REVIEW ARTICLE

Open thoracic or thoracoabdominal aortic aneurysm repair after previous abdominal aortic aneurysm surgery

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Objective: **The purpose of this study was to provide insight into the incidence of thoracic and thoracoabdominal aortic aneurysm repair following previous infrarenal abdominal aortic aneurysm (AAA) surgery and to determine whether thoracic or thoracoabdominal aortic aneurysm repair after prior infrarenal AAA surgery is associated with higher mortality and morbidity rates.**

Methods: **MEDLINE, Cochrane Library CENTRAL, and EMBASE databases were searched for relevant articles. Selected articles were critically appraised and meta-analyses were performed.**

Results: **A total of 12.4% of patients with thoracic aortic aneurysms and 18.7% of patients with thoracoabdominal aortic aneurysms have had prior AAA surgery. The chance of developing a thoracic aortic aneurysm in patients with AAA is 2.2% and 2.5% for developing a thoracoabdominal aortic aneurysm. The mean time interval between prior AAA surgery and subsequent thoracoabdominal aortic aneurysm surgery or detection is 8.0 years with a wide variation between individuals. Surgery in these patients is technically feasible. The 30-day mortality of patients undergoing open thoracoabdominal aortic aneurysm repair does not significantly differ from patients without prior AAA surgery and the 30-day mortality is 11.8%. No data were available about mortality of patients with prior AAA repair undergoing thoracic aortic aneurysm surgery. Morbidity risks are higher in patients with thoracic or thoracoabdominal aortic aneurysms. Prior AAA repair was a significant risk factor for neurological deficit after thoracic or thoracoabdominal aortic aneurysms surgery with relative risks (RRs) of 11.1 (95% confidence interval [CI] 3.8-32.3, *P* value < .0001) and 2.90 (95% CI 1.26-6.65, *P* value = .008), respectively. Prior AAA repair was a significant risk factor for developing renal failure in patients undergoing thoracoabdominal aortic aneurysm repair (RR 3.47, 95% CI 1.74-6.91, *P* value = .0001). Determinants of the prognosis in these patients include distal aortic perfusion, distal extent of the landing zone of the graft, drainage of cerebrospinal fluid for thoracic aortic aneurysm repair and age, history of cardiac diseases, extent of the aneurysm, rupture, amount of estimated blood loss, aortic clamp time, and visceral ischemic times for thoracoabdominal aortic aneurysm repair.**

Conclusions: **A considerable group of patients with thoracic or thoracoabdominal aortic aneurysms have had prior AAA repair. The risk of postoperative morbidity is increased in these patients. Mortality appears to be similar for patients with thoracoabdominal aortic aneurysms. Patients with prior AAA repair undergoing thoracic or thoracoabdominal aortic aneurysm repair should be provided maximum care to protect their spinal cord and renal function. (J Vasc Surg 2008; 48:761-8.)**

The incidence of thoracic aortic aneurysms is estimated at 5.9 to 10.4 patients per 100,000 person-years.[1-3] The incidence of thoracoabdominal aortic aneurysms is unknown. How many patients with thoracic or thoracoabdominal aortic aneurysms have had prior abdominal aortic aneurysm (AAA) repair is unclear, and the percentage of patients undergoing AAA repair who will develop thoracic or thoracoabdominal aortic aneurysms during follow-up is also unknown. The pathogenesis of the development of aortic aneurysms is complex with both inherited and environmental causes.[4] Coady et al reported that 19% of patients with thoracic aortic aneurysms had a family history of thoracic aortic aneurysms.[5] The pathogenesis of thoracic aortic aneurysms has many similarities with the pathogenesis of AAAs, however, some differences are described.[6] Davies et al reported that the diameter of thoracic aortic aneurysms is an important predictor for the risk of rupture

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Competition of interest: none.

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Table I. Numbers of patients with thoracic or thoracoabdominal aortic aneurysms that have had prior AAA surgery

Author	*Description of TA/TAA*	*N TA/TAA*	*N AAA*	*%*	*Description of AAA*	*LOE*
Thoracic aortic aneurysms						
Szeto[10]	Total arch repair because of saccular arch aneurysms	8	2	25	Prior AAA surgery[c]	3b
Flores[11]	Thoracic aortic aneurysms	25	10	40	Prior AAA surgery[c]	1b
Estrera[12]	Descending thoracic aortic aneurysms	300	31	10.3	Prior AAA surgery[c]	2b
Cheung[13]	Thoracic aortic aneurysms	75	17	23	Prior AAA surgery[c]	1b
Pressler[14]	Thoracic aortic aneurysms	260	23	8.8	Prior AAA surgery[c]	2b
Meta-analysis						
Prevalence of prior AAA surgery in patients with thoracic aortic aneurysms:						
History of prior AAA surgery		668	83	12.4%	(95% CI 9.9%-14.9%)	
Thoracoabdominal aortic aneurysms						
Back[15]	Visceral AAA[a]	158	23	15	Prior AAA surgery[c]	2b
Lombardi[16]	Thoracoabdominal aortic aneurysm repair	279	56	20	Prior AAA surgery[c]	1b
Cambria[17]	Thoracoabdominal aortic aneurysm repair	337	61	18.1	Prior AAA surgery[c]	2b
Fox[18]	Thoracoabdominal aortic aneurysms[b]	51	14	27.5	Prior AAA surgery[c]	2b
Meta-analysis						
Prevalence of prior AAA surgery in patients with thoracoabdominal aortic aneurysms:						
History of prior AAA surgery		825	154	18.7%	(95% CI 16.0%-21.3%)	

AAA, Abdominal aortic aneurysm; *LOE,* level of evidence[8]; *TA,* thoracic aortic aneurysm; *TAA,* thoracoabdominal aortic aneurysm.
[a]78 juxtarenal, 35 suprarenal, 40 type IV TAA, 5 type III thoracoabdominal aortic aneurysms.
[b]8 type III thoracoabdominal aneurysms, 6 type IV thoracoabdominal aneurysms.
[c]Numbers used for meta-analysis to estimate probability that patients with thoracic or thoracoabdominal aortic aneurysms have had prior AAA surgery.

or dissection and reported that these risks were 2% for small aneurysms, 3% for aneurysms 5.0 to 5.9 cm, and increases to 6.9% per year for thoracic aortic aneurysms of 6.0 cm in diameter or larger.[7]

The evidence regarding the impact of prior AAA repair on morbidity and mortality of thoracic and thoracoabdominal aortic aneurysm repair is limited, and many articles are case reports, patient series, or small cohort studies. Patients with prior AAA repair might possibly have a greater risk of complications of thoracic or thoracoabdominal aortic aneurysm repair. The aim of this study is to provide the best available evidence to answer the following questions by means of meta-analyses. What is the frequency of prior AAA repair in patients with thoracic or thoracoabdominal aortic aneurysms and to what extent does this history of previous AAA repair impact on mortality and morbidity?

METHODS

Literature search. MEDLINE, EMBASE, and Cochrane library CENTRAL databases were searched on October 23, 2007. The following search string was used for Medline: (AAA[Title/Abstract] OR "aortic aneurysm abdominal" [Title/Abstract] OR "abdominal aortic aneurysm" [Title/Abstract] OR "aneurysm abdominal aortic" [Title/Abstract] OR "aortic abdominal aneurysm" [Title/Abstract] OR "aortic aneurysm abdominal" [Title/Abstract] OR "infrarenal aneurysm" [Title/Abstract] OR "abdominal aneurysm" [Title/Abstract] OR "aortic aneurysm, abdominal" [MeSH Terms]) AND (TAAA[Title/Abstract] OR thora* [Title/Abstract] OR "Thorax" [MeSH Terms] OR "aorta, thoracic" [MeSH Terms] OR "Aortic Aneurysm, Thoracic" [MeSH Terms]). This resulted in 1491 articles.

The following search string was used for Embase: ((thoracic AND aortic AND 'aneurysm'/syn) AND (abdominal AND aortic AND 'aneurysm'/syn)) OR (('thorax'/syn AND 'aorta'/syn AND 'aneurysm'/syn) AND ('abdomen'/syn AND 'aorta'/syn AND 'aneurysm'/syn))) AND [embase]/lim. This resulted in 1373 articles. The Cochrane library CENTRAL database was browsed manually and did not result in relevant articles. After removal of duplicate articles, 2196 unique articles remained.

Selection of articles. All titles and abstracts of these 2196 articles were read by two independent investigators (FJS and BEM). Inclusion criteria were: (a) the domain of the study consisted of patients with thoracic or thoracoabdominal aortic aneurysms and (b) prior AAA repair was described in one or more of these patients. Full-text versions were obtained of all articles that matched these two inclusion criteria. All selected full-text articles were read by two independent investigators (FJS and BEM). Studies were excluded from analysis if they met one of the following criteria: reporting only about mycotic, infectious or traumatic aortic aneurysms, aortic aneurysms in children or

animals, thoracic aortic dissections, pseudoaneurysms or aneurysms associated with Marfan's, Ehler-Danlos, giant cell arteritis, Takayasu's or Cogan's syndrome. No language or publication date restrictions were applied. Reference lists were searched manually to locate additional relevant articles for inclusion in our study. This technique for selection of studies for inclusion resulted in 19 relevant articles.

Data extraction. Two independent investigators analyzed the selected articles (FJS and BEM). The following characteristics were extracted: number of patients, number of patients with thoracic or thoracoabdominal aortic aneurysms, number of patients with thoracic aortic aneurysms with prior AAA surgery, types of thoracic or thoracoabdominal aortic aneurysms in the reported patients, number of patients with prior AAA repair, number of patients with prior AAA repair that developed thoracic aortic aneurysms, number of patients with prior AAA repair that developed thoracoabdominal aortic aneurysms, time interval between prior AAA repair and development or surgery of thoracic or thoracoabdominal aortic aneurysms, mortality and morbidity results of patients with and without prior AAA surgery undergoing thoracic or thoracoabdominal aorta aneurysm repair, significance of difference in mortality and morbidity between patients with and without prior AAA repair undergoing thoracic or thoracoabdominal aortic aneurysm repair, and other determinants of morbidity and mortality in patients undergoing thoracic or thoracoabdominal aortic aneurysm repair after prior AAA repair. Validity of the selected articles was appraised per research question according to the levels of evidence from the Oxford Center For Evidence-Based Medicine.[8]

Statistical analysis. The extracted data regarding the prevalence of prior AAA repair in patients with thoracic or thoracoabdominal aortic aneurysms, the incidence of thoracic or thoracoabdominal aortic aneurysm development or surgery in patients with prior AAA repair, morbidity and mortality results and determinants of outcome were pooled and stratified for patients with thoracic or thoracoabdominal aortic aneurysms. Significance of differences between the pooled results was calculated using Episheet.[9] When *P* values were not presented in the reviewed articles; significance was calculated using Episheet if required information for calculation was available. A *P* value less than .05 was considered significant. The main findings are presented in this article.

RESULTS

Prevalence. Table I shows the prevalence of prior AAA repair in patients with thoracic or thoracoabdominal aortic aneurysms. An overall estimation of this prevalence has been performed by means of a meta-analysis. The prevalence of prior AAA surgery in patients with thoracic aortic aneurysms was 12.4% (95% confidence interval [CI] 9.9%-14.9%). and 18.7% in patients with thoracoabdominal aortic aneurysms (95% CI 16.0%-21.3%).

The risk of future development of thoracic or thoracoabdominal aortic aneurysms in patients undergoing AAA repair is described by a smaller number of articles and shown in Table II. The mean follow-up periods were relatively long with an approximate range of the average follow-up periods of 5 to 9 years. The risks of development of thoracic or thoracoabdominal aortic aneurysms during these total follow-up periods after prior AAA repair was 2.2% for thoracic aortic aneurysms and 2.5% for thoracoabdominal aortic aneurysms.

Time interval. Several authors have presented information regarding the time interval between initial AAA repair and detection or repair of subsequent thoracoabdominal aortic aneurysms. These results are shown in Table III and an overall estimation has been calculated by means of a meta-analysis. No articles were found for the time interval in patients with subsequent thoracic aortic aneurysms.

All but two articles did not report about the variation between individuals but reported only means and ranges of the time intervals. The mean time interval between AAA repair and detection or repair of thoracoabdominal aortic aneurysms was 8 years. Reported ranges were relatively wide (0.6 to 20 years). Two articles described standard deviations and these were relatively large (5.4 and 6.9 years).

Mortality. The mortality due to thoracoabdominal aortic aneurysm repair in patients with prior AAA surgery is considerable. The mortality results are listed in Table IV. The reviewed articles only reported about mortality in patients with thoracoabdominal aortic aneurysms and who underwent open aortic aneurysm repair. No data were available about mortality in patients with thoracic aortic aneurysms. A meta-analysis has been performed to estimate the overall 30-day mortality of thoracoabdominal aortic aneurysm surgery in patients with prior AAA repair. No significant differences were found between patients with and without prior AAA surgery (11.8% vs 13.5%, respectively; relative risk [RR] .87, 95% CI .49-1.56).

Morbidity. All articles that are listed in Table V reported only about patients that were treated with open aortic aneurysm surgery. The risk of developing neurological deficit after thoracic and thoracoabdominal aortic aneurysm repair was strongly increased in patients with prior AAA repair compared with patients without prior AAA repair. The risk of developing neurological deficit after thoracic aortic surgery was 19.5% in patients with prior AAA repair vs 1.8% in patients without prior AAA repair and a RR of 11.1 was calculated (95% CI 3.8-32.3, *P* value $< .0001$). Prior AAA repair was also a risk factor for neurological deficit after thoracoabdominal aortic surgery (9.1% vs 3.1%), with a RR of 2.90 (95% CI 1.26-6.65, *P* value = .008). Associations between prior AAA repair and other complications were only reported for patients undergoing thoracoabdominal aortic aneurysm repair. The risk of developing renal failure after thoracoabdominal aortic surgery was significantly higher in patients with prior AAA repair compared with patients without prior AAA repair:

Table II. Risk of patients with AAA to develop thoracic or thoracoabdominal aortic aneurysms

	Description of AAA	*N AAA*	*N TA/TAA*	*%*	*Description of TA/TAA*	*LOE*
Thoracic aortic aneurysms						
Kalman[19]	Patients with previous AAA repair	94	26	27.7	Descending thoracic aorta down	1b
	8 to 9 y ago	94	26	0.0	to the supraceliac artery, >3 cm	1b
					Thoracic aortic aneurysm, surgery indicated†	
Robinson[20]	Patients older than 80 y treated for AAA	22	2	9.1	Patients died from rupture of thoracic aortic aneurysm†	2b
Plate[21]	Previous AAA repair	1087	24	2.2	Thoracic aortic aneurysms†	2b
Total	Risk of thoracic aortic aneurysm development after prior AAA repair	1203	26	2.2%	(95% CI 1.3%-3.0%)	
Thoracoabdominal aortic aneurysms						
Kalman[19]	Patients with previous AAA repair	94	17	18.1	Descending thoracic aorta down	1b
	8 to 9 y ago	94	1	1.1	to the visceral aorta, >3 cm	1b
					Thoracoabdominal aortic aneurysm, surgery indicated[b]	
Plate[21]	Previous AAA repair	1087	5	0.5	Thoracoabdominal aortic aneurysms[b]	2b
Menard[22]	Patients with previous AAA repair	1104	49	4.4	Repair of thoracovisceral aortic aneurysms[a,b]	1b
Edwards[23]	Previous AAA repair, yearly ultrasound	53	4	7.5	True aortic aneurysms proximal to the prior graft[b]	2b
Total	Risk of thoracoabdominal aortic aneurysm development after prior AAA repair	2338	59	2.5%	(95% CI 1.9%-3.2%)	

AAA, Abdominal aortic aneurysm; *LOE,* level of evidence[8]; *TA,* thoracic aortic aneurysm; *TAA,* thoracoabdominal aortic aneurysm.
[a]13 lower visceral segment, 17 extended to diaphragm, 17 to distal or middle thoracic aorta, 2 entire remaining visceral and thoracic aorta.
[b]Numbers used for calculation of "Probability of detection of new aneurysms in the thoracic or thoracoabdominal aorta after prior AAA repair."

Table III. Time interval between prior AAA surgery and subsequent thoracoabdominal aortic aneurysm event

Author	*Description of AAA*	*Description of TAA*	*N*	*Interval (mean in y ± SD)*	*Range (y)*	*LOE*
Menard[22]	Prior AAA repair	Development of thoracovisceral aortic aneurysm	49	6.4 ± NR	Range 0.6-17	1b
Lombardi[16]	Prior AAA repair	Presentation of thoracoabdominal aortic aneurysms	56	8.7 ± NR	Range 1-20	1b
Coselli[24]	Prior AAA repair	Subsequent proximal aortic aneurysm surgery[a]	123	8.2 ± 5.4	NR	2b
Edwards[23]	Prior AAA repair	True aortic aneurysms proximal to pre-existing stent graft	4	6.8 ± 6.9	NR	4
Curl[25]	Prior AAA repair	Proximal true aortic aneurysms	6	9.5 ± NR	Range 3-15	4
Fox[18]	Prior AAA repair	Resection of thoracoabdominal aneurysm	14	8.5	Range 2-17	2b
Meta-analysis	Prior AAA repair	Thoracoabdominal aortic aneurysm detection and/or surgery	252	8.0	Range 0.6-20	

AAA, Abdominal aortic aneurysm; *LOE,* level of evidence[8]; *TAA,* thoracoabdominal aortic aneurysm; *NR,* not reported.
[a]98 thoracoabdominal, 17 juxtarenal, 1 transverse aortic, 7 descending thoracic aortic aneurysms.

15.5% vs 4.5%. This resulted in a RR of 3.47 (95% CI 1.74-6.91, *P* value = .0001).

DISCUSSION

Approximately one in eight patients with thoracic aortic aneurysms and one in five patients with thoracoabdominal aortic aneurysms have had prior AAA surgery. The mean time interval between prior AAA surgery and subsequent thoracoabdominal aortic aneurysm repair was 8 years with a large variation between individuals. No data were available about the time interval between prior AAA repair and subsequent thoracic aortic aneurysm surgery. Surgery in these patients with thoracic or thoracoabdominal aortic aneurysms and prior AAA repair is technically feasible. The 30-day mortality of thoracoabdominal aortic aneurysm repair was 11.8% and does not significantly differ from patients without prior AAA surgery. No data were available about mortality in patients with prior AAA repair undergo-

Table IV. Mortality of patients who underwent open repair of thoracoabdominal aortic aneurysms as presented in the reviewed articles

Author	*Domain*	*Period*	*Mortality in patients*		*Significance of difference*	*LOE*
			with prior AAA repair	*without prior AAA repair*		
Coselli[24]	Subsequent proximal aortic aneurysm surgery[a]	In-hospital	12.2%	—	—	2b
Lombardi[16]	Thoracoabdominal aortic aneurysm repair	30 d[b]	10.7%	11.7	$P = .84$	1b
Fox[18]	Thoracoabdominal aortic aneurysms	30 d[b]	28%	24%	$P = .76$[c]	2b
Menard[22]	Non-ruptured thoracovisceral aortic aneurysms	30 d[b]	4.1%	—	—	1b
		6 mo	14.6%	—	—	1b
	"Ruptured thoracovisceral aortic aneurysms"	30 d[b]	50%	—	—	1b
		6 mo	61%	—	—	1b
Back[15]	Visceral aortic aneurysms"	Perioperative	NR, higher	NR, lower	$P = .002$	2b
		Late death, 5 y	NR, higher	NR, lower	$P = .03$	2b
Meta-analysis	Mortality of thoracoabdominal aortic aneurysm surgery	30 d	11.8% 14/119 cases	13.5% 35/260 cases	RR 0.87 95% CI 0.49 to 1.56 P-value 0.65[c]	

AAA, Abdominal aortic aneurysm; *LOE,* level of evidence[8]; *NR,* not reported.
[a]98 thoracoabdominal, 17 juxtarenal, 1 transverse aortic, 7 descending thoracic aortic aneurysms.
[b]Numbers used for meta-analysis to estimate overall 30 d mortality.
[c]Calculated with Episheet[9], these numbers were not presented in the original article.

ing thoracic aortic aneurysm surgery. The risk of neurological deficit and renal failure was significantly higher in patients with a history of AAA repair that were undergoing repair of thoracoabdominal aortic aneurysms. Prior AAA repair was also a risk factor for neurological deficit in patients undergoing thoracic aortic aneurysms repair.

This article provides results that are based on large numbers of patients. The mean prevalence of prior AAA repair in patients with thoracic or thoracoabdominal aortic aneurysmal disease and the risk of developing thoracic or thoracoabdominal aortic aneurysms in patients with prior AAA repair could therefore be calculated in a relatively precise manner, especially when a comparison is made with the separate original studies. However, our meta-analysis may have some pitfalls. The meta-analysis showed that the RR of neurological deficit was higher in the patients with thoracic aortic aneurysms (RR 11.1) than in patients with thoracoabdominal aortic aneurysms (RR 2.9). Because thoracoabdominal aortic aneurysm repair is generally a more complex procedure, this finding may appear counterintuitive. Our results should be regarded as evidence which shows that prior AAA repair is an important risk factor for neurologic deficit after thoracic or thoracoabdominal aortic aneurysm repair. A more precise estimation of the effect of prior AAA repair on the risk of neurologic deficit should be determined by future studies.

Most articles provided results that were collected during relatively long follow-up periods with means ranging from 5 to 9 years. This length of time is comparable with reported mean life expectancies of patients undergoing thoracoabdominal aortic surgery.[26] Our results regarding the development of thoracic and thoracoabdominal aortic aneurysms after AAA surgery could be regarded as estimations of the lifetime risks, but may probably be an underestimation of the real incidences, because patients may have moved to other institutions and some patients could have been excluded from analysis because of rupture or death, despite presence of recurrent aneurysmal disease. The number of detected thoracic and thoracoabdominal aortic aneurysms after AAA surgery is likely to increase in the future with improvements in patient survival secondary to better treatment of cardiovascular diseases, aging of the population, and an increase in the number of radiological follow-up examinations after AAA repair.

Plate et al[21] reported that the mean time interval between prior AAA repair and detection of recurrent aneurysms was 5.2 ± 3.1 years (including thoracic, thoracoabdominal, abdominal aortic, iliac, femoral, popliteal, and renal artery aneurysms). A life table analysis for the risk of developing these recurrent aneurysms was performed and resulted in a risk of 2.9% for 5 years and 11.1% for 10 years. Unfortunately, no life table analyses were reported in the selected articles for survival specifically free of thoracic or thoracoabdominal development after AAA surgery and clear conclusions with regard to timing of follow-up examinations cannot be drawn from our data. Kalman et al recommend performing a computed tomography (CT) scan 5 years after prior AAA surgery, based on results of the Canadian Aneurysm Registry.[19]

Advantages of our study are the relatively large numbers of patients and mortality and morbidity related events, compared with the data of the separate original articles. These large numbers of patients and events allowed us to provide results about the risk of mortality and morbidity with relatively high statistical validity.

Our results showed that the 30-day mortality was not significantly different between patients with and without prior AAA repair undergoing thoracoabdominal aortic an-

Table V. Complication risks of thoracic or thoracoabdominal aortic aneurysm surgery in patients with prior AAA repair

Author	*Complication*	*Risk in patients with prior AAA surgery*	*Risk in patients without prior AAA surgery*	*Significance*	*Domain*	*LOE*
Neurological deficit						
Thoracic aortic aneurysms						
Flores[11]	Spinal cord ischemia	50.0%	6.7%	$P = .0296$	Thoracic aneurysm repair with extensive deployment of the stented elephant trunk	1b
Estrera[12]	Neurological deficit	9.7%	1.5%	$P = .005$	Descending thoracic aortic aneurysms	2b
Meta-analysis thoracic aortic aneurysms surgery						
Risk of neurological deficit		19.5% 8/41 cases	1.8% 5/284 cases	RR 11.1, 95% CI 3.8-32.3, P value $<.0001$[d]		
Thoracoabdominal aortic aneurysms						
Menard[22]	Permanent paresis	4.1%	—	—	Thoracovisceral aortic aneurysms	1b
Lombardi[16]	Paraplegia	5.4%	3.1%	$P = .90$	Thoracoabdominal aortic aneurysm repair	1b
Coselli[24]	Paraplegia	4.1%	—	—	Subsequent proximal aortic aneurysm surgery	2b
		16%	—	—	Type II thoracoabdominal aortic aneurysm	2b
	Paraparesis	8.1%	—	—	Subsequent proximal aortic aneurysm surgery	2b
Fox[18]	Paraplegia	14%	—	—	Thoracoabdominal aortic aneurysms[c]	2b
Meta-analysis thoracoabdominal aortic aneurysm surgery						
Risk of neurological deficit		9.1% 22/242 cases	3.1% 7/223 cases	RR 2.90, 95% CI 1.26-6.65, P value = .008[d]		
Renal failure						
Thoracoabdominal aortic aneurysms						
Lombardi[16]	Renal failure	8.9%	4.5%	$P = .26$[d]	Thoracoabdominal aortic aneurysm repair	1b
Coselli[24]	Non-oliguric renal failure	7.3%	—	—	Subsequent proximal aortic aneurysm	2b
		16%	—	—	surgery Type II thoracoabdominal aortic aneurysm	2b
	Oliguric renal failure	11.4%	—	—	Subsequent proximal aortic aneurysm surgery	2b
Fox[18]	Renal failure req dialysis	14%	—	—	Thoracoabdominal aortic aneurysms[c]	2b
Meta-analysis						
Risk of renal failure		15.5% 30/193 cases	4.5% 10/223 cases	RR 3.47, 95% CI 1.74-6.91, P value = .0001[d]		
Other complications						
Thoracoabdominal aortic aneurysms						
Lombardi[16]	Pulmonary	10.7%	7.2%	$P = .50$[d]	Thoracoabdominal aortic aneurysm repair	1b
Lombardi[16]	Return to OR[b]	8.9%	5.8%	$P = .51$[d]	Thoracoabdominal aortic aneurysm repair	1b
Lombardi[16]	Wound infection	3.6%	0.9%	$P = .17$[d]	Thoracoabdominal aortic aneurysm repair	1b
Lombardi[16]	Arrhythmia	18%	2.2%	$P < .0001$	Thoracoabdominal aortic aneurysm repair	1b
Menard[22]	Major morbidity[a]	30.6%	—	—	Thoracovisceral aortic aneurysms	1b
Lombardi[16]	Postoperative complications	38%	21%	$P = .008$	Thoracoabdominal aortic aneurysm repair	1b

AAA, Abdominal aortic aneurysm; *LOE,* level of evidence[8]; *req,* requiring; *OR*, operating room.
[a]Myocardial infarction, dialysis-dependent renal failure, stroke, paraparesis, colon ischemia, repeat operation to treat bleeding.
[b]Postoperative hemorrhage (17), aortic valve replacement (1).
[c]8 type III thoracoabdominal aneurysms, 6 type IV thoracoabdominal aneurysms.
[d]Calculated with Episheet[9], these numbers were not presented in the original article.

eurysm surgery. The risks of neurological deficit and renal failure are significantly increased in patients with prior AAA repair undergoing thoracoabdominal aortic aneurysm repair. The risk of neurological deficit was also increased in patients undergoing thoracic aortic aneurysm surgery with a history of AAA repair. None of the selected articles could provide significant association between prior AAA repair and neurological deficit or renal failure in patients with

thoracoabdominal aortic aneurysms. In this meta-analysis, we pooled the data and quantify risks that are more statistically significant than in the separate original articles, with a *P* value of .008 for the risk of neurological deficit and .0001 for the risk of renal failure after thoracoabdominal aortic aneurysm repair and a *P* value of <.0001 for the risk of neurological deficit after thoracic aortic aneurysm repair in patients with prior AAA repair. The major relevance of collateral flow from the pelvic and infrarenal circulation to the spinal cord has been described earlier.[16,27]

Several other determinants of outcome for the specific group of patients with a history of prior AAA repair who are undergoing thoracic or thoracoabdominal aortic aneurysm surgery were extracted from the articles. Flores[11] described that a landing zone more distal or equal to T7 in combination with a medical history of prior AAA repair are very predictive for spinal cord injury after thoracic aortic aneurysm repair (71% vs 6%, $P = .0047$, odds ratio 5.462, 95% CI 1.084-571.963). Estrera[12] showed that distal aortic perfusion and drainage of cerebrospinal fluid are significantly associated with a reduced risk of neurological deficit after thoracic aortic aneurysm surgery (odds ratio .19, $P = .02$).

The following authors reported determinants of outcome for patients with a history of prior AAA repair undergoing thoracoabdominal aortic aneurysm repair. Menard[22] presented rupture and larger extent of the aneurysm to be significantly associated with increased operative mortality risks (rupture $P < .030$, larger aneurysm extent $P < .007$) and worsening of long-term survival (rupture $P < .0001$, larger aneurysm extent $P < .0001$). Amount of estimated blood loss appeared to be a significant predictor of morbidity ($P < .023$). Coselli[24] showed that longer aortic clamp time and visceral ischemic times were significantly associated with in-hospital death, non-oliguric renal failure, and neurological deficit. Fox[18] described that mortality appeared to be associated with age (<72 years vs ≥72 years of age, $P = .04$), proximal extent of the aneurysm ($P = .05$), rupture ($P = .06$), history of myocardial infarction ($P = .03$), congestive heart failure ($P = .01$), and arrhythmia ($P = .005$).

We unfortunately lack information on differences in baseline characteristics between patients with and without prior AAA repair that could also have influenced their outcomes. Randomization of patients in groups "with exposure to prior AAA repair" and "without exposure to prior AAA repair" is not possible. Therefore, large cohort studies will continue to provide the best original evidence on these patients, and meta-analyses of these studies can improve their statistical validity.

The pathogenesis for the development of recurrent aortic aneurysms is still not fully understood. A significant association between hypertension and the risk of developing recurrent aneurysms has been described by Plate.[21] The 5-year risk of finding a new aneurysm was 4.7% for patients with hypertension and 1.8% for those without hypertension. The 10-year risk was in the same order, with a risk of finding a new aneurysm of 18.1% for patients with hypertension and 6.0% for patients without hypertension. Other factors, including demographics, tobacco use, and cardiac diseases, were not significantly associated with the probability of finding a new aneurysm.

Evidence on long-term follow-up of patients undergoing thoracic aortic aneurysm surgery with prior AAA repair is limited. To ensure that we can provide the best care for these patients and improve their prognosis, future research should be pointed towards long-term survival and treatments to protect their spinal cord and renal function when thoracic aortic or thoracoabdominal aneurysm repair is required.

CONCLUSIONS

Our meta-analysis shows that 12.4% of patients with thoracic aortic aneurysms and 18.7% of patients with thoracoabdominal aortic aneurysms underwent prior AAA surgery. The chance of developing thoracic aortic aneurysms in patients with prior AAA is 2.2% and of developing thoracoabdominal aortic aneurysms 2.5%. The mean time interval between prior AAA surgery and subsequent thoracoabdominal aortic aneurysm surgery or detection is 8.0 years with a wide variation between individuals. Surgery in these patients with prior AAA repair and thoracic or thoracoabdominal aortic aneurysms is technically feasible.

The 30-day mortality in patients undergoing thoracoabdominal aortic surgery does not significantly differ from patients without prior AAA surgery and is 11.8%. No data were available about mortality in patients with thoracic aortic aneurysms. Morbidity risks are, however, higher in patients with prior AAA repair undergoing thoracic or thoracoabdominal aortic aneurysm repair, especially regarding the risks of neurological deficit and renal failure. Prior AAA repair was a significant risk factor for neurological deficit with RRs of 11.1 (95% CI 3.8-32.3, *P* value <.0001) for thoracic aortic aneurysm surgery and 2.90 (95% CI 1.26-6.65, *P* value = .008) for thoracoabdominal aortic aneurysm surgery. Prior AAA repair was a significant risk factor for renal failure in patients undergoing thoracoabdominal aortic aneurysm repair (RR 3.47, 95% CI 1.74-6.91, *P* value = .0001).

Determinants of the prognosis in these patients include distal aortic perfusion, distal extent of the landing zone of the graft, drainage of cerebrospinal fluid for thoracic aortic aneurysm repair and age, history of cardiac diseases, extent of the aneurysm, rupture, amount of estimated blood loss, aortic clamp time, and visceral ischemic times for thoracoabdominal aortic aneurysm repair. The risk of postoperative complications is increased in patients with prior AAA repair undergoing thoracic or thoracoabdominal aortic aneurysm repair. Mortality appears to be similar for patients with thoracoabdominal aortic aneurysms. Patients with prior AAA repair undergoing thoracic or thoracoabdominal aortic aneurysm repair should be provided maximum care to protect their spinal cord and kidneys.

AUTHOR CONTRIBUTIONS

Conception and design: FS, HM, BM
Analysis and interpretation: FS, HM, HV, FM, BM
Data collection: FS, BM
Writing the article: FS, BM
Critical revision of the article: FS, HM, HV, FM, BM
Final approval of the article: FS, HM, HV, FM, BM
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