REVIEW ARTICLES

Richard P. Cambria, MD, Section Editor

Open repair, endovascular repair, and conservative management of true splenic artery aneurysms

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Objective: **True splenic artery aneurysms (SAAs) are a rare but potentially fatal pathology. For many years, open repair (OPEN) and conservative management (CONS) were the treatments of choice, but throughout the last decade endovascular repair (EV) has become increasingly used. The purpose of the present study was to perform a systematic review and meta-analysis evaluating the outcomes of the three major treatment modalities (OPEN, EV, and CONS) for the management of SAAs.**

Methods: **A systematic review of all studies describing the outcomes of SAAs treated with OPEN, EV, or CONS was performed using seven large medical databases. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed to ensure a high-quality review. All articles were subject to critical appraisal for relevance, validity, and availability of data regarding characteristics and outcomes. All data were systematically pooled, and meta-analyses were performed on several outcomes, including early and late mortality, complications, and number of reinterventions.**

Results: **Original data of 1321 patients with true SAAs were identified in 47 articles. OPEN contained 511 patients (38.7%) in 31 articles, followed by 425 patients (32.2%) in CONS in 16 articles and 385 patients (29.1%) in EV in 33 articles. The CONS group had fewer symptomatic patients (9.5% vs 28.7% in OPEN and 28.8% in EV; $P < .001$) and fewer ruptured aneurysms (0.2% vs 18.4% in OPEN and 8.8% in EV; $P < .001$), but no significant differences were found in existing comorbidities. CONS patients were usually older and had smaller-sized aneurysms than patients in the OPEN and EV groups. The only identified difference in baseline characteristics between OPEN and EV was the number of ruptured aneurysms (18.4% vs 8.8%; $P < .001$). OPEN had a higher 30-day mortality than EV (5.1% vs 0.6%; $P < .001$), whereas minor complications occurred in a larger number of the EV patients. EV required more reinterventions per year (3.2%) compared with OPEN (0.5%) and CONS (1.2%; $P < .001$). The late mortality rate was higher in patients treated with CONS (4.9% vs 2.1% in OPEN and 1.4% in EV; $P = .04$).**

Conclusions: **EV of SAA has better short-term results compared with OPEN, including significantly lower perioperative mortality. OPEN is associated with fewer late complications and fewer reinterventions during follow-up. Patients treated with CONS showed a higher late mortality rate. Ruptured SAAs are predictors of a significantly higher perioperative mortality compared with nonruptured SAAs in the OPEN and EV groups. (J Vasc Surg 2014;60:1667-76.)**

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True splenic artery aneurysms (SAAs) are a rare but potentially fatal pathology. The splenic artery is considered aneurysmal when the size of the artery is >1 cm in diameter. True SAAs are defined as expansions of all wall layers, whereas pseudoaneurysms are defined as expansions of the artery with focal disruption of the arterial wall.[1] Although rare, SAAs are the third most common abdominal aneurysms after aortic and iliac artery aneurysms and account for almost all visceral artery aneurysms.[2] Previous studies have shown a high risk for SAA rupture when the aneurysm measures >2 cm.[3,4] Although most SAAs are asymptomatic, they have the potential to rupture, which can result in life-threatening complications.[2-5] This emphasizes the importance of continued surveillance of SAAs and timely intervention if the SAA reaches the threshold limit.

SAA was first described in 1770 by Beaussier,[6] but surgical repair was not reported until 1940.[7] Open repair (OPEN) or conservative management (CONS) was the treatment of choice for many years. During the last decade, however, endovascular repair (EV) of SAAs has been increasingly used with good short-term results.[8-11] Because this disease is rare, most studies are retrospective, reporting only a small number of patients, and therefore, no Level 1 evidence is available.

With the more frequent use of diagnostic tests, there has been an increase in the detection of SAAs and, thus, an increasing need for clear directives. The current general consensus has been to intervene in all symptomatic patients and aneurysms >2 cm in diameter, but no clear guidelines for indications of treatment have been reported. All three management options have pros and cons. OPEN has shown excellent long-term results but high perioperative mortality.[12-15] EV has shown low short-term morbidity and mortality but a higher reintervention rate as result of long-term complications.[8-11] CONS has no immediate procedural risk but an increasing risk of aneurysm rupture potentially resulting in life-threatening hemorrhage.[2-5] However, most evidence is disseminated over several smaller studies over a broad period of time, and no clear overviews, guidelines, or management recommendations are available.

The purpose of the present study was to perform a systematic review and meta-analysis evaluating the outcomes of the three treatment modalities—OPEN, EV, and CONS—for the management of SAAs, taking into account the clinical presentation.

METHODS

Literature search. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used to perform this systematic review and meta-analysis.[16] To identify all articles describing treatment of SAAs, MEDLINE, EMBASE, Web of Science, Scopus, PubMed as supplied by the publisher, Cochrane Library Central, and Google Scholar were systematically searched through December 12, 2013. No publication date restriction was applied.

The following search string was used for EMBASE: ("spleen artery aneurysm"/de *or* (("spleen artery"/de *or* spleen/de) *and* ("aneurysm surgery"/exp *or* aneurysm/exp)) *or* ((spleen *or* splenic) NEAR/3 aneurysm*):ab,ti) *and* (therapy/exp *or* therapy:lnk *or* surgery/exp *or* surgery:lnk *or* procedures/de *or* (therap* *or* treat* *or* curing *or* cure *or* repair *or* technique* *or* procedure* *or* equipment* *or* surg* *or* operat*):ab,ti). This resulted in 1121 articles. A similar search string was used for other search engines. Details of search strings and number of articles can be found in the Appendix (online only). We identified 2702 articles, and after removal of duplicate articles, 1490 unique articles remained.

Selection of articles. Review of titles and abstracts was performed independently by two investigators (W.H. and A.L.). For a report to be excluded, both reviewers had to agree that the article was ineligible for inclusion. Disagreements between reviewers were discussed and resolved by consensus. Articles were included if (1) original data of characteristics and outcomes of true SAAs were reported, (2) they described OPEN, EV, or CONS management, and (3) reported at least 10 patients, because case reports and case series have the tendency toward publication bias, only reporting successful cases.[17] Exclusion criteria included (1) articles without original data, (2) articles specifically reporting pregnant patients with SAAs because of the different pathophysiology, (3) not describing OPEN, EV, or CONS management, (4) describing false/pseudoaneurysms, (5) if there was no clear distinction between splenic aneurysms and visceral aneurysm, and (6) if no useful information regarding the outcomes was presented. To prevent inclusions of duplicate cases, articles published by identical authors or institutions were studied in detail, and the most recent article was included.

Because administrative data (eg, Medicare files) are considered to be less reliable and less consistent and could have been published previously in other included articles, these articles were not included. To identify additional relevant articles, references of included articles were searched manually and retrieved three additional articles. A total of 47 relevant articles were identified and included in the final selection (Fig 1).

Data extraction. Two independent investigators (W.H., A.L.) analyzed the included articles and extracted the data. All extracted characteristics and outcomes were systematically included in a database. If a variable was described only for the whole group in an article that described multiple types of treatment, but not specific for OPEN, EV, or CONS, this variable was not included in the analysis. The variables extracted included year of publication, institution, number of patients, number of aneurysms, age, sex, size of the SAA, percentage of symptomatic patients, type of symptoms, percentage of ruptures, number of patients with hypertension, hyperlipidemia, diabetes mellitus, coronary artery disease, number of patients smoking, type of treatment, type of intervention, type of surgery, number of splenectomies, elective or emergency cases, technical success, conversion from EV to OPEN, 30-day minor complications, type of morbidity, major complications, 30-day mortality, cause of death <30 days, late complications, late (>30 days) mortality, number of reinterventions, hospital length of stay in days, length of follow-up in months, number lost to follow-up, and overall survival. Patient selection was based on the recommendations of the Quality of Reporting of Meta-analyses (QUOROM) statement.[18] Additional information on the exact techniques used for OPEN and EV is beyond the scope of this report, but the relevant information is addressed in the referenced article.[19] Original data of 1321 patients with true SAAs treated with OPEN, EV, or CONS were analyzed.

Statistical analyses. Statistical analyses were performed using IBM SPSS 22.0 software (IBM Corp, Armonk, NY), Review Manager (RevMan) 5.2 software

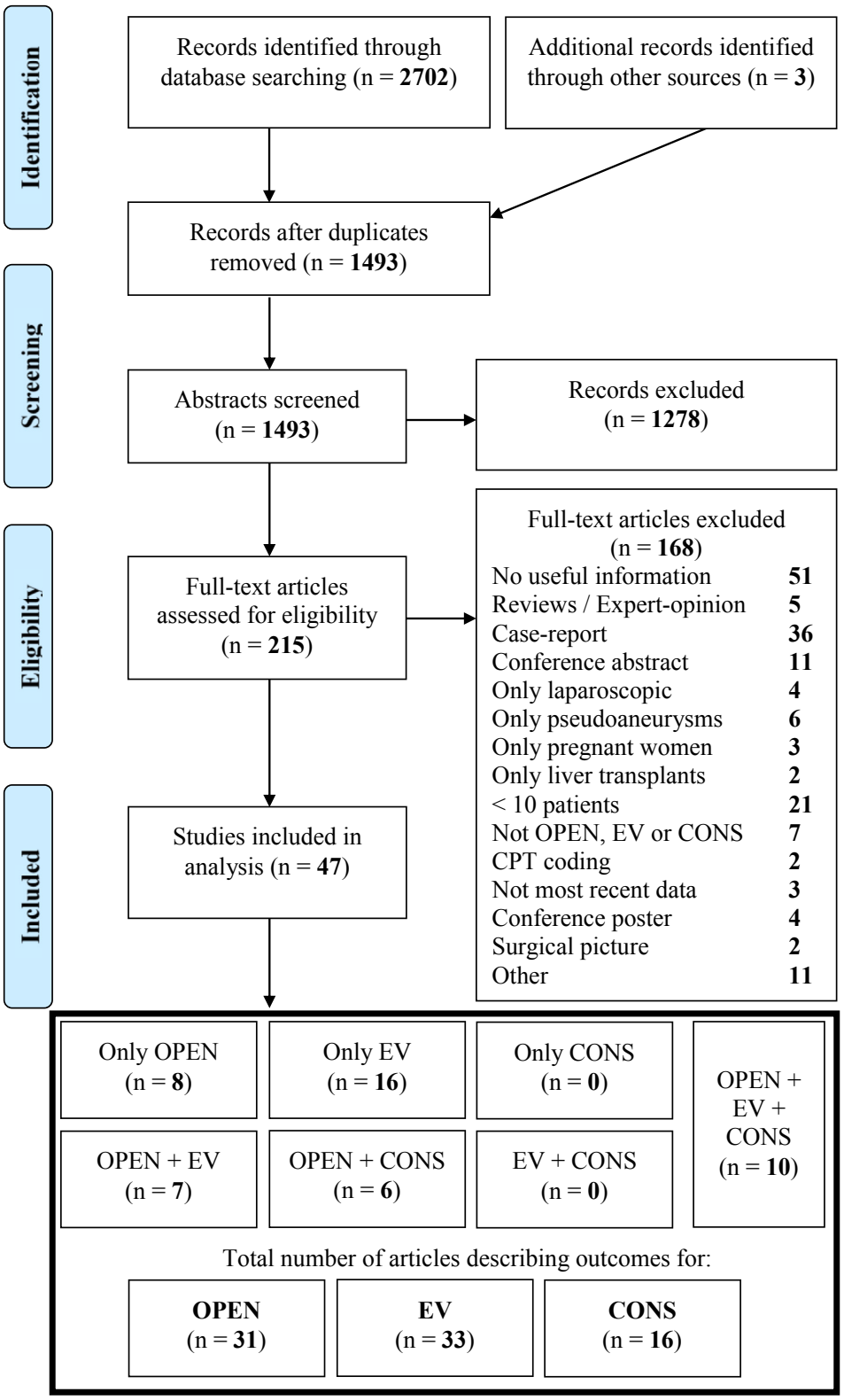

Fig 1. Flow diagram shows literature search and selection, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for splenic artery aneurysms (SAAs). *CONS,* Conservative management; *EV,* endovascular repair; *OPEN,* open repair.

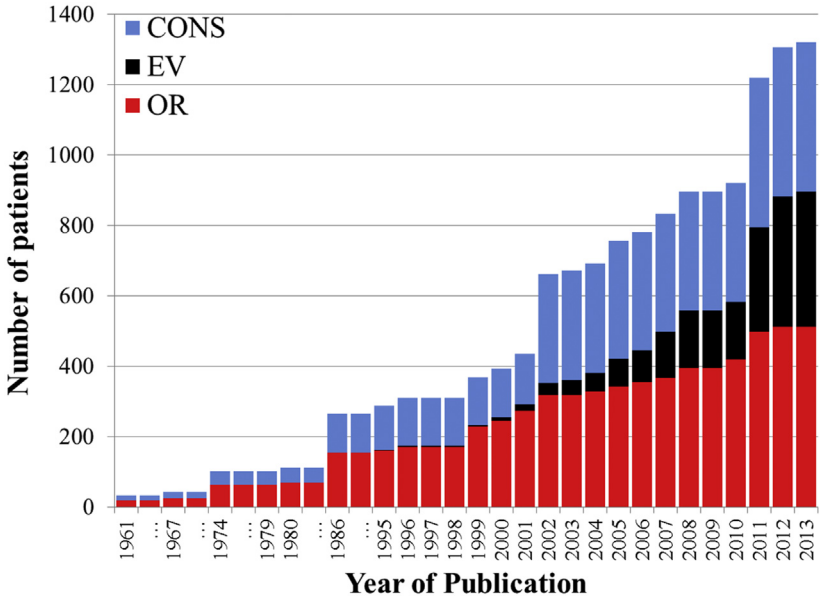

Fig 2. Cumulative number of patients treated with open repair (*OPEN*; *red*), endovascular repair (*EV*; *black*), or conservative management (*CONS*; *blue*) for splenic artery aneurysms (SAAs) by year of publication.

(The Cochrane Collaboration, The Nordic Cochrane Centre, Copenhagen, Denmark), and Excel 2010 software (Microsoft Corp, Redmond, Wash). Continuous variables are described using means and standard deviations, if possible, and categoric factors are reported in frequencies and percentages. Some of the percentages were calculated into rates per year (eg, for the reinterventions) by using the equation: [rate = −ln (1 − prob)/time]. Continuous variables were compared using the *t*-test for two groups or analysis of variance for more than two groups. Categoric characteristics and outcomes were used to compare variables and outcomes among OPEN, EV, and CONS using the χ^2 test or the Fisher exact test when the expected number was fewer than five.

Adjustment for learning curve and ruptures. Given the importance of the time of publication, an additional analysis was performed for OPEN vs EV only using data from articles published after 2000. The year 2000 was chosen as the cutoff point because there was still a learning curve for the EV group before 2000. Only a few small case studies or case reports were published before 2000 describing the EV of SAAs. Comparison was also performed between patients who presented with ruptured SAA and patients who were not reported as presenting with ruptured SAAs.

RESULTS

Literature search. Original data of 1321 patients with true SAAs were identified in 47 articles. OPEN contained the largest number of patients, at 511 (38.7%), followed by CONS with 425 (32.2%) and EV with 385 (29.1%). In total, 31 articles described characteristics and outcomes for patients treated with OPEN,[2-5,12-15,20-42] 33 articles for EV,[1,3-5,8-11,13-15,20-26,32-35,43-53] and 16 for CONS.[2-5,20-31] Details of the number of articles and patients are shown in Fig 1. Fig 2 shows the distribution of the different types of treatment by publication date. An increase of patients treated with EV can be seen after 2000: only 2% of all treated aneurysms were managed with EV in 1999 and was ~25% in 2000 to 2002, ~50% in 2003 to 2009, and ~70% in 2010 to 2013. Availability of the studied variables in the analyzed articles are reported in Table I.

Study characteristics. Baseline characteristics, frequencies, and significance levels are given in Table II. Patients in the CONS group were older than those in the OPEN and EV groups, with a mean age of 61.4 years vs 56.3 years in OPEN and 56.7 years in EV, and the CONS group contained a higher number of female patients (75.1%) compared with OPEN (63.9%) and EV (60.0%; $P = .001$). The CONS group had patients with a smaller aneurysm size (2.1 cm) compared with OPEN (3.1 cm) and EV (3.0 cm), a smaller number of symptomatic patients (9.5% vs 28.7% in OPEN and 28.8% in EV; $P < .001$), and less ruptured aneurysms (0.2% vs 18.4% in OPEN and 8.8% in EV; $P < .001$). Owing to the lack of reported standard deviations, ranges, and interquartile ranges in the evaluated reports, no standard deviation and, therefore, no statistical significance could be calculated for age and size of aneurysm.

There were no significant differences in the presence of different comorbidities (hypertension, hyperlipidemia, diabetes mellitus, coronary artery disease, and smoking) among the groups. The baseline characteristics were not significantly different between the OPEN and EV group, except for the number of ruptured aneurysms, which was higher in the OPEN group than in the EV group (18.4% vs 8.8%; $P < .001$).

Table I. Availability of data in the evaluated reports

Variable available	*All patients (N = 1321), No. (%)*	*OPEN (n = 511), No. (%)*	*EV (n = 385), No. (%)*	*CONS (n = 425), No. (%)*
Age	1277 (97)	506 (99)	384 (99)	387 (91)
Gender	847 (64)	341 (67)	265 (69)	241 (57)
Aneurysm				
Number	1321 (100)	511 (100)	385 (100)	425 (100)
Size	999 (76)	347 (68)	297 (77)	355 (84)
Location	448 (34)	183 (36)	219 (57)	46 (11)
Presence of				
Symptoms	1070 (81)	415 (81)	278 (72)	377 (89)
Rupture	1212 (92)	456 (89)	354 (92)	402 (95)
Hypertension	656 (50)	209 (41)	113 (29)	334 (79)
Hyperlipidemia	397 (30)	77 (15)	86 (22)	234 (55)
Diabetes	472 (36)	113 (22)	103 (27)	256 (60)
Coronary artery disease	434 (33)	92 (18)	102 (26)	240 (56)
Smoking	459 (35)	98 (19)	102 (26)	259 (61)
Type of intervention	896/896 (100)	511 (100)	385 (100)	NA
Elective/emergency	779/896 (87)	439 (86)	340 (88)	NA
Technical success	882/896 (98)	498 (97)	384 (99)	NA
Splenectomy	870/896 (97)	511 (100)	359 (93)	NA
Conversion	375/385 (97)	NA	375 (97)	NA
Thirty-day morbidity	1231 (93)	438 (86)	378 (98)	415 (98)
Thirty-day mortality	1307 (99)	498 (97)	384 (99)	425 (100)
Length of				
Hospital stay	233/896 (26)	64 (13)	169 (44)	NA
Follow-up	1104 (84)	377 (74)	342 (89)	385 (91)
Lost to follow-up	560 (42)	119 (23)	227 (59)	214 (50)
Late complications	909 (69)	335 (66)	354 (92)	220 (52)
Late mortality	918 (69)	334 (65)	349 (91)	235 (55)
Reinterventions	1211 (92)	450 (88)	384 (99)	377 (89)
Survival	895 (68)	317 (62)	241 (63)	337 (79)

CONS, Conservative management; *EV*, endovascular repair; *NA*, not applicable; *OPEN*, open repair.

Management. Surgical intervention in the OPEN group was resection of the aneurysm combined with splenectomy in most patients, followed by reconstruction of the splenic artery. The preferred method of EV was embolization, followed by stenting of the SAA (Table II).

Early outcomes. Technical success was achieved in 97.8% of the OPEN cases and in 95.2% of the EV cases (Table III). Conversion to open surgery was necessary in 1.8% of the EV cases to successfully exclude the aneurysm. The 30-day mortality in the OPEN group was much higher compared with the EV patients (5.1% vs 0.6%; $P < .001$), whereas a larger number of patients treated with EV experienced minor complications (wound infection, postembolization syndrome). The incidence of major long-term complications was low and was similar, with 1.1% for OPEN and 0.8% for EV. The mean hospital length of stay was longer in the OPEN group (9.8 days) compared with the EV group (2.0 days).

Late outcomes. The mean length of follow-up was much shorter for EV than for OPEN and CONS, at 30.8 months, 61.2 months, and 61.8 months, respectively, due to the relatively new procedures and techniques of EV. During these follow-up periods, more late complications developed in patients in the EV group and they required more reinterventions than the OPEN and CONS patients. Patients in the CONS group, however, had a higher rate of late mortality compared with OPEN and EV (Table III). An average of 3.7% complications per year developed in the EV patients, and 3.2% required reinterventions per year. Patients initially treated with CONS required 1.2% interventions per year, whereas the OPEN group only required 0.5% reinterventions per year ($P < .001$).

Adjusting for the learning curve. More minor complications and fewer late deaths after OPEN were reported after 2000 compared with the period before 2000 (Table IV). All the other outcomes were not significantly different statistically. This comparison was not performed for patients treated with EV because there were insufficient cases before to 2000 to perform a meaningful analysis (n = 5).

Outcomes between OPEN and EV after 2000 are reported in Table V and show the same outcomes as reported for the outcomes of all time periods combined, which were given in Table III. Technical success ($P = .018$) and 30-day mortality ($P < .001$) were higher in the OPEN group. The number of acute minor complications ($P = .012$), number of late complications ($P < .001$), and number of reinterventions ($P = .007$) were higher in the EV group.

Ruptured vs unruptured SAAs. Because the only difference in the baseline characteristics between OPEN and EV was the number of patients with ruptured SAAs, the

Table II. Baseline characteristics of patients with splenic artery aneurysms (*SAAs*)

Characteristic	*OPEN (n = 511), No. (%) or mean*	*EV (n = 385), No. (%) or mean*	*CONS (n = 425), No. (%) or mean*	P *value*	
				All groups	*OPEN vs EV*
Age, years	56.3	56.7	61.4	–[a]	–[a]
Gender, % female	218 (63.9)	159 (60.0)	181 (75.1)	.001	.322
Aneurysms/patient, No.	1.16	1.06	1.13	–[a]	–[a]
Aneurysm size, cm	3.1	3.0	2.1	–[a]	–[a]
Location					
Proximal	27 (14.8)	41 (18.7)	4 (10.3)	.316	.291
Middle	50 (27.3)	71 (32.4)	11 (28.3)	.523	.267
Distal/hilar	106 (57.9)	107 (48.9)	24 (61.5)	.114	.070
Symptomatic	119 (28.7)	80 (28.8)	35 (9.5)	<.001	.977
Ruptured SAA	84 (18.4)	31 (8.8)	1 (0.2)	<.001	<.001
Hypertension	84 (40.1)	54 (47.7)	154 (46.2)	.299	.189
Hyperlipidemia	18 (23.7)	28 (33.1)	68 (29.1)	.426	.194
Diabetes	13 (11.3)	13 (12.5)	26 (10.0)	.782	.801
Coronary artery disease	15 (16.0)	15 (14.7)	50 (21.0)	.343	.758
Smoking	29 (29.7)	19 (18.8)	55 (21.1)	.139	.070
Type of intervention					
Ligation	63 (12.3)	NA	NA		
Reconstruction	100 (19.6)	NA	NA		
Resection	51 (10.0)	NA	NA		
Splenectomy	291 (56.9)	6 (1.6)	NA		
Stent	NA	13 (3.4)	NA		
Embolization	NA	365 (94.8)	NA		
Other	6 (1.2)	1 (0.3)	NA		

CONS, Conservative management; *EV,* endovascular repair; *NA,* not applicable; *OPEN,* open repair.
[a]Owing to the lack of reported standard deviations, ranges, and interquartile ranges in the evaluated reports, no standard deviations and, therefore, no statistical significance could be calculated for age, aneurysm size, and aneurysm number.

30-day mortality for patients with ruptured and unruptured aneurysms was specifically analyzed. Data were available for 810 patients describing ruptured or unruptured SAAs and the 30-day mortality. These results are shown as a subanalysis in Table V and demonstrate that a higher mortality was reported for ruptured and unruptured patients in the OPEN group compared with the EV group.

DISCUSSION

The results of this meta-analysis show that EV of SAA has better short-term results than OPEN. However, OPEN is associated with fewer late complications and reinterventions during follow-up. Patients who were treated with CONS were not at immediate risk of perioperative death but showed a higher late mortality rate. These patients were usually older, had smaller aneurysms than patients in the OPEN and EV groups, and had fewer symptoms and ruptures. Except for the difference in number of ruptured SAAs, there were no other differences between the OPEN and EV group, thus making them eligible for comparison.

SAAs account for up to 75% of all visceral artery aneurysms and are more commonly reported in female patients than in male patients at a ratio of 4:1.[3,14,54] We observed a higher number of female patients in the articles used in this meta-analysis, with women accounting for 66.0% of the patients. With a mean age of 58.0 for the entire group, SAAs are predominantly found in elderly women. Why SAAs predominate in women is not exactly clear, but a hormonal contribution has been postulated.[55]

This meta-analysis, with >1300 included patients, is by far the most extensive analysis of patients with true SAAs to date. Given the rarity of the disease, most published articles are, not surprisingly, small retrospective studies. The strength of a meta-analysis is that by pooling many studies, the effective sample size is greatly increased, and therefore, more characteristics and outcomes can be evaluated.[56]

There are, however, some limitations. First, data collection was restricted to information available in the existing literature, and information about many variables could not be retrieved for all of the patients; for example, data regarding the size of the aneurysm were only available for 76% of patients. Regrettably, this is inherent to meta-analyses in general. In addition, we rely completely on published reports on whether aneurysms are true or false. Articles reporting false aneurysms, or in case this was not clear in the report, were excluded.

The second limitation is that no statistical comparison could be performed for several characteristics, including age and aneurysm size, due to the lack of comprehensive statistical information in the articles. To perform an accurate statistical test, one needs at least the standard deviations, ranges, or interquartile ranges when combining the means, and unfortunately, these were poorly described in the literature. When crudely comparing the patient ages and aneurysm sizes among the groups, OPEN and EV were performed in very similar patient populations consisting of younger patients (56.3 years vs 56.7 years) with

Table III. Outcomes of patients with splenic artery aneurysms (SAAs) after treatment

Outcome	*OPEN (n = 511), No. (%) or mean*	*EV (n = 385), No. (%) or mean*	*CONS (n = 425), No. (%) or mean*	P *value*	
				All groups	*OPEN vs EV*
Technical success	487 (97.8)	366 (95.2)	NA	NA	.041
Conversion	0 (0.0)	7 (1.8)	NA	NA	NA
Complications					
Minor	49 (11.3)	95 (25.1)	NA	NA	<.001
Major	3 (1.1)	3 (0.8)	NA	NA	.690
Thirty-day mortality	25 (5.1)	2 (0.6)	2 (0.5)	<.001	<.001
Length of					
Hospital stay, days	9.8	2.03	NA	—[a]	—[a]
Follow-up, months	61.2	30.8	61.8	—[a]	—[a]
Late complications	9 (2.5)	34 (9.1)	2 (0.8)	<.001	<.001
Late mortality	7 (2.1)	5 (1.4)	11 (4.9)	.040	.510
Reinterventions	9 (2.4)	30 (7.9)	22 (5.8)	.004	<.001

CONS, Conservative management; *EV,* endovascular repair; *NA,* not applicable; *OPEN,* open repair.
[a]Owing to the lack of reported standard deviations, ranges, and interquartile ranges in the evaluated reports, no standard deviations and, therefore, no statistical significance could be calculated for length of hospital stay and follow-up.

Table IV. Outcomes of patients with splenic artery aneurysms after open repair (*OPEN*) before and after the year 2000

OPEN outcome[a]	*Before 2000 (n = 228), No. (%) or mean*	*After 2000) (n = 283), No. (%) or mean*	P *value*
Technical success	208 (96.7)	279 (98.6)	.221
Conversion	0 (0)	0 (0)	NA
Complications			
Minor	10 (4.9)	39 (16.9)	<.001
Major	0 (0)	3 (1.4)	.566
Thirty-day mortality	11 (5.2)	14 (5.0)	.932
Length of			
Hospital stay, days	NA	9.8	—[b]
Follow-up, months	72.8	54.2	—[b]
Late complications	0 (0)	9 (3.3)	.122
Late mortality	6 (7.1)	1 (0.4)	.001
Reinterventions	1 (1.0)	8 (2.9)	.457

NA, Not applicable.
[a]Analysis by year of publication only performed for patients treated with OPEN because of the lack of patients treated with endovascular repair (EV) before 2000 (n = 5).
[b]Owing to the lack of reported standard deviations, ranges, and interquartile ranges in the evaluated reports, no standard deviations and, therefore, no statistical significance could be calculated for length of hospital stay and follow-up.

Table V. Outcomes of patients with splenic artery aneurysms (SAAs) after treatment after the year 2000

Outcome after 2000	*OPEN (n = 283), No. (%) or mean*	*EV (n = 380), No. (%) or mean*	P *value*
Technical success	279 (98.6)	362 (95.2)	.018
Conversion	0 (0)	7 (1.8)	NA
Complications			
Minor	39 (16.9)	95 (25.3)	.012
Major	3 (1.4)	3 (0.9)	.407
Thirty-day mortality	14 (5.0)	2 (0.6)	<.001
Unruptured	5 (2.6)	0 (0.0)	.008
Ruptured	9 (20.4)	2 (6.7)	.196
Length of			
Hospital stay, days	9.8	2.03	—[a]
Follow-up, months	54.2	30.7	—[a]
Late complications	9 (3.3)	34 (9.2)	.006
Late mortality	1 (0.4)	3 (1.2)	.405
Reinterventions	8 (2.9)	30 (8.0)	.007

EV, Endovascular repair; *NA,* not applicable; *OPEN,* open repair.
[a]Owing to the lack of reported standard deviations, ranges, and interquartile ranges in the evaluated reports, no standard deviations and, therefore, no statistical significance could be calculated for length of hospital stay and follow-up.

larger aneurysms (3.1 cm vs 3.0 cm) compared with CONS (61.4 years and 2.1 cm).

Another limitation of this systematic review is that only publications with ≥10 patients were included. As a result, no case reports or case series were included, which reduced the number of patients included in this review but increased the data quality. Furthermore, because case reports and case series usually report successful interventions, whereas retrospective reviews with >10 patients will include the failures as well, this approach reduced selection bias and publication bias.[17] The 10 articles describing all three treatment modalities contributed 515 patients (40% of all patients).

Before 2000, when EV treatment was first being described, only CONS or OPEN treatment were reported. To highlight this, none of the articles described only CONS and only eight described only OPEN treatment. Articles are more robust when they report multiple treatment options, because the outcomes will be exactly defined; however, this is not always the case. In addition, our reported outcomes are objective (mortality, reintervention, etc), and do not include subjective parameters, such as pain for example, where you can expect reporting bias.

To strengthen the results presented here, additional analyses were performed by year of publication (before and

after 2000) and specifically for patients with and without ruptured aneurysms. Because postoperative care has likely improved considerably during the past decade, comparing results of EV (almost all of which were performed after 2000) with results of OPEN performed during last 50 years would not be reasonable.

Initially, we also planned to perform an additional analysis of outcomes for patients with and without splenectomy. The comparison was, unfortunately, not possible because splenectomy was not well described in the included studies. Most studies described how many patients had a splenectomy and the number of patients who had complications or died, but failed to report the morbidity and mortality and long-term survival. Because of this, a Kaplan-Meier survival curve could not be created.

Combining the perioperative mortality and long-term mortality showed that OPEN has a higher combined mortality compared with EV and CONS. This is also likely to be the result of a higher number of patients with ruptured aneurysms. In addition, EV has a lower combined mortality compared with CONS, which is likely the result of the inclusion of older patients with more comorbidities in the CONS group compared with the EV group.

The last important limitation is our inability to stratify patients by the location of the SAA because location was reported in only 34% of the patients. In addition, detailed outcomes related to the location of the SAA were available in only two articles, preventing us from performing an extensive analysis.[45,48] The incidence of splenectomies in the series was high (56.9%). Because the location of the aneurysm on the splenic artery was not known in most cases, commenting on whether some of these splenectomies could be avoided is not possible. It has been reported in series of splenorenal bypass procedures that, provided that the splenic artery is transected proximal to the left gastroepiploic artery, this is well tolerated and no splenectomy is indicated.[57]

Finally, although some studies reported that the postembolization syndrome (PES) occurred more frequently in treated aneurysms located in the splenic hilum, no studies reported differences in mortality between aneurysms located in different segments of the splenic artery.[5,25,49,52]

One final caveat is in regards to the type of articles included in this meta-analysis. Because most articles in our meta-analysis were retrospective, treatment of SAA was not randomized and the indication for treatment might have been primarily based on the risk of future events. The resulting imbalance in the underlying risk profile between the EV and OPEN groups can generate bias by indication. However, the only difference in baseline characteristics between the groups was the number of ruptured aneurysms, and an analysis stratified for rupture vs nonrupture was performed to prevent this type of bias.

There is no Level 1 evidence comparing the treatment options for the management of true SAAs, and this current study provides the most extensive overview of the current literature, which can guide the management by the vascular surgeon. The only prospective randomized comparison for the management of SAAs was a comparison of open and laparoscopic intervention for true SAAs.[42] However, we did not include laparoscopic intervention in our analysis because only two studies of laparoscopic intervention reported more than >10 patients, which we concluded would increase the uncertainty for the pooled outcomes and decrease the quality of this meta-analysis. Laparoscopic repair of the SAA is the most performed laparoscopic intervention of all aneurysms because of the easy-to-access location.[58] The largest study of laparoscopic interventions, consisting of 16 patients, reported no conversions, need for reoperation or related deaths.[59]

In addition, out meta-analysis consisted of 1 RCT (low power/quality, Level 2 evidence), 10 Level 2 studies, 13 Level 3 studies, and 24 Level 4 studies and is the best evidence available at the moment.

The interesting fact that more minor complications developed in people in the EV group than in the OPEN group has not been extensively discussed in previous reports. No significant difference was found between the number of major complications between OPEN and EV. Still, most reviews report a "higher morbidity and mortality" for patients treated with OPEN.[54,60] In this meta-analysis, we included PES as a minor complication, which can be responsible for this higher number of minor complications. PES, which can present as fever, abdominal pain, pleural effusion, and possibly pancreatitis after splenic infarction, is the most common complication after EV and can potentially require prolonged hospitalization. PES is reported in up to 30% of patients, which is similar to the 25.1% reported in this meta-analysis.[44] We note that most OPEN repairs included splenectomy as part of the procedure, which prevents PES.

This meta-analysis, which pooled the characteristics and outcomes of all the available data in the literature is descriptive rather than prescriptive. Therefore, it is not possible to exactly guide treatment based on this meta-analysis. The current general consensus is to treat all patients with symptomatic and ruptured aneurysms and asymptomatic patients with a SAA >2.0 cm. In addition, treatment is recommended in women of childbearing age who present with aneurysms <2 cm in diameter in anticipation of future pregnancy.[49] However, whether these treatment recommendations are similar for elderly or high-risk patients is not clear. Future research, with a more individual-based approach should give these answers.

In addition, there is currently no evidence to support the superiority of stenting or embolization. Surgical excision of the SAA is recommended when the pancreas is not close to the aneurysm, both proximally and distally. Proximal and distal ligation of the artery is recommended when the aneurysm is close to the pancreas. Splenectomy will be required if the aneurysm is located in the hilus of the spleen.[61]

A lot of questions remain regarding the optimal treatment of true SAAs, and one cannot make recommendations tailored to the patient on the basis of these results. The decision about which intervention would be preferred

in a 50-year-old low-risk woman would be different from a 90-year-old high-risk man. Furthermore, morbidity, mortality, and number of reinterventions are not the only important considerations, but also the quality of life, associated interventional and lifetime costs, and expected reinterventions over the remaining lifetime. The three major treatment modalities all have pros and cons and a well-conducted risk-benefit analysis could be performed with a clinical decision model to create patient-tailored recommendations for treatment of true SAAs.

Finally, the long-term importance of splenectomy on, for example, postsplenectomy infection and prevention of sepsis in asplenic patients, should be assessed in future research. Other future research projects could focus on the effect of aneurysm size on late mortality in patients treated with CONS.

CONCLUSIONS

EV of the SAA has better short-term results compared with OPEN, including significantly lower perioperative mortality; however, OPEN is associated with fewer late complications and reinterventions during follow-up. Patients treated with CONS showed a higher late mortality rate. Ruptured SAAs are predictors for a significant higher perioperative mortality compared with nonruptured SAAs in the OPEN and EV group. The results of this meta-analysis show that SAAs >2 cm should be treated, given the good short-term and long-term results. EV repair has the best outcomes and should be the treatment of choice if the splenic artery has a suitable anatomy for EV repair.

AUTHOR CONTRIBUTIONS

Conception and design: WH, AL, FM, GG, BS
Analysis and interpretation: WH, MH, BS
Data collection: WH, AL
Writing the article: WH, AL
Critical revision of the article: MH, FM, GG, BM, BS
Final approval of the article: WH, AL, MH, FM, GG, BM, BS
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WH and AL participated equally and share first authorship.

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APPENDIX (online only).

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("spleen artery aneurysm"/de *or* (("spleen artery"/de *or* spleen/de) *and* ("aneurysm surgery"/exp *or* aneurysm/exp)) *or* ((spleen *or* splenic) NEAR/3 aneurysm*):ab,ti) *and* (therapy/exp *or* therapy:lnk *or* surgery/exp *or* surgery:lnk *or* procedures/de *or* (therap* *or* treat* *or* curing *or* cure *or* repair *or* technique* *or* procedure* *or* equipment* *or* surg* *or* operat*):ab,ti)

Medline (OvidSP) 535

((("splenic artery"/ *or* spleen/) AND (aneurysm/)) *or* ((spleen *or* splenic) ADJ3 aneurysm*).ab,ti.) AND (exp therapeutics/*or* therapy.xs. *or* exp "Surgical Procedures, Operative"/*or* surgery.xs. *or* methods/ *or* methods.xs. *or* (therap* *or* treat* *or* curing *or* cure *or* repair *or* technique* *or* procedure* *or* equipment* *or* surg* *or* operat*).ab,ti.)

Cochrane 2

(((spleen *or* splenic) NEAR/3 aneurysm*):ab,ti) *and* ((therap* *or* treat* *or* curing *or* cure *or* repair *or* technique* *or* procedure* *or* equipment* *or* surg* *or* operat*):ab,ti)

Web of Science 312

TS=((((spleen *or* splenic) NEAR/3 aneurysm*)) *and* ((therap* *or* treat* *or* curing *or* cure *or* repair *or* technique* *or* procedure* *or* equipment* *or* surg* *or* operat*)))

Scopus 615

TITLE-ABS-KEY((((spleen *or* splenic) W/3 aneurysm*)) AND ((therap* *or* treat* *or* curing *or* cure *or* repair *or* technique* *or* procedure* *or* equipment* *or* surg* *or* operat*)) *and* (clinical* *or* patient* *or* trial* *or* retrospect* *or* prospect*))

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(((spleen *or* splenic) *and* aneurysm*[tiab])) *and* ((therap*[tiab] *or* treat*[tiab] *or* curing[tiab] *or* cure [tiab] *or* repair[tiab] *or* technique*[tiab] *or* procedure* [tiab] *or* equipment*[tiab] *or* surg*[tiab] *or* operat* [tiab])) *and* English[la] *and* publisher[sb]

Google Scholar 100

"(spleen|splenic) * aneurysm" (therapy|treatment|curing|cure|repair|technique|procedure|equipment|surgery|surgical|operative)
(clinical|patient|patients|trial|retrospective|prospective)

Appendix (online only).

Database	*No. retrieved*	*After duplicates removed*
Embase.com	1121	1116
Medline (OvidSP)	535	83
Web of Science	312	77
Scopus	615	183
PubMed as supplied by publisher	17	8
Cochrane	2	1
Google Scholar	100	22
Total	2702	1490