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From the Canadian Society for Vascular Surgery

A systematic review of nonoperative management in blunt thoracic aortic injury

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ABSTRACT

Objective: The objective was to characterize the growing body of literature regarding nonoperative management of blunt thoracic aortic injury (BTAI).

Methods: A systematic search of MedLine, Embase, and Cochrane Central was completed to identify original articles reporting injury characteristics and outcomes in patients with BTAI managed nonoperatively during their index hospitalization. Article title and abstract screening, full-text review, and data abstraction were performed in duplicate, with discrepancies resolved by a third reviewer. The quality of each study was evaluated using the Oxford Centre for Evidence-Based Levels of Evidence.

Results: Of 2162 identified studies, 74 were included and reported on 8606 patients with BTAI who were managed nonoperatively between 1970 and 2016. Only one study was prospective. The median nonoperative sample size per study was 11 patients. The characterization of aortic injury grade differed across studies. Follow-up varied widely from 1 day to 118 months. Injury healing or improvement on follow-up imaging occurred in 34% (226 of 673 patients; reported in 37 studies), most often in the context of grade I intimal injury. Injury progression or requirement for a thoracic endovascular aneurysm repair for injury progression was 7.6% (66 of 873 patients; reported in 46 studies). A total of 37 studies reported aortic-related death, with an overall rate of 4.5% (37 of 827 patients) and a rate of 1% in grade I and II injuries (1 of 153 patients) and 18% in grade III and IV (9 of 50 patients).

Conclusions: An increasing number of reports support nonoperative management of grade I intimal injury, consistent with Society for Vascular Surgery guidelines. However, a retrospective interpretation of the determinants of management, heterogeneous injury characterization, and variable follow-up remain major limitations to the informed use of nonoperative management across all BTAI grades. (J Vasc Surg 2019;70:1675-81.)

Keywords: Thoracic aortic injury; Blunt trauma; Management; Conservative treatment; Systematic review

Urgent open operative repair was historically considered for all cases of blunt thoracic aortic injury (BTAI).[1] However, certain patients were not operative candidates and were medically managed with strict blood pressure control to decrease aortic wall shear stress via attenuation of ejection dynamics.[1] In some of these cases, the aortic lesion was noted to heal spontaneously on follow-up imaging.[2]

With the development of higher resolution computed tomography (CT) scanners and widespread use of screening CT angiograms in major trauma, intimal tears and small pseudoaneurysms are more readily detected. The phrase "minimal aortic injury" was coined to represent aortic injury of lesser severity for which intervention may not be required.[3] Subsequent guidelines have supported nonoperative management of intimal tears,[4,5] and a population-based analysis of BTAI in Canada has shown an increasing frequency of nonoperative management.[6] Furthermore, owing to lower morbidity, thoracic endovascular aneurysm repair (TEVAR) has made it possible to intervene in patients who would not previously have had their aortic injury repaired.[5-7] Given the improved diagnostic sensitivity and a reduced threshold for intervention, defining the evolving role of nonoperative management is an important area of research in the endovascular era. In fact, a growing body of literature on nonoperative management in BTAI has emerged since the 2011 publication of Society for Vascular Surgery (SVS) practice guidelines.[4] Our objective was, therefore, to summarize the existing knowledge through a systematic review of the evolving role of nonoperative management in blunt thoracic aortic injury.

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Author conflict of interest: none.

Presented at the Fortieth Annual Meeting of the Canadian Society for Vascular Surgery, Montreal, Quebec, Canada, September 28, 2018.

Additional material for this article may be found online at www.jvascsurg.org.

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The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a conflict of interest.

0741-5214

https://doi.org/10.1016/j.jvs.2019.02.023

Table I. Inclusion and exclusion criteria used in abstract and full text screening of articles on blunt thoracic aortic injury

	Inclusion	Exclusion
Publication year, journal, language	Any year, journal or language understood by investigators	Retracted publications
Study subjects and setting	Any population (pediatric, adult, geriatric) geographic location or year	Nonhuman
Study design	Any (case report, case series, case control, cohort, experimental study)	Systematic review, guidelines, commentary, research letter
Diagnostic modality	Any (CTA, echo, IVUS, angio)	None
Aortic injury	Blunt (MVC, crush, fall) thoracic aortic injury of any grade	Penetrating injury to the aorta Nontraumatic pathology of the aorta (dissection, aneurysm) Injury to the aorta that does not include an injury of the descending thoracic aortic segment: aortic root, arch, abdominal
Nonaortic injuries	Any	None
Management	At least one case managed medically, regardless of the method of nonsurgical management or the outcome Postdischarge surgical intervention (open or TEVAR)	Surgical management (open or TEVAR) on index trauma admission

Angio, Angiography; *CTA*, computed tomography angiography; *echo*, echocardiogram; *IVUS*, intravascular ultrasound; *TEVAR*, thoracic endovascular aneurysm repair.

METHODS

We performed a systematic review of MEDLINE, Embase, and Cochrane CENTRAL databases from 1946 to January 2018. Our review was guided by the usage of the PRISMA statement, and our search strategy was devised and carried out with the help of a full-time information and communication technologies expert at our institution.[8] Included terms as well as complete search strategy are provided in the Supplementary Appendix (online only). All original articles pertaining to thoracic aortic injury secondary to blunt trauma were considered for inclusion in the systematic review with specific inclusion and exclusion criteria (Table I).

After the initial database search, the review process was divided into three steps: title and abstract screening, full text review and data collection. Each step was completed by two independent reviewers (J.J.B. and K.S.), and any discrepancies were resolved by a third reviewer (C.d.M.).

We collected the following publication-related data for all studies passing screening and full-text review: first author, publication year, country, subject enrollment period, diagnostic modality, anatomic location of aortic injury. In patients managed nonoperatively, the proportion of pediatric patients (age ≤16 years), their SVS aortic injury grade, any medical management protocol, and their clinical course (in-hospital and aortic-related mortality, injury resolution or improvement, injury progression or need for delayed intervention, and length of follow-up) was recorded. The quality of each study was evaluated using the Oxford Centre for Evidence-Based Medicine Levels of Evidence.[9]

RESULTS

Study characteristics. After screening and full text review, 74 studies were included (Fig 1) that were published between 1981 and 2018 (Supplementary Table, online only). Over this 37-year period, 45% of the 74 studies (n = 33) were published after the 2011 publication of the SVS Clinical Practice Guidelines.[4] There was 1 prospective cohort study, 65 retrospective cohort studies or case series, and 8 case reports. The majority (48/74 [65%]) of studies were conducted in the United States; 16% (12/74) were conducted in Europe and the United Kingdom, 9% (7/74) in Canada, 6.8% (5/74) in Asia, and 2.7% (2/74) in Australia. By the Oxford Center for Evidence Based Medicine classification, studies were respectively categorized as level 3, level 4, and level 5 in 4, 60, and 10 instances.

Diagnostic modality and location of injury among all patients with BTAI. Sixty-one studies reported the diagnostic modalities used to characterize BTAI: CT angiography in 52 studies (85%), conventional angiography in 34 (56%), transesophageal echocardiogram in 11 (18%), and intravascular ultrasound in 6 (10%). Over the study period, CT became the dominant diagnostic modality while seeing a drop in angiography (Fig 2).

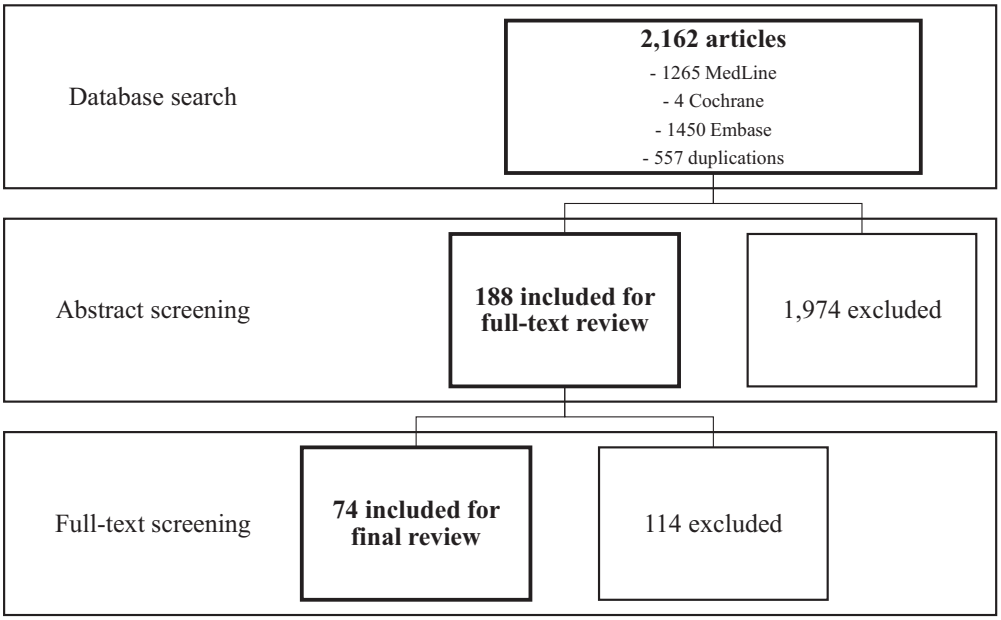

Fig 1. Study inclusion flow chart.

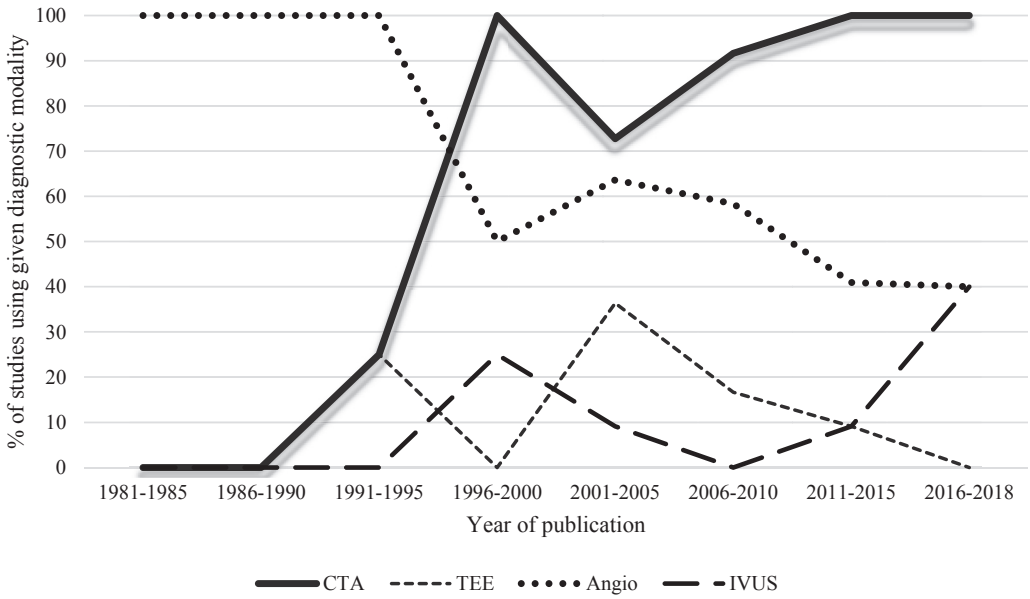

Fig 2. Blunt thoracic aortic injury diagnostic modalities over time. *Angio*, Angiography; *CTA*, computed tomography angiography; *IVUS*, intravascular ultrasound; *TEE*, transesophageal echocardiography.

Injury location was described in 86% of studies (64/74). Nonspecific injury location descriptors (eg, "thoracic aorta") were presented in 34% of studies (25/74). Many reports also included injuries of the ascending or abdominal aorta (Fig 3).

Aortic injury severity among patients with BTAI managed nonoperatively. Across the 74 studies, 8606 patients were identified as managed nonoperatively between 1970 and 2016. There was a median of 11 patients managed nonoperatively per study (interquartile range, 5-23; mean, 118 ± 617) and only nine pediatric patients (≤16 years old) in total. Fifty-nine studies (80%) reported some measure of aortic injury grade with 57 using the SVS classification or a description compatible with the SVS system (Fig 4).

Medical management protocols. Twenty-seven of the 74 studies (36%) included specifics on the blood pressure parameters and antihypertensive agents used for patients with BTAI managed nonoperatively. In most cases, the primary hemodynamic parameter target was

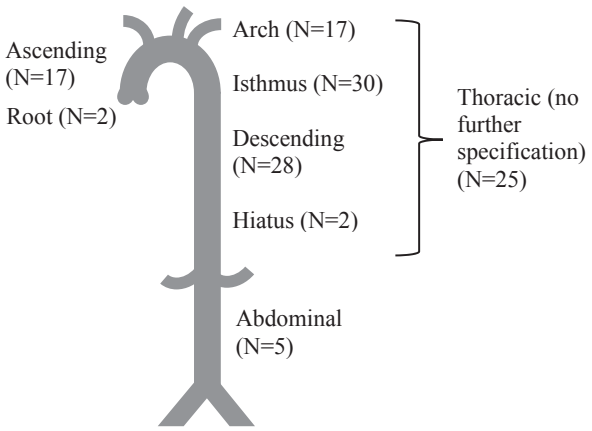

Fig 3. Location of aortic injury and the number of contributing studies reporting on nonoperative management of blunt thoracic aortic injury (BTAI).

a systolic blood pressure of less than 120 mm Hg using an intravenous beta-blocker as a first-line agent. With respect to maximum systolic blood pressure, the target of 120 mm Hg was most common (11 of 26 studies) followed by 100 to 110 mm Hg (6 studies), 130 to 140 mm Hg (4 studies), 90 mm Hg (1 study), and 160 mm Hg (1 study). The remaining four studies used a maximal mean arterial pressure target of 60 to 80 mm Hg. Other stated parameters for maximal target heart rate ranged from 60 to 90 and vasodilators (nitroprusside and hydralazine) were frequently cited second-line antihypertensive agents.

Follow-up. Of the 64 studies reporting a follow-up duration, 49 studies (77%) including 2356 patients provided follow-up information beyond the index hospitalization. The length of follow-up, including in-hospital, ranged widely from 1 day to 118 months. Because all but one study was retrospective, follow-up within individual studies varied widely as well (eg, 1-826 days, 3.1-79.0 months, 1-4 years).

Clinical outcomes. The overall in-hospital mortality among all patients with BTAI managed nonoperatively was 34% (n = 2853 of 8476), and the reported aortic-related mortality was 4.5% (39 of 866). A restricted set of 59 studies reporting aortic injury severity provided more reliable information on aorta-specific complications and clinical course. In these studies, a similar all-cause mortality (27%) and aortic-related mortality (4.5%) was identified (Table II). Because these studies used different injury severity classification systems, we standardized patients into two categories of SVS injury grades (I/II and III/IV) to derive a more meaningful interpretation of aortic injury healing, progression, or late intervention and aortic-related mortality. When doing so, injury healing or improvement was observed more frequently in grade I and II injuries (55 of 137 patients [40%]) than in grades III and IV injuries (9 of 28 patients [24%]) but, in both cases, occurred only in a minority of patients (Table III). Recognizing the aforementioned caveat that there was limited follow-up in many studies, injury progression and later intervention were very uncommon in grade I and II injuries (5 and 1 of 146 patients, respectively). In grade III and IV injuries, however, injury progression was as frequently reported as injury healing (Table III). Also more common than in grades I and II, late intervention was undertaken in 4 of 45 patients with grade III and IV injuries. (Table III). Aortic-related mortality was 18% in grade III and IV injuries and 1% in grade I and II injuries (Table III).

Pediatric patients. From four studies including 26 patients with blunt aortic injury 16 years old of younger, there were nine (35%) who were managed nonoperatively. Of the three studies reporting imaging modality, computed tomography angiography was the primary diagnostic modality in two studies, with angiography but not necessarily CT routinely performed in the third study. There were 4 grade I, 1 grade III, 1 grade IV, and 3 with an unspecified grade of aortic injury. There were four in-hospital deaths, of which one was aorta related in a grade IV injury. Of the five patients (40%) who survived their hospital stay, three did not have aorta-specific outcomes reported and the other two, with grade I intimal injuries, showed injury healing by 3 months and 2.6 years.

DISCUSSION

The present systematic review included 8606 patients with BTAI nonoperatively managed reported in 74 observational studies, of which only one was prospective. Our review found inconsistent reporting of aortic injury location, injury grade, and duration of follow-up. All-cause mortality was 34% with an aortic-related mortality of 4.5%, injury healing or improvement rate of 34%, and injury progression rate of 7.8%. Outcomes were better in less severe aortic injury grade.

The most frequently described reason for nonoperative management was minimal aortic injury. The current SVS guidelines regarding the management of BTAI suggest nonoperative management is only advised in grade I injury (intimal tear).[4] Based on our review, there are multiple additional anatomic criteria proposed for nonoperative management including: only intimal tears of less than 1 cm without the presence of an external contour abnormality, intramural hematoma, certain small pseudoaneurysms (<1 cm or <50% of aortic circumference or low ratio of diameter of the pseudoaneurysm to diameter of the aorta distal to the subclavian artery).[10-14] However, these criteria are based on a minority of patients with BTAI because 20% of studies including 87% of patients did not report aortic injury severity. Furthermore, differences in aortic injury severity grading

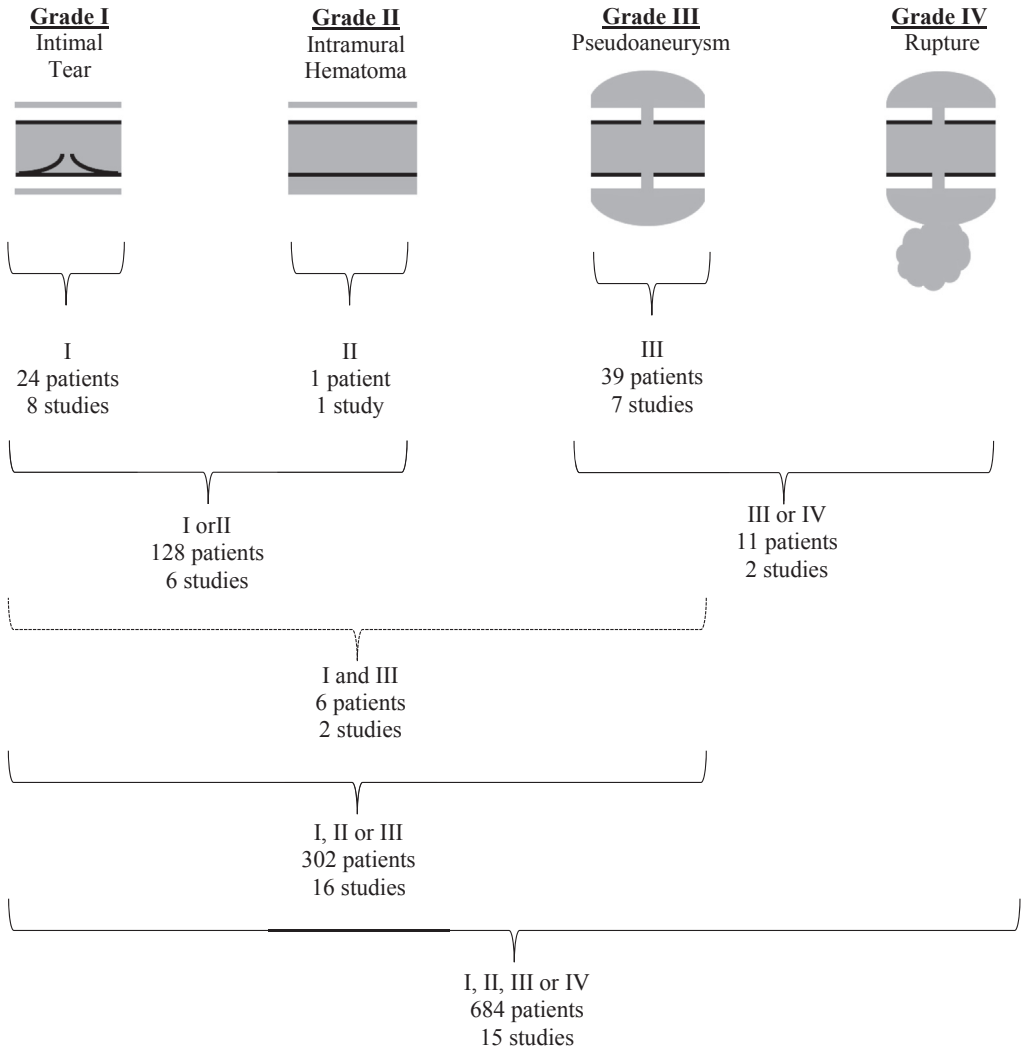

Fig 4. Schematic representation of patients' reported aortic injury grade among the 57 studies using the Society for Vascular Surgery (SVS) classification system or a compatible injury severity description.

Table II. Clinical course of nonoperative management of blunt thoracic aortic injury

Outcome	All 74 studies			Subgroup of 59 studies reporting aortic injury grade		
	No. of studies	No. of patients	Outcome frequency, % (No.)	No. of studies	No. of patients	Outcome frequency, % (No.)
In-hospital mortality	72[a]	8476	34 (2853)	57[a]	1120	27 (301)
Aortic-related mortality	55	866	4.5 (39)	37	827	4.5 (37)
Injury improvement/healing	38	674	34 (226)	37	673	34 (226)
Injury progression and/or late interventions	50	890	7.8 (69)	46	863	7.6 (66)

[a]Two studies were excluded: one did not report in-hospital mortality among patients managed nonoperatively; the other provided an in-hospital mortality rate of 27%, but did not provide a number of patients managed nonoperatively.

(eg, Vancouver Classification,[15] the Presley Trauma Center CT Grading System of Aortic Injury,[16] and other modifications of the current SVS grading system[12,17]) impede even a crude comparison of outcomes across studies that do characterize aortic injury grade. We put forward that a standardized injury grading system is critical to ongoing research efforts and that modification or additional caveats to the existing SVS grading should be considered to better guide patient selection for nonoperative management.

Table III. Clinical course of nonoperative management of blunt thoracic aortic injury by Society for Vascular Surgery (SVS) aortic injury grade[a]

Outcome	Grade I-II (patients managed nonoperatively)	Grade III-IV (patients managed nonoperatively)
In-hospital mortality	8.8 (9/103)	36 (18/50)
Aortic-related mortality	0.65 (1/153)	18 (9/50)
Injury improvement/healing	40 (55/137)	24 (9/38)
Injury progression	3.4 (5/146)	23 (9/39)
Late intervention	0.68 (1/146)	8.9 (4/45)

Values are presented as percent (n/N).
[a]Data drawn from selected studies where outcomes could be stratified by SVS injury grade categories.

It should also be highlighted that, in a significant proportion of patients, hemodynamic instability,[18] severe associated injuries such as severe traumatic brain injury,[18-20] comorbidities,[19] anatomic contraindications to open or endovascular repair,[20] and patient or family preference[20] were cited as indications for initial nonoperative management. Given that all studies but one were retrospective, the actual clinical determinants of management may differ from the reasons cited on retrospective publication.

Follow-up for nonoperative management of BTAI was also heterogeneous. This finding may reflect a lack of consensus on ideal follow-up duration, an inherent limitation of retrospective study design, or be partially attributable to poor compliance with follow-up in a young trauma population.[21] Despite the variable follow-up available, low injury progression rates and need for further intervention (7.8% overall and 3.4% in grades I-II), supports a generally favorable natural history with nonoperative management among grade I and II patients with BTAI. However, fairly low reported injury improvement and/or healing (34% overall, 40% for grades I-II) compared with the injury progression rates may also suggest that many low-grade injuries persist overtime. A justification for a more aggressive use of TEVAR in grade I and II injuries based on these data would require the assumption that there is an aortic-related mortality risk attributable to persistent low-grade injury. However, only one patient among 153 with a grade I or II injury suffered aortic-related mortality. Furthermore, there are also inherent, albeit low, short-term risks of thoracic endograft use to consider. Most clearly, these data reinforce that minimal aortic injuries managed nonoperatively intuitively require ongoing imaging follow-up.

Aortic-related mortality was reported in 9 of 50 patients (18%) with grade III or IV injuries and injury progression or late intervention were also frequent at 23% and 9%, respectively, in grades III or IV. These results suggest TEVAR should be considered in all higher grade injuries and justify TEVAR as the current standard of care for grade III and IV injuries.

This review highlights the limitations of existing data on the topic of nonoperative management of blunt thoracic aortic injury and underscores the fact that cautious interpretation of existing data should inform treatment decisions. Ultimately, a prospective multicenter registry with long-term follow-up will be best suited to provide an accurate description of the clinical outcomes of nonoperative management, as well as characterize the clinical and anatomic determinants of these outcomes. Such a registry is currently being accrued through the Aortic Trauma Foundation and, as of August 2018, includes 271 patients from 22 centers across North America.[22] This exciting initiative should offer unique insight into patient selection for nonoperative management as well as the duration and intensity of follow-up.[23]

CONCLUSIONS

Existing data on the nonoperative management of BTAI are derived from the study of highly selected patients with retrospective interpretation of the determinants of management. Variable reporting of aortic injury severity and variable follow-up significantly hinder the informed use of nonoperative management across all BTAI grades. Acceptable outcomes can only be cautiously inferred in intimal tears and intramural hematomas. However, additional caveats to current SVS aortic injury grading seem to be necessary and data from a multicenter, prospective registry by the Aortic Trauma Foundation should address gaps in our understanding of the role of nonoperative management in BTAI.

The authors thank Teruko Kishibe, Information Specialist at the Scotiabank Health Sciences Library, Li Ka Shing Knowledge Institute, St Michael's Hospital, Toronto, for her input and guidance with the database searches.

AUTHOR CONTRIBUTIONS

Conception and design: JB, KS, AK, MH, TF, MA, CM
Analysis and interpretation: JB, KS, CM
Data collection: JB, KS, CM
Writing the article: JB, CM
Critical revision of the article: JB, KS, AK, MH, TF, MA, CM
Final approval of the article: JB, KS, AK, MH, TF, MA, CM

Statistical analysis: Not applicable
Obtained funding: Not applicable
Overall responsibility: CM

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Submitted Sep 10, 2018; accepted Feb 5, 2019.

Additional material for this article may be found online at www.jvascsurg.org.

SUPPLEMENTARY APPENDIX (online only).

Database Search Strategy

Database: All Ovid Medline <1946 - present>.

Search Strategy:

1 Aorta, Thoracic/ (35029)
2 (thoracic adj4 aort*).tw,kf. (22835)
3 1 or 2 (46804)
4 Wounds, Nonpenetrating/ (21672)
5 blunt.tw,kf. (31183)
6 nonpenetrat*.tw,kf. (1429)
7 non-penetrat*.tw,kf. (1231)
8 5 or 6 or 7 (33471)
9 pseudoaneurysm*.tw,kf. (12431)
10 transection*.tw,kf. (19938)
11 dissection*.tw,kf. (114905)
12 rupture*.tw,kf. (123192)
13 disruption*.tw,kf. (140330)
14 intimal tear*.tw,kf. (811)
15 intimal flap*.tw,kf. (961)
16 intimal injur*.tw,kf. (368)
17 intramural h?ematoma*.tw,kf. (1791)
18 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 (399800)
19 8 and 18 (7025)
20 4 or 19 (25003)
21 3 and 20 (1112)
22 Aorta, Thoracic/in [Injuries] (2167)
23 (blunt adj1 aortic injur*).tw,kf. (141)
24 BTAI.tw,kf. (78)
25 minimal aortic injur*.tw,kf. (21)
26 21 or 22 or 23 or 24 or 25 (2595)
27 Practice Guidelines as Topic/ (112562)
28 treatment outcome/ (927398)
29 Endovascular Procedures/ (13724)
30 manage*.tw,kf. (1178821)
31 guideline*.tw,kf. (303412)
32 treatment*.tw,kf. (4227350)
33 (endovascular adj4 repair*).tw,kf. (11308)
34 TEVAR.tw,kf. (1327)
35 stent graft*.tw,kf. (8393)
36 delayed repair*.tw,kf. (733)
37 delayed treatment*.tw,kf. (2952)
38 nonoperative*.tw,kf. (11490)
39 non-operative*.tw,kf. (5468)
40 medical*.tw,kf. (1110419)
41 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 (6306739)
42 26 and 41 (1265)

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Database: EBM Reviews - Cochrane Central Register of Controlled Trials <November 2017>.

Search Strategy:

1 Aorta, Thoracic/ (149)
2 (thoracic adj4 aort*).ti,ab,hw. (433)
3 1 or 2 (433)
4 Wounds, Nonpenetrating/ (144)
5 blunt.ti,ab,hw. (1039)
6 nonpenetrat*.ti,ab,hw. (206)
7 non-penetrat*.ti,ab,hw. (95)
8 5 or 6 or 7 (1247)
9 pseudoaneurysm*.ti,ab,hw. (132)
10 transection*.ti,ab,hw. (289)
11 dissection*.ti,ab,hw. (4516)
12 rupture*.ti,ab,hw. (3866)
13 disruption*.ti,ab,hw. (2017)
14 intimal tear*.ti,ab,hw. (11)
15 intimal flap*.ti,ab,hw. (9)
16 intimal injur*.ti,ab,hw. (5)
17 intramural h?ematoma*.ti,ab,hw. (11)
18 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 (10652)
19 8 and 18 (81)
20 4 or 19 (219)
21 3 and 20 (1)
22 Aorta, Thoracic/in [Injuries] (1)
23 (blunt adj1 aortic injur*).ti,ab,hw. (2)
24 BTAI.ti,ab,hw. (2)
25 minimal aortic injur*.ti,ab,hw. (0)
26 21 or 22 or 23 or 24 or 25 (4)
27 Practice Guidelines as Topic/ (1390)
28 treatment outcome/ (111098)
29 Endovascular Procedures/ (263)
30 manage*.ti,ab,hw. (74140)
31 guideline*.ti,ab,hw. (17809)
32 treatment*.ti,ab,hw. (474473)
33 (endovascular adj4 repair*).ti,ab,hw. (480)
34 TEVAR.ti,ab,hw. (42)
35 stent graft*.ti,ab,hw. (181)
36 delayed repair*.ti,ab,hw. (19)
37 delayed treatment*.ti,ab,hw. (527)
38 nonoperative*.ti,ab,hw. (535)
39 non-operative*.ti,ab,hw. (339)
40 medical*.ti,ab,hw. (75444)
41 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 (542475)
42 26 and 41 (4)

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Database: Embase Classic+Embase <1947 to 2018 January 04>.

Search Strategy:

1 thoracic aorta/ (21568)
2 (thoracic adj4 aort*).tw,kw. (28957)
3 1 or 2 (36974)
4 exp blunt trauma/ (25061)
5 blunt.tw,kw. (37409)
6 nonpenetrat*.tw,kw. (1792)
7 non-penetrat*.tw,kw. (1711)
8 5 or 6 or 7 (40257)
9 pseudoaneurysm*.tw,kw. (15194)
10 transection*.tw,kw. (24000)
11 dissection*.tw,kw. (154219)
12 rupture*.tw,kw. (154557)
13 disruption*.tw,kw. (166117)
14 intimal tear*.tw,kw. (971)
15 intimal flap*.tw,kw. (1160)
16 intimal injur*.tw,kw. (475)
17 intramural h?ematoma*.tw,kw. (2367)
18 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 (499154)

19 8 and 18 (8911)
20 4 or 19 (29459)
21 3 and 20 (904)
22 aorta injury/ (2683)
23 (blunt adj1 aortic injur*).tw,kw. (171)
24 BTAI.tw,kw. (93)
25 minimal aortic injur*.tw,kw. (29)
26 21 or 22 or 23 or 24 or 25 (3266)
27 practice guideline/ (330247)
28 treatment outcome/ (771175)
29 exp endovascular surgery/ (29727)
30 manage*.tw,kw. (1522574)
31 guideline*.tw,kw. (433896)
32 treatment*.tw,kw. (5597471)
33 (endovascular adj4 repair*).tw,kw. (13869)
34 TEVAR.tw,kw. (1995)
35 stent graft*.tw,kw. (10314)
36 delayed repair*.tw,kw. (865)
37 delayed treatment*.tw,kw. (3918)
38 nonoperative*.tw,kw. (12588)
39 non-operative*.tw,kw. (7324)
40 medical*.tw,kw. (1536472)
41 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 (8155250)
42 26 and 41 (1685)
43 limit 42 to embase (1450)

Supplementary Table (online only). List of articles included in the review

First author	Publication year	Title	Journal	Oxford CEBM level of evidence
Akins	1981	Acute traumatic disruption of the thoracic aorta: a ten-year experience.	Annals of Thoracic Surgery	4
Aladham	2010	Traumatic aortic injury: computerized tomographic findings at presentation and after conservative therapy	Journal of Computer Assisted Tomography	4
Anderson	2008	Traumatic aortic injuries in the pediatric population.	Journal of Pediatric Surgery	4
Arthurs	2009	Functional and survival outcomes in traumatic blunt thoracic aortic injuries: an analysis of the National Trauma Databank.	Journal of Vascular Surgery	4
Azizzadeh	2011	The utility of intravascular ultrasound compared to angiography in the diagnosis of blunt traumatic aortic injury.	Journal of Vascular Surgery	4
Benjamin	2008	Blunt thoracic aortic injury.	American Surgeon	4
Caffarelli	2010	Early outcomes of deliberate nonoperative management for blunt thoracic aortic injury in trauma.	Journal of Thoracic & Cardiovascular Surgery	4
Cannon	2012	Open repair of blunt thoracic aortic injury remains relevant in the endovascular era.	Journal of the American College of Surgeons	4
Ching	2008	Endovascular repair in traumatic thoracic aortic injuries: comparison with open surgical repair.	Journal of Vascular & Interventional Radiology	4
Coppi	2012	Aberrant right subclavian artery in blunt aortic injury: implication for treatment and review of the literature.	Annals of Vascular Surgery	5
de Mestral	2013	Evolution of the incidence, management, and mortality of blunt thoracic aortic injury: a population-based analysis	Journal of the American College of Surgeons	4
DuBose	2015	Contemporary management and outcomes of blunt thoracic aortic injury: a multicenter retrospective study.	Journal of Trauma & Acute Care Surgery	3
Durham	2010	A contemporary rural trauma center experience in blunt traumatic aortic injury.	Journal of Vascular Surgery	4
Erdogan	2013	Traumatic aortic intramural hematoma.	Akademik Acil Tip Olgu Sunumlari Dergisi	5
Fabian	1998	Prospective study of blunt aortic injury: helical CT is diagnostic and antihypertensive therapy reduces rupture.	Annals of Surgery	3
Fattori	1998	Evolution of post-traumatic aortic aneurysm in the subacute phase: magnetic resonance imaging follow-up as a support of the surgical timing.	European Journal of Cardio-Thoracic Surgery	4
Fisher	1990	Conservative management of aortic lacerations due to blunt trauma.	Journal of Trauma-Injury Infection & Critical Care	4
Forcillo	2015	Outcomes of traumatic aortic injury in a primary open surgical approach paradigm.	Trauma Monthly	4
Forman	2013	Blunt thoracic aortic injuries: CT characterisation and treatment outcomes of minor injury.	European Radiology	4
Fortuna	2016	Injury grade is a predictor of aortic-related death among patients with blunt thoracic aortic injury.	Journal of Vascular Surgery	4
Gandhi	2016	Nonoperative management of grade III blunt thoracic aortic injuries.	Journal of Vascular Surgery	4

Supplementary Table (online only). Continued.

First author	Publication year	Title	Journal	Oxford CEBM level of evidence
Gombert	2017	Treatment of blunt thoracic aortic injury in Germany-Assessment of the TraumaRegister DGU.	PLoS ONE [Electronic Resource]	3
Gunn	2014	Minimal aortic injury of the thoracic aorta: imaging appearances and outcome.	Emergency Radiology	4
Heijmen	2001	Two-stage, delayed endovascular treatment of traumatic rupture of the thoracic aorta.	European Journal of Vascular & Endovascular Surgery	5
Heneghan	2016	Call for a new classification system and treatment strategy in blunt aortic injury.	Journal of Vascular Surgery	4
Hifumi	2013	Clinical experience with landiolol hydrochloride in conservative management of blunt aortic injury.	American Journal of Emergency Medicine	5
Hiller	2010	Aortic transection: demographics, treatment and outcomes in Victoria, Australia.	Emergency Medicine Journal	4
Hirose	2006	Nonoperative management of traumatic aortic injury.	Journal of Trauma-Injury Infection & Critical Care	4
Holmes	2002	Natural history of traumatic rupture of the thoracic aorta managed nonoperatively: a longitudinal analysis.	Annals of Thoracic Surgery	4
Hong	2011	The advent of thoracic endovascular aortic repair is associated with broadened treatment eligibility and decreased overall mortality in traumatic thoracic aortic injury.	Journal of Vascular Surgery	4
Karmy-Jones	2003	Management of traumatic rupture of the thoracic aorta in pediatric patients.	Annals of Thoracic Surgery	4
Kasirajan	2003	Acute thoracic aortic trauma: a comparison of endoluminal stent grafts with open repair and nonoperative management.	Annals of Vascular Surgery	4
Katsumata	1998	Operation for chronic traumatic aortic aneurysm: when and how?	Annals of Thoracic Surgery	5
Jepros	2002	Aortic intimal injuries from blunt trauma: resolution profile in nonoperative management.	Journal of Trauma-Injury Infection & Critical Care	5
Kidane	2012	Natural history of minimal aortic injury following blunt thoracic aortic trauma.	Canadian Journal of Surgery	4
Kidane	2013	Review of the management of blunt thoracic aortic injuries according to current treatment recommendations.	Annals of Vascular Surgery	4
Kwon	2002	Delayed operative intervention in the management of traumatic descending thoracic aortic rupture.	Annals of Thoracic Surgery	4
Lamarche	2012	Vancouver simplified grading system with computed tomographic angiography for blunt aortic injury.	Journal of Thoracic & Cardiovascular Surgery	4
Lang	2010	The limitations of thoracic endovascular aortic repair in altering the natural history of blunt aortic injury.	Journal of Vascular Surgery	4
Lebl	2006	Dramatic shift in the primary management of traumatic thoracic aortic rupture.	Surgery Today	4
Lin	2016	Blunt aortic injury: risk factors and impact of surgical approaches.	Annals of Vascular Surgery	4
Maggisano	1995	Traumatic rupture of the thoracic aorta: should one always operate immediately?	Annals of Vascular Surgery	4

(Continued on next page)

Supplementary Table (online only). Continued.

First author	Publication year	Title	Journal	Oxford CEBM level of evidence
Mak	2007	Case report of traumatic aortic disruption: a lethal injury requiring rapid and accurate diagnosis to lower mortality.	Hong Kong Journal of Emergency Medicine	5
Malgor	2013	Trends in clinical presentation, management, and mortality of blunt aortic traumatic injury over an 18-year period.	Vascular & Endovascular Surgery	4
Malgor	2015	Outcomes of blunt thoracic aortic injury in adolescents.	Annals of Vascular Surgery	4
Malgor	2015	The impact of blunt thoracic aortic injury on patients aged 80 years or older.	Acta Chirurgica Belgica	4
Malhotra	2001	Minimal aortic injury: a lesion associated with advancing diagnostic techniques.	Journal of Trauma-Injury Infection & Critical Care	4
Melton	2004	The evolution of chest computed tomography for the definitive diagnosis of blunt aortic injury: a single-center experience.	Journal of Trauma-Injury Infection & Critical Care	4
Mosquera	2011	Role of conservative management in traumatic aortic injury: comparison of long-term results of conservative, surgical, and endovascular treatment.	Journal of Thoracic & Cardiovascular Surgery	4
Mosquera	2012	Minimal traumatic aortic injuries: meaning and natural history.	Interactive Cardiovascular & Thoracic Surgery	4
Osgood	2014	Natural history of grade I-II blunt traumatic aortic injury.	Journal of Vascular Surgery	4
Pate	1999	Traumatic rupture of the aortic isthmus: program of selective management.	World Journal of Surgery	4
Paul	2011	Minimal aortic injury after blunt trauma: selective nonoperative management is safe.	Journal of Trauma-Injury Infection & Critical Care	4
Pezzella	1982	Nonoperative management of unusual blunt traumatic rupture of the thoracic aorta.	Texas Heart Institute Journal	5
Rabin	2014	Parameters for successful nonoperative management of traumatic aortic injury.	Journal of Thoracic & Cardiovascular Surgery	4
Reddy	2013	Grading system modification and management of blunt aortic injury.	Chinese Medical Journal	4
Reed	2006	Timing of endovascular repair of blunt traumatic thoracic aortic transections.	Journal of Vascular Surgery	4
Riesenman	2012	Acute blunt traumatic injury to the descending thoracic aorta.	Journal of Vascular Surgery	4
Rousseau	2005	Acute traumatic aortic rupture: a comparison of surgical and stent-graft repair.	Journal of Thoracic & Cardiovascular Surgery	4
Sandhu	2017	Determinants and outcomes of nonoperative management for blunt traumatic aortic injuries.	Journal of Vascular Surgery	4
Shackford	2017	The evolution of care improves outcome in blunt thoracic aortic injury: a Western Trauma Association multicenter study.	The Journal of Trauma and Acute Care Surgery	3
Spencer	2018	Nonoperative management rather than endovascular repair may be safe for grade II blunt traumatic aortic injuries: an 11-year retrospective analysis.	The Journal of Trauma and Acute Care Surgery	4

Supplementary Table (online only). Continued.

First author	Publication year	Title	Journal	Oxford CEBM level of evidence
Stampfl	2006	Mid-term results of conservative, conventional and endovascular treatment for acute traumatic aortic lesions.	European Journal of Vascular & Endovascular Surgery	4
Starnes	2012	A new classification scheme for treating blunt aortic injury.	Journal of Vascular Surgery	4
Steenburg	2008	Acute traumatic thoracic aortic injuries: experience with 64-MDCT.	American Journal of Roentgenology	4
Symbas	2002	Traumatic rupture of the aorta: immediate or delayed repair?	Annals of Surgery	4
Tagami	2015	Thoracic aortic injury in Japan–nationwide retrospective cohort study.	Circulation Journal	4
Tam	2012	Minimal injury of the descending aorta secondary to blunt trauma.	Injury	5
Tanizaki	2016	Blunt thoracic aortic injury with small pseudoaneurysm may be managed by nonoperative treatment.	Journal of Vascular Surgery	4
Ultee	2016	National trends in utilization and outcome of thoracic endovascular aortic repair for traumatic thoracic aortic injuries.	Journal of Vascular Surgery	4
Vignon	1995	Role of transesophageal echocardiography in the diagnosis and management of traumatic aortic disruption.	Circulation	4
Vignon	2005	Transesophageal echocardiography and therapeutic management of patients sustaining blunt aortic injuries.	Journal of Trauma-Injury Infection & Critical Care	4
Warren	1992	Acute traumatic disruption of the thoracic aorta: emergency department management.	Annals of Emergency Medicine	4
Wigle	1991	Spontaneous healing of a traumatic thoracic aortic tear: case report.	Journal of Trauma-Injury Infection & Critical Care	5