REVIEW ARTICLE

From the Southern Association for Vascular Surgery

Meta-analysis of endovascular vs open repair for traumatic descending thoracic aortic rupture

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Objectives: **Traumatic thoracic aortic injuries are associated with high mortality and morbidity. These patients often have multiple injuries, and delayed aortic repair is frequently used. Endoluminal grafts offer an alternative to open surgical repair. We performed a meta-analysis of comparative studies evaluating endovascular vs open repair of these injuries.**

Methods: **A systematic search of studies reporting treatment of traumatic aortic injury was performed using the following databases: Medline/PubMed, CINAHL, Proquest, Up to Date, Database of Abstracts of Reviews of Effects (DARE), ClinicalTrials.gov, the Cochrane Central Register of Controlled Trials and the Cochrane Database of Systematic Reviews. Search terms were thoracic aortic trauma, traumatic thoracic aortic injury, traumatic aortic rupture, stent graft repair, and endovascular repair. Outcomes analyzed were procedure-related mortality, overall 30-day mortality, and paraplegia/paraparesis rate using odds ratios (OR) and 95% confidence intervals (CI). Publication bias was investigated using funnel plots. Assessment of homogeneity was performed using the Q test; statistical heterogeneity was considered present at $P < .05$. Weighted averages of age, interval to repair, and injury severity score were compared with the Welch t test; $P < .05$ was considered statistically significant.**

Results: **Seventeen retrospective cohort studies from 2003 to 2007 were included. All were nonrandomized; no prospective randomized trials were found. These studies reported on 589 patients; 369 were treated with open repair, and 220 underwent thoracic stent graft placement. There was no significant difference in age (mean 38.8 years for both) or interval to repair (mean 1.5 days for endoluminal repair; 1 day for open repair). Injury severity score was higher for patients undergoing endoluminal repair (mean, 42.4 vs 37.4 for open repair, $P < .001$). Procedure-related mortality was significantly lower with endoluminal repair (OR, 0.31; 95% CI, 0.15-0.66; $P = .002$). Overall 30-day mortality was also lower after endoluminal repair (OR, 0.44; 95% CI, 0.25-0.78; $P = .005$). Sixteen studies reported data for postoperative paraplegia; 215 patients were treated with endograft placement and 333 with open repair. The risk of postoperative paraplegia was significantly less with endoluminal repair (OR, 0.32; 95% CI, 0.1-0.93; $P = .037$). The Q test did not indicate significant heterogeneity for the outcomes of interest; publication bias was limited.**

Conclusions: **Meta-analysis of retrospective cohort studies indicates that endovascular treatment of descending thoracic aortic trauma is an alternative to open repair and is associated with lower postoperative mortality and ischemic spinal cord complication rates. (J Vasc Surg 2008;48:1343-51.)**

Blunt rupture of the thoracic aorta is devastating, and most patients die at the time of injury.[1] In order of frequency, rupture occurs at the aortic isthmus, the ascending aorta, the aortic arch, the distal descending aorta, and the abdominal aorta.[2,3] The force from rapid deceleration necessary to tear the aorta often leads to other organ injuries. Pate et al[4] found that associated injuries were present in >90% of patients with aortic transection, and 24% of them required a major operation before aortic repair. More than 85% of motor vehicle occupants who sustain a thoracic aortic laceration exsanguinate at the scene.[5-7]

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Traditional treatment of blunt traumatic aortic rupture has been early open surgical repair with graft interposition,[8-10] β-Blockers control the blood pressure and modify the left ventricle systolic ejection dynamics, allowing stabilization of other injuries and delayed repair.[4] Despite reported success in delaying repair, patients remain at risk of rupture. Owing to associated injuries such as pulmonary contusion, solid organ injury, and head injury, open repair with anticoagulation is associated with a significant mortality risk ranging from 24% to 42%.[11] Because of these considerations, interest in less invasive, less traumatic methods of repair has developed.

Dake et al[12] in 1994 reported preliminary results indicating that endovascular stent graft repair is safe in highly selected patients with descending thoracic aortic aneurysms, and Semba et al[13] in 1997 demonstrated that stent graft repair is technically feasible in acute rupture of the descending thoracic aorta. Results of several other clinical studies[14-17] have shown successful emergency repair of acute thoracic aortic disease by endovascular stent grafting.

Table I. Quality assessment of the 17 included studies

First author (year)	*Mechanism of injury*	*Assessment of injury (CTA/angio-gram)*	*Type of device*	*Location of injury*	*Mortality rate*	*Paraplegia or paraparesis*	*Conversion rate*
Chung (2007)	0	1	0	0	1	1	1
Lebl (2006)	0[a]	0[a]	0	1	1	1	0
Ott (2003)	1	1	1	1	1	1	1
McPhee (2006)	1	1	1	1	1	1	1
Rousseau (2005)	1	1	1	1	1	1	1
Amabille (2004)	1	1	1	1	1	1	1
Kasirajan (2003)	1	1	1	1	1	1	1
Andrassy (2006)	1	1	1	1	1	1	1
Doss (2005)	0	1	1	0	1	1	0[a]
Kuhne (2005)	0	0	0	0	1	0	1
Riesenman (2007)	1	1	1	1	1	1	1
Buz (2007)	1	1	1	1	1	1	1
Broux (2006)	1	1	1	1	1	1	1
Stampfl (2005)	1	1	1	0	1	1	1
Pacini (2004)	1	1	1	0	1	1	1
Kokotsakis (2007)	1	1	1	1	1	1	1
Cook (2006)	1	1	1	1	1	1	0

CTA, Computed tomography angiography; *ISS,* injury severity score.
[a]Mentioned in the report but no specific data given.

The purpose of this report was to perform a meta-analysis of comparative studies evaluating endovascular vs open repair of thoracic aorta traumatic (TAT) lesions.

METHODS

Published and unpublished data were searched with computerized bibliographies, hand searching of relevant journals, reference lists of a textbook of vascular surgery[18] and correspondence with study authors. Studies reported between 1966 and 2007 were evaluated. The following databases were searched: Medline/PubMed, CINAHL, ClinicalTrials.gov, Proquest, Up to Date, MD Consult, Database of Abstracts of Reviews of Effects (DARE), the Cochrane Central Register of Controlled Trials, and the Cochrane Database of Systematic Reviews. The descriptors "thoracic aortic trauma," "traumatic thoracic aortic injury," "traumatic aortic rupture," "stent graft repair," and "endovascular repair" were used to query the databases. A MEDLINE search with MeSH headings "Aorta, Thoracic/injuries" or "Aorta, Thoracic/surgery" (exploded) and "Angioplasty" (exploded), limited to human and journal articles as well as MeSH heading "Aorta, Thoracic" and "Wounds and Injuries" or "Injuries" (exploded) and "Angioplasty" was performed. Reports in all languages were considered. The "related articles" function was used to broaden the search.

All article titles, abstracts, and subject headings were screened by one reviewer for potential relevance. Abstracts of articles selected by title were read online to reduce the number of articles for full-text examination. Finally, additional titles were sought in the bibliographies of the retrieved articles. Authors' files were also reviewed.

Inclusion criteria. The articles included satisfied the following requirements: (1) studies comparing outcomes of endoluminal treatment of traumatic thoracic aortic injury vs open repair and (2) reporting at least one outcome of interest. To determine study eligibility, two reviewers independently assessed the citations identified for a full text examination. In studies where patients with nontraumatic aortic rupture were included, the number of patients with traumatic injury and their treatment was extracted from the text, or if this was not possible, the authors were contacted and asked to provide additional information about the subset of patients with traumatic rupture.

Articles were excluded either because there was no open surgical repair cohort comparison, or they represented a duplicate publication. Some reports included patients with degenerative (aneurysm, dissection, ulcer) and traumatic aortic rupture. Only the subset of trauma patients were included from these if the relevant data could be extracted from the text or through communication with the authors, otherwise the report was excluded.

Data extraction. Two authors extracted the data independently and reconciled any disagreement by repeat review of the articles in question. Data extraction was done from text, graphs, or tables. A standard form was used to extract the data from the articles, which included characteristics of study design, study population, demographics, other injuries, type of intervention, conversion rate, endograft placement–related complications, systemic and local complication rate, paraplegia/paraparesis rate, length of follow-up, and need for reintervention. Immediate- and delayed-repair groups were reported in three studies,[19-21] but only the data pertaining to immediate repair, as defined by the authors, were used in the statistical analysis.

Three outcomes were examined: procedure-related mortality (death ≤30 days of the procedure related to aortic graft placement), 30-day mortality (death ≤30 days of the procedure from all causes), and paraplegia/paraparesis. Authors were contacted, if necessary, to provide additional information or to clarify the data presented in their reports. Four authors[22-25] kindly provided additional information on request.

Table I. Continued.

Interval to repair	*ISS*	*Reintervention rate*	*Report of endoleak*	*Report of left subclavian coverage*	*Follow-up period*	*Total*
1	0	1	1	1	1	9
0	1	0	0	0	0	4
1	1	1	1	1	1	13
1	1	1	1	1	1	13
1	1	1	1	1	1	13
1	0	1	1	1	1	12
1	1	0	1	1	1	12
1	0	1	1	1	1	12
0	0	0[a]	1	0	0[a]	5
1	1	0	0	0	0	4
1	1	1	1	1	1	13
1	1	1	1	1	1	13
1	1	1	1	0	1	12
0	1	1	1	1	1	11
1	0	1	1	1	1	11
1	1	1	1	1	1	13
0[a]	1	1	1	1	0	10

Study quality. All the studies identified were retrospective cohort studies; thus, prospective randomization was not considered a factor in evaluating study quality. Study quality was assessed by whether it contained:

1. a mechanism of injury,
2. an objective assessment of the aortic injury with computed tomography or angiogram,
3. the type of endograft used,
4. location of injury,
5. mortality rate, as defined above,
6. paraplegia/paraparesis rate,
7. conversion rate from endovascular to open repair,
8. interval time between injury and repair,
9. injury severity score (ISS) or other assessment of the extent of injury,
10. report of coverage of the left subclavian artery,
11. reintervention rate,
12. endoleak rate, and
13. the length of follow-up time.

Each of the preceding items was graded as 1 or 0, so that a perfect study would score 13, with a decrease of 1 point for each unmet requirement.

Statistical analysis. Data analysis was performed using the Comprehensive Meta Analysis 2 computer program (CMA Biostat, Englewood, NJ). We used four strategies to assess study homogeneity. First, we evaluated publication bias using funnel plots. These are simple scatter plots of the treatment effect from individual studies (expressed on the x-axis as the odds ratio [OR]) vs a measure of the sample size (expressed on the y-axis as the log of the standard error). The precision of the treatment effect increases with the size of the study. Therefore, larger studies will cluster at the top, whereas smaller studies will scatter more widely at the bottom of the graph in an inverted "funnel" shape. Large gaps in the scatter plot relative to a "funnel" indicate areas where studies have possibly been excluded from publication.

Second, a sensitivity analysis was performed by removing each of the studies, one at a time, and evaluating the effect on the results.

Third, the meta-analyses were done using both random and fixed effects models.

Finally, Q tests were performed to determine homogeneity of the samples; statistical heterogeneity was considered present if $P < .05$.

Overall means for the patient characteristics of age, ISS, and time to procedure were calculated by taking the mean of the study means weighted by the sample size. The Welch *t* test was used for statistical comparisons, and a value of $P < .05$ was considered statistically significant.

Meta-analysis was performed by calculating the pooled ORs and 95% confidence intervals (CIs) for the study outcomes. The OR represents the odds of an adverse event occurring in the thoracic endovascular aneurysm repair (TEVAR) group divided by the odds in the open repair group. An OR of <1.0 favors the TEVAR group, and the point estimate of the OR is considered statistically significant at the $P < .05$ level if the 95% CI does not include the value 1.0. Studies with no occurrence of an outcome in either the endoluminal or the open repair group were excluded from the statistical calculations for that outcome. All statistical testing was two-tailed. The meta-analysis conformed with Cochrane Collaboration recommendations and quality of reporting of meta-analyses guidelines.[26,27]

RESULTS

The search retrieved 11,036 titles. After reviewing selected abstracts, 21 potentially relevant retrospective cohort studies from 2003 to 2007 were identified.[19-25,28-40] Twenty were published and one is unpublished (Chung et al, data presented at the Society of Interventional Radiology 32nd

Table II. Summary of data obtained from the included studies

First author (year)	*Gender*	*Open ISS, mean (± SD) or range*	*TEVAR ISS, mean (± SD) or range*	*Age mean ± SD (or range) years*		*Technique for open repair*
				Open	*TEVAR*	
Amabille (2004)	Open (7 M, 2 F), TEVAR (3 M)	N/A	N/A	32 (15-51)	32 (19-51)	9 bypass
Andrassy (2006)	TEVAR (12 M, 3 F)	N/A	N/A	44 ± 16.2	38 ± 16	Clamp & sew
Broux (2006)	Combined (21 M, 9 F)	35 ± 12	46 ± 18	35 ± 15	46 ± 18	N/A
Buz (2007)	Open (28 M, 6 F), TEVAR (34 M, 5 F)	34 (9-66)	41 (13-66)	36 (14-73)	36 (15-82)	33 bypass; 2 clamp & sew
Chung (2007)	N/A	N/A	N/A	N/A	N/A	N/A
Cook (2006)	N/A	34.5 ± 9.9	38.9 ± 10	N/A	N/A	19 bypass, 26 clamp & sew
Doss (2005)	N/A	N/A	N/A	N/A	N/A	28 bypass
Kasirajan (2003)	Open (8 M, 2 F), TEVAR (4 M, 1 F)	32 ± 11	42 ± 9	44 ± 24	38 ± 19	7 bypass; 3 clamp & sew
Kokotsakis	Open (9 M), TEVAR (19 M)	48 ± 4	49 ± 5	42 ± 4	26 ± 2	6 bypass
Kuhne (2005)	N/A	37 ± 11	41 ± 8	34 ± 15	29 ± 13	N/A
Lebl (2007)	N/A	34.9 ± 3.4	35.1 ± 3.7	39 ± 5	59 ± 8	Both techniques
McPhee (2006)	Open (3 M, 2 F), TEVAR (6 M, 2 F)	39	46	40.6	30.8	Clamp & sew
Ott (2003)	Open (7 M, 5 F), TEVAR (5 M, 1 F)	47.5	46	31.5	43.5	4 bypass; 8 clamp & sew
Pacini (2005)	N/A	N/A	N/A	N/A	N/A	41 bypass; 10 clamp & sew
Riesenman (2007)	Open (36 M, 12 F), TEVAR (9 M, 5 F)	41	38	40.7	40.2	41 bypass; 7 clamp & sew
Rousseau (2005)	N/A	33 ± 1.9	35 ± 2.1	N/A	37 ± 19	17 bypass; 11 clamp & sew
Stampfl (2005)	Open (2 M, 3 F), TEVAR (5 M, 0 F)	43.8 (34-57)	53.2 (34-59)	30 (20-58)	40 (20-74)	5 bypass

N/A, Information not available or could not be extracted; *TEVAR,* Thoracic endovascular aneurysm repair; *mon*, months; *Y*, years; *M*, male; and *F*, female.
[a]Medtronic, Minneapolis, Minn.
[b]W. L. Gore and Assoc, Flagstaff, Ariz.
[c]Cook, Bloomington, Ind.
[d]JOTECH GmbH, Hechingen, Germany.
[e]Relay Bolton Medical, Sunrise, Fla.
[f]Guidant, Indianapolis, Ind.
[g]Boston Scientific, Natick, Mass.

Annual Meeting, Seattle, WA; 2007). All were nonrandomized; no prospective randomized trials were found. Four studies were excluded because the mortality and paraplegia rate in the trauma patient subset could not be extracted from one study,[31] one study did not have an open surgical trauma cohort,[22] one study presented duplicate data,[23] and one study reported emergency open repair vs delayed TEVAR.[38] In the remaining 17 studies, 220 patients underwent endoluminal repair and 369 had open repair. All studies reported both procedure-related and all-cause 30-day mortality, and 16 reported paraplegia/paraparesis. Studies that do not appear in the forest plots had zero outcomes for both the endoluminal and the open repair groups.

In the 13 studies that reported age, the overall mean was 38.8 years in both groups. The mean ± standard deviation ISS of the patients from the 12 studies that underwent TEVAR was higher than the ISS of the patients that had open repair (42.4 ± 9.3 vs 37.4 ± 9.0, $P < .001$). There was no significant difference in the mean length of time to procedure: 1.5 days in the TEVAR group vs 1 day in the open repair group.

The measures of study quality are presented in Table I, and the data extracted from these studies are reported in Table II. The average quality rating was 10.6 of 13 (range, 4-13): 13 studies scored ≥10. Three studies had significantly lower quality scores (4 or 5).[30,32,34] We tested the sensitivity of our results by comparing the pooled ORs with and without these three studies; these ORs did not vary significantly from the overall study results. Inspection of the funnel plot for 30-day mortality showed study results demonstrated appropriate dispersion and little publication bias (Fig 1). Also, the Q

Table II. Continued.

Conversion to open repair	*Mean follow-up period (range)*	*Endoleaks*	*Left subclavian coverage*	*Device*
0	Open, 36 (3-41) mon; TEVAR, 15.1 (3-41) mon	0	N/A	Talent[a]
3/15	Open, 117 (17-166) mon; TEVAR, 36 (2-78) mon	1/15	3/15	Talent, Excluder,[b] Zenith[c]
0	TEVAR, 31 ± 17 mon	0	N/A	Talent, thoracic Excluder
2/39	Open, 6 (0-15.6) y; TEVAR, 2.2 (1-7.3) y	1/39	20/39	27 Talent, 9 E-Vita,[d] 3 Relay[e]
N/A	TEVAR, 12.2 (3-42) mon	0	20/29	N/A
0	N/A	0	0	11 Gore cuff extenders, 3 AneuRx cuff extenders,[a] 1 Ancure,[f] 1 TAG, 1Talent, 1 homemade device, 1 contra limb abdominal Excluder
N/A	36.4 ± 12.8 mon	N/A	N/A	Talent, Excluder
N/A	Open, 7 ± 6 mon; TEVAR, 10.3 ± 6 mon	0	4/5	3 Talent, 1 thoracic Excluder, 1 homemade graft
0	Open, 46.7 mon; EVAR, 10.3 mon	2/22	2/22	13 Talent, 4 Valiant,[a] 5 Relay
0	N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A	N/A
0	Open, 33.3 (12-54) mon; TEVAR, 16.6 (8-30) mon	0	4/8	1Thoracic Excluder, 1Talent, 6 AneuRx cuffs
0	TEVAR, 24 (17-37) mon	0	6/6	N/A
0	TEVAR, 7 y	0	5/15	14 Talent, 1 Thoracic Excluder
N/A	TEVAR, 9.4 mon	1/14	0	TAG, Talent, Vanguard,[g] Excluder extension cuffs
0	Combined 46 (13-90) mon	1/8	N/A	Thoracic Excluder, Talent, Vanguard
N/A	Open, 63 (5-108) mon; TEVAR, 28 mon	1/5	2/5	Talent, Thoracic Excluder

test did not reveal significant heterogeneity (P = .09 for mortality and procedure-related mortality; P = .08 for paraplegia/paraparesis). The sensitivity analyses for all three outcomes did not demonstrate that any single study overly influenced the results.

Random and fixed effects were the same for each outcome, indicating that the meta-analyses estimated a single common effect for all studies. Procedure-related mortality was significantly lower with endoluminal repair, 2% with TEVAR vs 14% with open repair (OR, 0.31; 95% CI, 0.15-0.66; P = .002; Fig 2, Table III). Overall 30-day mortality was also lower after endoluminal repair compared with open repair, 8% with TEVAR vs 20% with open repair (OR, 0.44; 95% CI, 0.25-0.78; P = .005; Fig 3, Table III). Data regarding postoperative paraplegia were reported in 16 of these studies and included 215 patients treated with TEVAR and 333 patients with open repair. The risk of postoperative paraplegia was significantly lower after TEVAR at 0% vs 7% with open repair (OR, 0.32; 95% CI, 0.1-0.93; P = .037; Fig 4, Table III).

DISCUSSION

The results of this meta-analysis indicate that mortality and the risk of paraplegia is significantly lower after endovascular vs open repair of traumatic thoracic aortic injuries. The current status of traumatic aortic tear as treated with traditional open repair is not ideal.[41-43] Traumatic rupture of the thoracic aorta is often immediately fatal, and patients who survive frequently have multisystem injuries, including pulmonary contusions, cranial injuries, multiple fractures, and solid organ injuries. Open repair of TAT involving thoracotomy, aortic cross-clamping, and, in some cases left

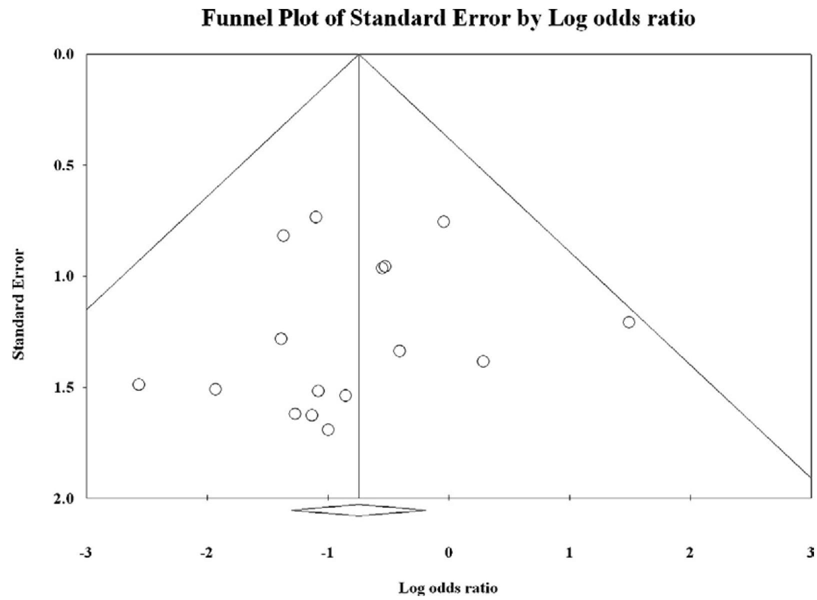

Fig 1. Study results demonstrate an overall inverted funnel shape indicating minimal publication bias.

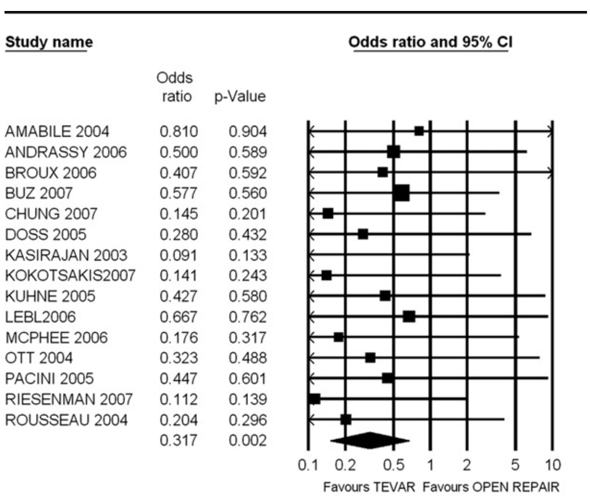

Fig 2. Forest plot shows procedure-related mortality *(PRM)* in thoracic endovascular aneurysm repair (*TEVAR*) vs open repair of traumatic descending aortic rupture. *CI,* Confidence interval.

heart bypass, is accompanied by significant mortality and morbidity. Respiratory compromise from lung and chest wall injuries is compounded by thoracotomy, and aortic cross-clamping and unclamping complicate pre-existing hemodynamic and cardiac instability in these critically injured patients. Lung contusions make single-lung ventilation problematic, and proper positioning may pose risks of worsening neurologic deficits in patients with unstable spinal fractures.[44] Paraplegia, a complication of any elective thoracic aortic procedure, remains a significant problem in the trauma setting.

Studies of operative repair of thoracic aortic injury[45,46] have reported mortality rates approaching 18% to 28% and paraplegia rates of 2.3% to 14% among survivors. Because of the high risk of immediate surgery, some have advocated delaying intervention with β-blocker therapy until the patient is more stable. Pate et al[4] noted that 15 of 47 patients (32%) underwent delayed operative repair of TAT, ranging from 2 days to 25 months, to allow stabilization of associated injuries. Further, Maggisano et al[47] reported that 31 of 59 patients (53%) with TAT underwent delayed repair ranging from 1 day to 7 months to allow resolution of concomitant severe injuries. Careful blood pressure control in stable patients with TAT is central to nonoperative management. Formal pharmacologic protocols with β-blockers were used in the abovementioned studies before operation. Delayed repair may improve survival after aortic surgery in selected cases where immediate operation in a patient with other life-threatening injuries would carry high mortality risk.[43,48] However, delayed open surgery may lead to in-hospital death from untreated TAT in 2% to 5% of patients.[49,50]

A variety of technical improvements, including the use of shunts for distal perfusion and cardiopulmonary bypass, seem to have decreased the mortality rate of open repair[49] but overall, thoracic aortic surgery in trauma victims has a high complication rate. When aortic repair is performed with cross-clamping alone, the mean rate of postoperative paraplegia is 7%. Use of circulatory assistance decreases the incidence of spinal cord ischemia to 3%, but systemic heparinization increases the risk of fatal hemorrhage, especially in patients with cerebral or pulmonary contusion.[49]

After the initial reports of stent graft repair for abdominal and thoracic aneurysm disease, surgeons have considered this minimally invasive approach for treatment of thoracic aortic pathology.[12] Although TEVAR in the

Table III. Outcomes from 17 studies of endovascular versus open repair of traumatic descending thoracic aortic Rupture

	Patients, No. (%)			*Procedure-related mortality, No. (%)*		*30-day mortality, No. (%)*		*Paraplegia/paresis, No. (%)*	
First author (year)	*Total*	*TEVAR*	*Open*	*TEVAR*	*Open*	*TEVAR*	*Open*	*TEVAR*	*Open*
Amabile (2004)	12	3 (25)	9 (75)	0 (0)	1 (11)	0 (0)	1 (11)	0 (0)	0 (0)
Andrassy (2006)	31	15 (48)	16 (52)	1 (7)	2 (13)	2 (13)	3 (19)	0 (0)	2 (13)
Broux (2006)	30	13 (43)	17 (57)	0 (0)	1 (6)	2 (15)	4 (24)	0 (0)	1 (6)
Buz (2007)	74	39 (53)	35 (47)	2 (5)	3 (9)	3 (8)	7 (20)	0 (0)	0 (0)
Chung (2007)	71	29 (41)	42 (59)	0 (0)	4 (10)	0 (0)	4 (10)	0 (0)	8 (19)
Cook (2006)	42	19 (45)	23 (55)	0 (0)	0 (0)	4 (21)	5 (22)	0 (0)	1 (4)
Doss (2005)	19	7 (37)	12 (63)	0 (0)	2 (17)	0 (0)	2 (17)	1 (14)	0 (0)
Kasirajan (2003)	15	5 (33)	10 (67)	0 (0)	5 (50)	1 (20)	5 (50)	0 (0)	0 (0)
Kokotsakis (2007)	32	22 (69)	10 (31)	0 (0)	1 (10)	1 (5)	1 (10)	0 (0)	1 (10)
Kuhne (2005)	41	5 (12)	36 (88)	0 (0)	6 (17)	0 (0)	6 (17)	N/S	N/S
Lebl (2006)	17	7 (41)	10 (59)	1 (14)	2 (20)	1 (14)	2 (20)	0 (0)	0 (0)
Mcphee (2006)	13	8 (62)	5 (38)	0 (0)	1 (20)	2 (25)	1 (20)	0 (0)	0 (0)
Ott (2004)	18	6 (33)	12 (67)	0 (0)	2 (17)	0 (0)	2 (17)	0 (0)	2 (17)
Pacini (2005)	66	15 (23)	51 (77)	0 (0)	3 (6)	0 (0)	4 (8)	0 (0)	4 (8)
Riesenman (2007)	62	14 (23)	48 (77)	0 (0)	11 (23)	2 (14)	19 (40)	0 (0)	0 (0)
Rousseau (2004)	36	8 (22)	28 (78)	0 (0)	6 (21)	0 (0)	6 (21)	0 (0)	3 (11)
Stampfl (2005)	10	5 (50)	5 (50)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Total	589	220 (37)	369 (63)	4 (2)	50 (14)	18 (8)	72 (20)	1 (0)[a]	22 (7)[a]

N/S, Indicates outcome not studied; *TEVAR,* thoracic endovascular aneurysm repair.
[a]Total sample is less due to Kuhne (2005) not including this outcome.

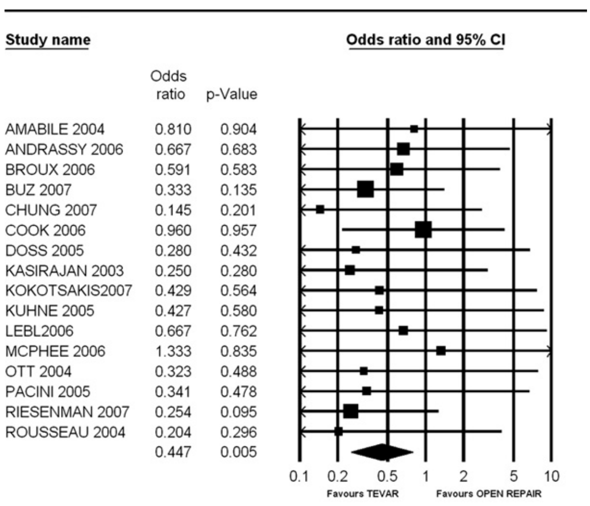

Fig 3. Forest plot shows 30-day mortality in thoracic endovascular aneurysm repair *(TEVAR)* vs open repair of traumatic descending aortic rupture.

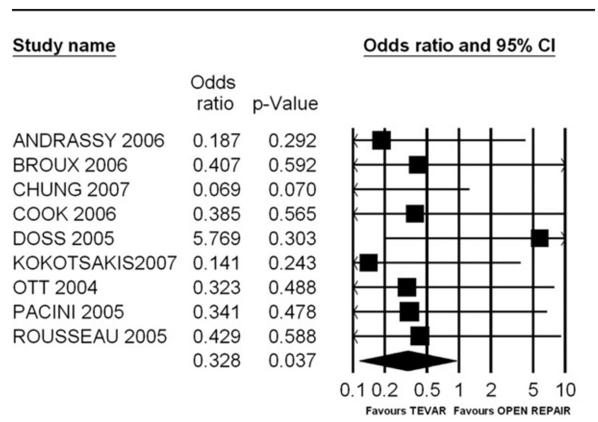

Fig 4. Forest plot shows paraplegia/paraparesis in thoracic endovascular aneurysm repair *(TEVAR)* vs open repair of traumatic descending aortic rupture.

United States has only been approved for the treatment of degenerative aneurysmal disease, applications for other pathologies such as dissection and trauma are emerging. Endoluminal stent graft insertion for the treatment of TAT seems to avoid many of the complications associated with open thoracic aortic repair. Specifically, the attendant risk of paraplegia using the endovascular technique is reported to range from 0% to 5%.[51,52] From the studies included in our report, only one patient developed paraplegia after TEVAR.[34] This patient had initially undergone placement of a thoracic endograft for TAT and 24 months later developed a distal endoleak. This was treated with deployment of a second stent graft and he developed paraplegia on the second postoperative day. An additional paraplegia event was recently reported by Cambria et al in a prospective study of 59 patients, assessing the utility of the Gore TAG (W. L. Gore & Assoc, Flagstaff, Ariz) thoracic endoprosthesis for thoracic aortic rupture, acute complicated Type B dissection and traumatic aortic tear (Cambria et al: Stent Graft Repair Of Complex Thoracic Aortic Pathology: A Multicentre Prospective Trial. Abstract presented at the

Society for Vascular Surgery 2007 Vascular Annual Meeting, Baltimore, MD).

Advantages of TEVAR include avoidance of thoracotomy, single-lung ventilation, aortic cross-clamping, and left heart or cardiopulmonary bypass. TEVAR also requires considerably less time and can be done expeditiously in relatively unstable patients. The development of endovascular techniques has led to a number of studies examining the outcomes of endovascular repair in thoracic aortic trauma.[53,54] Retrospective series of patients with traumatic thoracic aortic disruptions treated with an endovascular approach have shown successful emergency repair of acute thoracic aortic disease.[55,56] Pratesi et al[57] reported 11 patients that were treated with stent grafts for acute rupture of the thoracic aorta; no neurologic deficits developed, and 30-day mortality was 9.1%.[57] Similarly, no procedure related paralysis was observed after TEVAR in 30 patients with TAT, and mortality was 6.6%.[58]

Endovascular treatment for trauma can be logistically as well as technically challenging, requiring expeditious imaging, personnel trained in endovascular procedures, and an available stock of equipment. The use of thoracic endografts in TAT is an off-label use of these devices. A technical limitation of thoracic aortic stent graft placement in younger individuals is that these patients have usually smaller aortas than patients with aneurysmal disease. Thus it may be necessary to use aortic cuffs designed for repair of infrarenal aortic aneurysms; if the delivery system is too short, a conduit may be required. Over sizing may be related to collapse of the stent graft.[58] Questions about long-term side effects and durability of the repair remain to be answered. Retrospective case series with follow-up intervals up to 90 months[19] have demonstrated the midterm durability of this type of repair with acceptable complication and reintervention rates.[36,37,56]

A limitation of our study is that all reports were retrospective cohort studies, without randomization. Owing to the relatively small number of patients with these lesions, as well as ethical issues, it is unlikely that there will be comparison of TEVAR and open repair in a prospective randomized trial. Another possible concern is related to the interval from injury to repair, which varied widely among reports. We used immediate repair data (as characterized by the authors) from studies that reported subcategories of delayed vs emergency repair to address this problem. The two groups were comparable in terms of age and interval from operation to injury. Heterogeneity and publication bias was shown to be limited. Some studies reported higher mortality after open repair compared with others.[19,28,32,39] Performing the meta-analyses by excluding these reports did not alter the statistical outcome.

CONCLUSION

Endoluminal repair of traumatic thoracic aortic injury is associated with lower rates of mortality and spinal cord ischemia complications compared with open repair. Although short-term data are encouraging, concerns have been raised about stent graft failure, collapse due to the acute angle of the aortic arch in young patients, stent graft migration, and need for repeat intervention. Obviously, the issue of durability of endovascular repair is highly relevant in younger patients, and patients with an endovascular graft for aortic rupture will have to be closely monitored for a long period of time. Nevertheless, many centers have reported a shift in the way thoracic aortic rupture is managed, using the endoluminal approach as the procedure of choice.[30,59] Because it is not likely that randomized trials will be performed, prospective population-based studies including all patients with thoracic aortic rupture will provide the best attainable level of evidence on this issue.

AUTHOR CONTRIBUTIONS

Conception and design: EX
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Data collection: NA, OH
Writing the article: EX, DD
Critical revision of the article: EE, DM
Final approval of the article: EX, ES
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REFERENCES

1. Smith RS, Chang FC. Traumatic rupture of the aorta: Still a lethal injury. Am J Surg 1986;152:660-3.
2. Feczko JD, Lynch L, Pless JE, Clark MA, McClain J, Hawley DA. An autopsy case review of 142 non-penetrating (blunt) injuries of the aorta. J Trauma 1992;33:846-9.
3. Williams JS, Graff JA, Uku JM, Steinig JP. Aortic injury in vehicular trauma. Ann Thorac Surg 1994;57:726-30.
4. Pate JW, Fabian TC, Walker W. Traumatic rupture of the aortic isthmus: an emergency? World J Surg 1995;19:119-26.
5. Parmley LF, Mattingly TW, Manion WC, Jahnke EJ. Non penetrating traumatic injury of the aorta. Circulation 1958;17:1086-100.
6. Eddy AC, Rusch VW, Fligner CL, Reay DT, Rice CL. The epidemiology of traumatic rupture of the thoracic aorta in children: a thirteen year review. J Trauma 1990;30:989-92.
7. Cowley RA, Turney SZ, Hankins JR, Rodriguez A, Attar S, Shankar BS. Rupture of thoracic aorta caused by blunt trauma. J Thorac Cardiovasc Surg 1990;100:652-61.
8. Nishimoto M, Fukumoto H, Nishimoto Y, Furubayashi K, Morita H, Sasaki S. Surgical treatment of traumatic thoracic aorta rupture: a 7-year experience. Jpn J Thorac Cardiovasc Surg 2003;51:138-43.
9. Jamieson WR, Janusz MT, Gudas VM, Burr LH, Fradet GJ, Henderson C. Traumatic rupture of the thoracic aorta: Third decade of experience. Am J Surg 2002;183:571-5.
10. Lindsay J, de Bakey ME, Beall AC. Diagnosis and treatment of diseases of the aorta. In: Schlant RC, Alexander RW, Eds. The Heart. McGraw Hill; 1994. p. 2163-80.
11. Cardarelli MG, McLaughlin JS, Downing SW, Brown JM, Attar S, Griffith BP. Management of traumatic aortic rupture a 30-year experience. Ann Surg 2002;236:465-9.
12. Dake MD, Miller DC, Semba CP, Mitchell RS, Walker PJ, Liddell RP. Transluminal placement of endovascular stent-grafts for the treatment of descending thoracic aortic aneurysms. N Engl J Med 1994; 29:1729-34.
13. Semba CP, Kato N, Kee ST, Lee GK, Mitchell RS, Miller DC, Dake MD. Acute rupture of the descending thoracic aorta: repair with use of endovascular stent-grafts. J Vasc Interv Radiol 1997;8:337-42.
14. Czermak BV, Waldenberger P, Fraedrich G, Dessl AH, Roberts K, Bale RJ, et al. Treatment of Stanford type B aortic dissection with stent-grafts: preliminary results. Radiology 2000;217:544-50.

15. Nienaber CA, Fattori R, Lund G, Dieckman C, Wolf W, Nicolas V, et al. Nonsurgical reconstruction of thoracic aortic dissection by stent-graft placement. N Engl J Med 1999;340:1539-45.
16. Murgo S, Dussaussois L, Golzarian J, Cavenaile JC, Abada HT, Ferreira J, et al. Penetrating atherosclerotic ulcer of the descending thoracic aorta: treatment by endovascular stent-graft. Cardiovasc Interv Radiol 1998;21:454-8.
17. Dake MD, Kato N, Mitchell RS, Semba CP, Razavi MK, Shimono T, et al. Endovascular stent-graft placement for the treatment of acute aortic dissection. N Engl J Med 1999;340:1546-52.
18. Rutherford RB. Rutherford Vascular Surgery. 6th edition. Philadephia, PA: Elsevier Saunders; 2005.
19. Rousseau H, Dambrin C, Marcheix B, Richeux L, Mazerolles M, Cron C, et al. Acute traumatic aortic rupture: A comparison of surgical and stent graft repair. J Thorac Cardiovasc Surg 2005;129:1050-5.
20. Amabile P, Collart F, Gariboldi V, Rollet G, Bartoli J, Piquet P. Surgical versus endovascular treatment of traumatic thoracic aortic rupture. J Vasc Surg 2004;40:873-9.
21. Andrassy J, Weidenhagen R, Meimarakis G, Rjung L, Jauch K-W, Kopp R. Stent versus open surgery for acute and chronic traumatic injury of the thoracic aorta: A single center experience. J Trauma 2006;60:765-772.
22. Stone DH, Brewster DC, Kwolek CJ, Muraglia G, Conrad MF, Chung TK, et al. Stent-graft versus open-surgical repair of the thoracic aorta: mid-term results. J Vasc Surg 2006;44:1188-97.
23. Doss M, Balzer J, Martens S. Surgical versus endovascular treatment of acute thoracic aortic rupture: A single center experience. Ann Thor Surg 2003;76:1465-1470.
24. Broux C, Thony F, Chavanon O, Bach V, Hacini R, Sengel C, et al. Emergency endovascular stent graft repair for acute blunt thoracic aortic injury: a retrospective case control study. Intensive Care Med 2006;32:770-4.
25. Cook J, Salerno C, Krishnadasan B, Nicholls S, Meissner M, Karmy-Jones R. The effect of changing presentation and management on the outcome of blunt rupture of the thoracic aorta. J Thorac Cardiovasc Surg 2006;131:594-600.
26. Stroup DF, Berlin JA, Morton SC, Olkin I, Williamson GD, Renie D, et al. Meta-analysis of observational studies in epidemiology; a proposal for reporting. JAMA 2000;283:2008-12.
27. Higgins J, Green S. The Cochrane handbook for systematic reviews of interventions. http://www.cochrane.org/resources/handbook/Handbook4.2.6Sep2006.pdf.
28. Kasirajan K, Heffrman D, Langsfeld M. Acute thoracic aortic trauma: a comparison of endoluminal stent grafts with open repair and nonoperative management. Ann Vasc Surg 2003;17:589-95.
29. Ott M, Stewart T, Lawlor D, Gray DK, Forbes T. Management of blunt thoracic aortic injuries: endovascular stents versus open repair. J Trauma 2004;56:565-70.
30. Lebl D, Dicker R, Spain D, Brundage S. Dramatic shift in the primary management of traumatic thoracic aortic rupture. Arch Surg 2006;141:177-80.
31. Morishita K, Kurimoto Y, Kawaharada, Fukada J, Hachiro Y, Fujisawa Y, et al. Descending thoracic aortic rupture: role of endovascular stent-grafting. Ann Thor Surg 2004;78:1630-4.
32. Kuhne C, Ruchholtz S, Voggenreiter G, Eggebracht H, Paffrath T, Waydhas C, et al. Traumatische Aortenverletzungen bei poly traumatisierten patienten. Unfallchirurg 2005;109:279-87.
33. McPhee JT, Asham EH, Rohrer MJ, Singh MJ, Wong G, Vorhies RW, et al. The midterm results of stent graft treatment of thoracic aortic injuries. J Surg Res 2007;138:181-8.
34. Doss M, Wood J, Balzer J, Martens S, Deschka H, Moritz MD. Emergency endovascular interventions for acute thoracic aortic rupture: four-year follow-up. J Thorac Cardiovasc Surg 2005;129:645-51.
35. Buz S, Zipfel B, Mulahasanovic S, Pasic M, Weng Y, Hetzer R. Conventional surgical repair and endovascular treatment of acute traumatic rupture. Eur J Cardiothorac Surg (In Press).
36. Pacini D, Angeli E, Fattori RL, Rocchi G, Marco LD, et al. Traumatic rupture of the thoracic aorta: ten years of delayed management. J Thorac Cardiovasc Surg 2005;129:880-884.
37. Stampfl P, Greitbauer M, Zimpfer D, Fleck T, Schoder M, Lammer J, et al. Mid-term results of conservative, conventional and endovascular treatment for acute traumatic aortic lesions. Eur J Vasc Endovasc Surg 2006;31:475-80.
38. Reed A, Thompson K, Crafton C, Delvecchio C, Giglia J. Timing of endovascular repair of blunt traumatic thoracic aortic transections. J Vasc Surg 2006;43:684-688.
39. Riesenman PJ, Farber MA, Rich PB, Sheridan BC, Mendes RR, Marston WA, et al. Outcomes of surgical and endovascular treatment of acute traumatic thoracic aortic injury. J Vasc Surg 2007;46:934-40.
40. Kokotsakis J, Kaskarelis I, Misthos P, Athanasiou T, Kanakakis K, Athanasiou C, et al. Endovascular versus open repair for blunt thoracic aortic injury: short term results. Ann Thorac Surg 2007;84:1965-70.
41. Pierangeli A, Turinetto B, Galli R, Ferrera L, Fattori R, Gavelli G. Delayed treatment of isthmic aortic rupture. Cardiovasc Surg 2000;8:280-3.
42. Gammie JS, Shah AS, Hattler BG, RL, Peitzman AB, Griffith BP, et al. Traumatic aortic rupture: diagnosis and management. Ann Thorac Surg 1998;66:1295-300.
43. Galli R, Pacini D, Di Bartolomeo R, Fattori R, Turinetto B, Grillone G, et al. Surgical indications and timing of repair of traumatic ruptures of the thoracic aorta. Ann Thorac Surg 1998;65:461-4.
44. Williams JS, Graff JA, Uku JM, Steinig. Aortic injury in vehicular trauma. Ann Thorac Surg 1994;57:726-30.
45. Cowley RA, Turney SZ, Hankins JR, Rodriguez A, Attar S, Shankar BS. Rupture of thoracic aorta caused by blunt trauma: a fifteen-year experience. J Thorac Cardiovasc Surg 1990;100:652-61.
46. von Oppell UO, Dunne TT, De Groot MK, Zilla P. Traumatic aortic rupture: twenty-year meta-analysis of mortality and risk for paraplegia. Ann Thorac Surg 1994;58:585-93.
47. Maggisano R, Nathens A, Alexandrova NA, Cina C, Boulanger B, McKenzie R. Traumatic rupture of the thoracic aorta: should one always operate immediately? Ann Vasc Surg 1995;9:44-52.
48. Pierangeli A, Turinetto B, Galli R, Caldarera L, Fattori R, Gavelli G. Delayed treatment of isthmic aortic rupture. Cardiovasc Surg 2000;8:280-3.
49. Jahromi AS, Kazemi K, Safar HA, Doobay B, Cina CS. Traumatic rupture of the thoracic aorta: Cohort study and systematic review. J Vasc Surg 2001;34:1029-34.
50. Fabian TC, Richardson JD, Croce MA, Smith JS, Rodman J, Kearney PA, et al. Prospective study of blunt aortic injury: multicenter trial of the American Association for the Surgery of Trauma. J Trauma 1997;42:374-83.
51. Karmy-Jones R, Hoffer E, Meissner M, Nicholls SM. Endovascular stent grafts and aortic rupture: A case series. J Trauma 2003;55:805.
52. Schoder M, Grabenwöger M, Hölzenbein T, Cejna M, Ehrlich MP, Rand T, et al. Endovascular repair of the thoracic aorta necessitating anchoring of the stent graft across the arch vessels. J Thorac Cardiovasc Surg 2006;131:380-7.
53. Wellons ED, Milner R, Solis M, Levitt A, Rosenthal D. Stent-graft repair of traumatic thoracic aortic disruptions. J Vasc Surg 2004;40:1095-100.
54. Orford VP, Atkinson NR, Thomson K, Milne PY, Campbell WA, Roberts A, et al. Blunt traumatic aortic transection: the endovascular experience. Ann Thorac Surg 2003;75:106-12.
55. Stoica L, Chocron S, Falcoz P, Etivent JP. Endovascular stent grafting for contained rupture of the descending thoracic aorta. Eur J Cardiothor Surg 2003;23:1068-70.
56. Dunham MB, Zygun D, Petrasek P, Kortbeek JB, Karmy-Jones R, Moore RD. Endovascular stent grafts for acute blunt aortic injury. J Trauma 2004;56:1173-8.
57. Pratesi C, Dorigo W, Troisi N, Pratesi G, Santoro G, Stefano P, et al. Acute traumatic rupture of the descending thoracic aorta: endovascular treatment. Am J Surg 2006;192:291-5.
58. Tehrani HY, Peterson BG, Katariya M, Morash MD, Stevens R, DilUozzo G, et al. Endovascular repair of thoracic aortic tears. Ann Thorac Surg 2006;82:873-7
59. Richeux L, Dambrin C, Marcheix BV, Meites G, Mazerolles M, et al. Towards a new management of acute traumatic aortic ruptures. J Radiol 2004;85:101-6.

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