these studies assessed the rescue splenectomy rate specifically among patients presenting hypotensive. Furthermore, our study demonstrates that the rate of failed AE has decreased over recent years, suggesting improved performance and/or selection of patients. Improvements in time to AE may also widen the scope of patients appropriate for upfront AE over splenectomy, as we found that patients chosen for initial AE took 50% longer to reach the angiography suite than those taken for splenectomy took to roll into the OR. This has important implications for the implementation of the hybrid OR concept and full-time in-house interventional capability.

Although this study provides the most recent, largest, and risk-adjusted analysis comparing AE with splenectomy for this population of injured patients, it has inherent limitations. These are mostly related to the retrospective data included in the TQIP database, which are not granular enough to determine response to resuscitation, location of transfusions, antifibrinolytics (eg, tranexamic acid) administration, details of the embolization procedure (eg, how selective the embolization was), timing of the complications, specific location of organ site infection, incidence of pseudoaneurysm, and limited information about abdominal examination. These are important data points that influence clinical decision-making. We hesitated in comparing the incidence of complications as in order to produce an adjusted comparison of nonlethal complications, one would need to conduct a risk-competing survival analysis, censoring for both discharge and death, which requires the date of when the complication occurred. Unfortunately, TQIP does not have the date (or hospital day) when the complications occurred. We attempted to control for interfacility clustering, but AE, transfusion, and other trauma protocols also vary substantially between institutions. Although we contemplated an analysis of isolated spleen injuries, unfortunately, the number of patients with isolated spleen injury was small, and these patients do not reflect most of the population for whom the decision studied here would apply. In addition, with such a small number, appropriate control of confounding would be severely limited. In addition, we did not examine the effects of splenorraphy, which may mitigate some of the complications of splenectomy. It is important to note that the AIS coding of spleen injury severity remained constant across the study period; however, the American Association for the Surgery of Trauma revised the Organ Injury Scale (OIS) grading criteria in December of 2018 to integrate vascular injury assessments.[38] This change results in some spleen injuries originally classified as OIS grade 2 with contrast extravasation now being reclassified as OIS grade 5. It is possible that each hospital used different OIS-AIS correlation practices, potentially introducing a severity bias. Unfortunately, the TQIP database lacks details on the original OIS gradings. We examined the distribution of AIS severity grades across the study period and noticed a slight increase in the proportion of AIS 4/5 from 20.9% in 2017–2018 (before the publication of the new scale in December of 2018) to 24.2% in 2019–2022 (and a decrease in AIS 2/3 from 79.8% to 75.7%) of all spleen injuries across the study period. We hope that adjustment for year of admission in all models and intrafacility clustering minimized this potential bias. Finally, in addition to short-term outcomes observed during the hospital stay, the long-term effects of splenectomy, including the risk of infection and the need for vaccinations, were not available for study. Despite imperfect adjustment for confounders, in the absence of an RCT, we provide this as the best evidence to date comparing 2 interventions currently used in similar clinical scenarios. We used EB as a method of covariate balance to best match “treatment” and “control” groups while validating this analysis in a second confounder-adjusted analysis. Our findings illuminate the equipoise of this clinical management dilemma, which justifies a prospective, randomized study focused on this specific patient population. The wider availability of hybrid ORs, in-house interventional capability, and the use of the partial resuscitative endovascular balloon occlusion of the aorta (REBOA) also influence the decision-making. For example, we believe that patients who maintain an SBP >90 mm Hg, without TBI, with a partial REBOA in a hybrid OR may be candidates for AE.

In conclusion, we report that among patients with severe, blunt splenic injuries presenting with shock but stabilizing enough to complete a CT scan, AE first is currently practiced in nearly half of all trauma centers, has increasingly been used over recent years, and does not result in significantly worse outcomes than splenectomy first, especially in patients without TBI or other intraabdominal injuries. Failed AE in this patient cohort is not significantly associated with worse outcomes than splenectomy first as a treatment strategy.

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Conflict of Interest/Disclosure

The authors have no related conflicts of interest to declare.

CRediT authorship contribution statement

Terry R. Schaid: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ernest E. Moore:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Renaldo Williams:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Angela Sauaia:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Isabella M. Bernhardt:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Fredrick M. Pieracci:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Daniel D. Yeh:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [https://doi.org/10.1016/j.surg.2024.109058].

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