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ORIGINAL ARTICLE

Deceleration thoracic aortic ruptures in trauma center level I areas: a 6-year retrospective study

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Abstract

Objectives This retrospective study aimed to analyze the trend of mortality due to thoracic aortic ruptures caused by deceleration injuries that occurred within the catchment area of Hradec Kralove University Hospital.

Materials and methods The study sample comprised 175 patients who had sustained thoracic aortic ruptures caused by deceleration injuries and were transported to Hradec Kralove University Hospital in 2009–2014. The small proportion of patients enrolled in this retrospective study were diagnosed and treated at the emergency department (ED). However, the overwhelming majority of the sample comprised of patients who died at the accident scene and later underwent an autopsy at the Institute of Forensic Medicine in our hospital.

Results Of 175 patients, 150 underwent an autopsy. Of these, 139 individuals (79%) died at the incident scene, and 11 (6%) were transported to the ED and later died of their injuries. A total of 36 patients were admitted to the hospital; 29 were admitted primary (11 later died), and 7 were transferred. No deaths occurred in the group of secondary admissions. Thus, 31% of all patients hospitalized died following transport to the hospital. Of 175 patients, 15% (or 69% of all hospitalized patients) survived their injuries. Among patients who died as a result of thoracic aortic injury, no unexpected deaths were recorded (i.e., no deaths among patients with survival probability more than 50% = $PS > 0.5$).

Conclusion Our results suggested that the lethality of thoracic aortic injuries might be minimized by transporting triage-positive patients directly to trauma centers. Accurate diagnoses and treatments were supported by admission chest X-rays, a massive transfusion protocol, and particularly, CT angiography, which is not routinely included in primary surveys. An additional prognostic parameter was clinical collaboration between an experienced trauma surgeon, an interventional radiologist, and a vascular or thoracic surgeon.

Keywords Thoracic aorta · Deceleration injury · Mortality · Stent graft · Surgery

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Introduction

A deceleration rupture of the thoracic aorta is a severe, non-penetrating injury associated with high-energy collision. The majority of cases result from a traffic accident or a fall from a height [1]. The pre-hospital mortality is 75–90% [2–4]. Ruptures of the thoracic aorta are the second leading cause of traumatic death, after head injuries [5]. The basic mechanisms of the thoracic aorta rupture are blunt deceleration injuries or anteroposterior compression of the thorax with caudorostral hyperextension [6]. Traumatic rupture tends to occur at sites where the aorta is attached to other tissues. Although any portion of the aorta may be involved in a rupture, about 50–90% of the lesions comprise a transverse tear at the level of the isthmus of the aorta, immediately distal to the left subclavian artery [7, 8]. Aortic lacerations in the area of the isthmus are attributed to shear force, which results from a differential rate of deceleration between the arch and the descending aorta [7]. The other potential sites of aortic injury include the ascending aorta, the origin of the truncus brachiocephalicus, and the descending aorta at the level of the diaphragm [5]. A complete transection of the aortic wall is associated with an extremely high mortality rate [8]. Once transported to the hospital, patients have a greater chance of survival, with rapid diagnostics and subsequent conservative or endovascular therapy. Survival probability (SP) decreases in patients that require emergency surgical procedures, and it is also influenced by concomitant injuries, which most often include other serious injuries of the chest and abdomen.

Deceleration thoracic aortic traumas were evaluated in the University Hospital of Hradec Králové 20 years ago in the Forensic and Cardiovascular surgery departments. Hazuková et al. published an incidence analysis of traumatic aortic ruptures that occurred in traffic accidents from 1994 to 1997 [9]. In 2007, authors from the radiology clinic published initial 5-year results of treatments with endovascular stent grafts (in use since 1999); they showed that minimally invasive, rapid stabilization of the aorta enabled further treatment of associated injuries [10].

The present retrospective study aimed to analyze the 6-year trend in mortality due to thoracic aortic trauma caused by deceleration injuries that occurred within the catchment area of the Hradec Králové University Hospital. We also aimed to compare our results to previous findings from the above-mentioned works from the same region. This study included data on all patients from our catchment region with deceleration thoracic aortic traumas; we included all patients who received treatment at any department of our hospital, and all individuals who died on the scene and were taken directly to the Forensic Medicine department.

Materials and methods

This retrospective study is aimed to analyze the trend of mortality due to thoracic aortic ruptures caused by deceleration injuries that occurred within the catchment area of Hradec Králové University Hospital where there are approximately 1 million inhabitants. Patients who survived were transported directly to the emergency department of our hospital. A few patients also came from smaller hospitals in our region after diagnosis of thoracic aortic rupture. Patients who died at the scene were transported to the Institute of forensic medicine which is also part of our hospital. Because of the legal obligation to perform an autopsy for each death due to injury, we believe we were able to capture all the thoracic aortic injuries from our region during the given period.

Patients

The study sample comprised of 175 patients with deceleration trauma-related thoracic aortic ruptures that were transported to the Hradec Králové University Hospital from 2009 to 2014. We reviewed all blunt thoracic aorta injuries with a diagnosed aortic disruption. One criterion for including the case into the study was that the thoracic aorta rupture was associated with a deceleration injury of the chest. A deceleration injury is defined as a motion injury, where the body is forcibly stopped, but the contents of the body cavities remain in motion due to inertia. All patients were included in the study, whether they died at the scene, died in the hospital, or survived the injury. For patients who survived in the Emergency Department (ED) of University Hospital in Hradec Králové, the diagnosis of deceleration thoracic aortic injury was established during investigation of the injuries. In the group of deceased patients, the deceleration thoracic aortic injury was revealed during autopsy, performed in the Department of Forensic Medicine of the University Hospital in Hradec Králové. The study population was divided into two groups: patients who died and patients who survived. In all cases, we collected data on age, gender, type (partial or complete) of rupture, localization of the aortic rupture, and the mechanism of injury. In the group of deceased patients, we assessed the degree of atherosclerosis of the aorta. One of the main sources of data was the chest X-ray. All patients that were triage positive and were transported to our ED underwent a chest X-ray during the admission examination [11].

Radiological signs of aortic injury on a plain anteroposterior image were defined as any of the following: mediastinal width > 80 mm; blurred aortic arch; obliterated aortopulmonary window; presence of an apical cap; depressed left main bronchus; elevated right main bronchus; tracheal deviation to the right; nasogastric tube deviation to the right; and left-sided fractures of the first and second ribs (Fig. 1). Suspected mediastinal hematoma, or other radiographic signs of thoracic aortic injury were indications for computed tomographic angiography (CTA) with a contrast agent bolus [12, 13]. The thoracic aorta CTAs was evaluated by experienced radiologists; based on those results, and after consulting an interventional radiologist, patients were referred for endovascular treatment. Treatment timing depended on the patient's overall condition, associated injuries, and the type of aortic injury.

Other studied parameters included the time interval from injury to admission at the ED and injury severity, according to the Revised Trauma Score (RTS) and Abbreviated Injury Scale (AIS) [14]. The combination scoring system known as the Trauma–Injury Severity Score

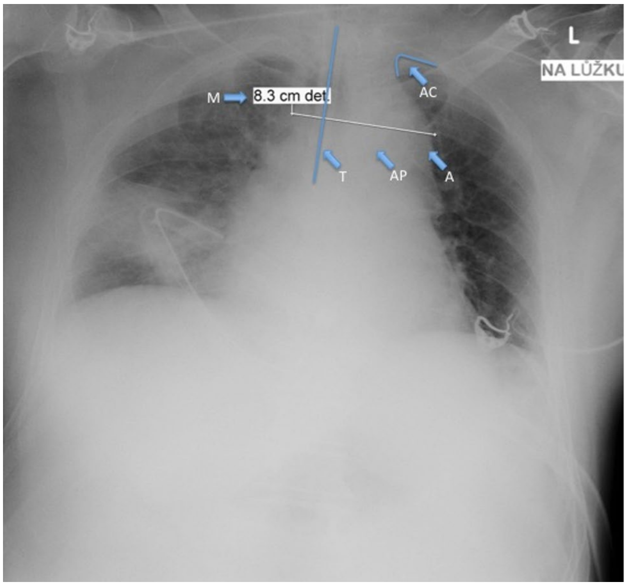

Fig. 1 The most common X-ray signs of thoracic aortic injury. *A* blurred aortic arch, *AP* obliterated aortopulmonary windows, *M* mediastinal width > 8 cm, *T* tracheal deviation to the right, *AC* apical cap

(TRISS) was used to evaluate the SP [15]. Unexpected survival and unexpected death were analyzed in detail. In addition to these parameters, we examined intensive care unit lengths of stay, total hospitalization duration, and treatment complications. In cases of death, we also studied the time interval from injury to death, the cause of death, and the autopsy findings of the thoracic aorta.

Endovascular therapy

Endovascular treatment was performed under fluoroscopic guidance in a standard angiography suite (Allura Xper FD 20, Philips, the Netherlands). The procedure was performed with the patient in the supine position, under general anesthesia, with antibiotic prophylaxis. Percutaneous access technique for stent graft insertion was used in all cases. After right femoral artery puncture under ultrasound navigation, we placed a 0.035-in. × 300-cm stiff Back-up Meier guidewire (Boston Scientific, Boston, MA, USA) in the aortic arch. The distal part of wire was manually bent according to the aortic arch angulation. A calibrated pigtail catheter was then introduced via the left femoral or left brachial artery, and a calibrated aortic arch angiography was performed. Under fluoroscopic guidance, a stent graft was subsequently deployed to cover the aortic lesion in the left anterior oblique projection and after reducing the mean arterial pressure to 70 mmHg. The final angiogram was perfomed to confirm stent graft position, in relation to the left subclavian artery and to exclude endoleak. Closure technique with two

Table 1 Basic characteristics of patients with deceleration thoracic aortic ruptures

$n = 175$	Non-survivors $n = 150$ (86%)	Survivors $n = 25$ (14%)
Mean age, year ± SD	49.2 ± 19.48	42.3 ± 16.84
Men, *n* (%)	118 (78.7)	19 (76.0)
Women, *n* (%)	32 (21.3)	6 (24.0)

Perclose ProGlide 6F (Abbott Vascular, Rewood City, CA, USA) was used to reach the access site hemostasis of femoral artery. In accordance with our standard protocol, a CTA examination of the thoracic aorta was performed on the 5th post-operative day; then again during the 3rd and 6th post-operative months; and finally, annually thereafter [10].

Statistical analysis

A basic statistical analysis, including graphic and tabular data processing, was performed with Microsoft Excel® (Microsoft Corp., Redmond, WA, USA). In specific cases, the SP was expressed as an odds ratio (OR), when comparing results obtained for individual groups. The statistical analysis was performed with Fisher's test, and significance levels were set to $P < 0.05$, $P < 0.01$, and $P < 0.001$. GraphPad Prism version 5.00 (GraphPad Software, San Diego, CA, USA, https://www.graphpad.com) was used for all data analyses.

Results

The study sample comprised 175 individuals (137 men and 38 women) with a mean age of 48 years (range 17–87) (Table 1). A total of 150 patients died (139 at the incident scene, and 11 after transport to the hospital) and 25 patients survived. The most common cause of injury was a motor vehicle accident (occupant; $n = 82$, 59%). In 27 cases, pedestrians or cyclists were struck by a vehicle (19%). In 19 (14%) cases, the cause of injury was falling from a height. Less frequent causes of injury included impacts with a train ($n = 7$, 5%) or falling masonry ($n = 4$, 3%) (Table 2). A total of 32 radiographs were evaluated (Figs. 2, 3). Four patients did not receive X-ray examinations, because they died during uninterrupted CPR. Of the studied radiographic parameters, blurred aortic arch and obliterated aortopulmonary window were the most frequently recorded (both 59%), followed by a mediastinal width > 8 cm (56%). The greatest recorded number of concomitant signs was five, observed in two patients (6%); conversely, four patients (12%) had no signs. The most common number (highest incidence) recorded was three concomitant signs of thoracic aortic injury, observed in

Table 2 Mechanisms of deceleration thoracic aortic ruptures

Mechanism of injury	Death at scene $n=139$ (79%)	Death at hospital $n=11$ (7%)	Survivors $n=25$ (14%)
Fall from height	19 (14)	3 (27)	4 (16)
Struck by vehicle	27 (19)	–	2(8)
Struck by train	7 (5)	–	–
Crushed by masonry	4 (3)	–	1 (4)
MV accident	82 (59)	7 (64)	17 (68)
Other	–	1 (9)	1(4)

Values represent the number (%) of individuals in each group

MV motor vehicle

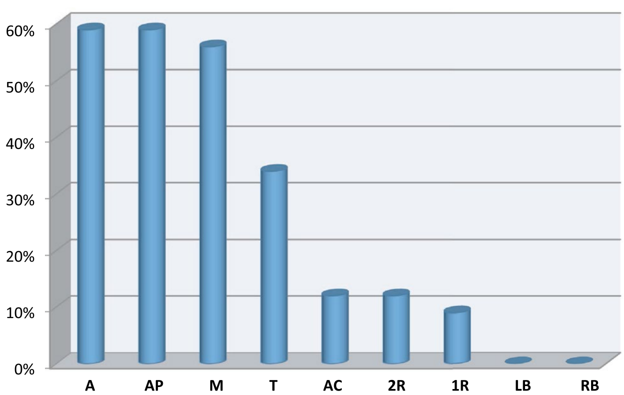

Fig. 2 Proportions of individual X-ray signs of thoracic aortic injury (in-hospital patients, $n=32$). *A* blurred aortic arch, *AP* obliterated aortopulmonary windows, *M* mediastinal width > 8 cm, *T* tracheal deviation to the right, *AC* apical cap, *2R* fracture of second rib on left side, *1R* fracture of first rib on left side, *LB* left bronchus depression, *RB* right bronchus depression

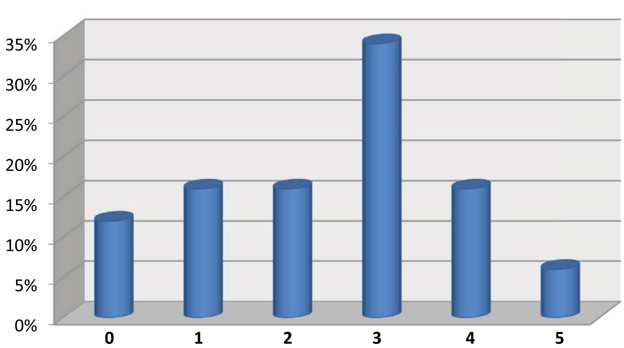

Fig. 3 Proportions of patients with the indicated number of X-ray signs of thoracic aortic injury (in-hospital patients, $n=32$)

11 (34%) patients. In the survivor group, six patients (24%) with deceleration injury thoracic aortic ruptures were managed conservatively, and a verification CTA was performed within 24 h of admission. Another 19 patients (76%) underwent endovascular interventions; of these, 8 (32%) required partial or complete coverage of the left subclavian artery and 2 patients (8%) had absent peripheral pulses without functional or neurologic deficits. No other health complications were observed in patients with a primary diagnosis of thoracic aortic trauma.

In patients that were primary admitted (directly from the incident), the mean time from injury to admission to the ED was 77 min (range 35–323), and the mean ED length of stay was 56 min (range 6–121). In interhospitaly transfered patients (secondary admitted after initial assessment in another hospital), the mean time from injury to admission to the primary medical facility was 68 min (range 35–108), and the mean time from injury to admission to our ED was 355 min (range 140–942). All secondary transported patients were transferred by clinicians at the primary medical facility, after CT angiography revealed a thoracic aortic rupture. The mean Injury Severity Score (ISS) was 36 (range 25–57; med. 36; IQR 10.5) for survived patients, and the mean chest AIS score was 4.4 (range 4–5; med. 4; IQR 1). Clear differences in these values were observed between the non-survivors and the survivors, and between patients admitted primary and transferred patients (Table 3). The non-survivors had higher regional injury severity scores and overall severity scores, compared to the non-survivor group. Primary admitted patients had higher overall injury severity scores than transferred patients. In the survivor group (25 patients), the mean duration of hospitalization was 34 days (range 4–104). The mean SP for this group was 73.5 ± 28%, and four patients had an SP < 50%. The mean SP for the 11 patients that died after admission was 16.2 ± 27.9%. Deceleration rupture of the ascending thoracic aorta was found in 36 cases (21%). Of these, 17 (47%) patients were deceased and 19 (53%) patients were survivors. Rupture of the aortic arch was described in 29 cases (17%); of these, four patients (16%) survived. Rupture of the descending thoracic aorta was recorded in 87 cases (50%); of these, only one patient (1%) survived. We found 23 cases (13%) of multiple disruptions of the thoracic aorta; only one patient (4%) survived this type of injury. Multiple injuries of the thoracic aorta were most often associated with death at the scene (22/96%). Similarly, ruptures of the descending aorta (80/93%) and injuries of the aortic arch (22/73%) were significantly related to high pre-hospital mortality. Only 15 patients (42%) with ascending aorta traumas died at the scene. A complete transection of the aorta was found in 78 (52%) individuals that died. An incomplete (partial) rupture of the aorta was recorded in 72 (48%) individuals that died. In the deceased group, first-degree atherosclerosis of the aorta was found in 80 cases (53%); second-degree aortic atherosclerosis was found in 33 cases (22%); and third-degree aortic atherosclerosis was found in 37 cases (25%). There was no significant

Table 3 Chest Abbreviated Injury Scale (AIS) score and overall Injury Severity Score (ISS) of patients hospitalized with deceleration thoracic aortic ruptures

Severity of injury $n=36$	Death in hospital $n=11$	Total survivors $n=25$	Primary admitted $n=18$	Interhospitaly transferred $n=7$
AIS chest				
Median/IQR	5/1	4/1	4/1	5/0
Average/min–max	5.09/4–6	4.4/4–5	4.22/4–5	4.86/4–5
ISS overall				
Median/IQR	66/25	36/10.5	50/22	33/16
Average/min–max	63.64/50–75	37.92/25–57	39.55/25–57	33.71/25–50

Patients that survived were divided into groups of primary or secondary admissions (interhospitaly transfered)

IQR interquartile range

relationship between the degree of atherosclerosis and the type or localization of the rupture.

Discussion

In the Czech Republic, the most frequently encountered aortic injuries are the result of blunt deceleration forces (e.g., motor vehicle accidents and falls from heights), and they are mostly complicated with other concomitant injuries. The mechanisms and structures of these injuries impose a heavy burden on the clinician in identifying treatment priorities and methods, and determining the timing of therapeutic and diagnostic procedures. Higher mortality can be expected from descending aortic injuries and from multiple aortic ruptures. Increased use of safety belts and airbag implementation over the last few decades have led to a reduction in head-on collisions that cause fatal thoracic aortic transections; however, a complete descending aortic transection after a side-impact motor vehicle crash has been associated with the greatest risk of death [16, 17].

We compared our results from a sample of 175 patients to the results from a previous study with patients from the same catchment region who were treated at our hospital from 1994 to 1997. During the previous study, all patients died, 89 traffic fatalities (occupants) occurred at the incident scene, and nine patients died after admission, but they were not diagnosed with or treated for thoracic aortic rupture [9]. During the 6-year period analyzed in the present study, 82 traffic fatalities (occupants) occurred at the incident scene and 24 patients were transported to the ED. Of those 24 patients, 7 died shortly after admission, but 57% had received some treatment prior to death, and the diagnosis was made antemortem. The remaining 17 patients diagnosed with thoracic aortic injury survived and were successfully treated with endovascular stent grafting (76%) or conservative procedures (24%).

Our traumatology department performs anteroposterior chest radiographs for every patient that is triage positive [11]. Radiographic assessment is often complicated by poor image quality, image rotation, and failure to capture the entire volume of the lung. When a thoracic aortic injury is suspected, the detection of a mediastinal hematoma is crucial. Although radiographic sensitivity in detecting mediastinal hematomas is high (up to 95%), its specificity is very low [18]. Mediastinal hematomas can also be caused by a thoracic spinal injury, bleeding from mediastinal venous structures, or, for example, a sternal fracture. The CTA is indicated to confirm or rule out mediastinal hematomas and when other radiographic signs of thoracic aortic injury are present. However, the negative predictive value of chest radiographs is up to 98% with normal findings; i.e., normal chest radiograph findings indicate minimal probability of thoracic aortic injury [19, 20]. We consider chest radiography to be absolutely essential during the initial stabilization and diagnostic phase. In addition to detecting signs of mediastinal injury, it also enables the detection of numerous other life-threatening conditions. An evaluation of mediastinal widening alone is not sufficient to diagnose aortic injuries. It is necessary to take into account the position of the patient's body and the distance from the X-ray tube and cassette. The mediastinal-width to chest-width (M/C) ratio is (in addition to other signs of injury) a reliable guide for diagnosing aortic injuries. Some studies have reported an M/C ratio of 0.25, with up to 95% sensitivity and 75% specificity; and one study reported an M/C ratio of 0.28 with 100% specificity, but only 79% sensitivity. However, in the present study sample, radiographic imaging did not reveal any sign of thoracic aortic injury in several patients. For this reason, in patients with deceleration injuries, when the patient's condition permits, a CTA examination should be incorporated into the differential diagnosis [13, 19, 21].

Given the potential for negative CTA findings upon patient admission, the bleed source may not be identified at first, but it may later become apparent after achieving adequate volume therapy and after hemostasis of other major bleeding sources. Consequently, clinicians should consider (in indicated cases) whether a repeat CTA exam might be actually preferable to a control ultrasound. In our group, we recorded two cases of thoracic aortic ruptures that were not detected until the autopsy. The first patient was a man with severe cranio-cerebral trauma, who died 4 days after the injury. The second patient died due to bleeding from the expanding retroperitoneal hematoma into the left hemithorax caused by the aberrant renal artery. The thoracic aortic rupture was not apparent even during the operative revision of left hemithorax. In both cases, it was a partial rupture that would require only conservative treatment. Both patients will be discussed in more detail in the following paragraphs.

Extracorporeal circulation, which is necessary for surgical treatment of thoracic aortic rupture, is very risky in patients with concomitant injuries of the pelvis, extremities, brain and in patients with potential abdominal injuries. Among patients with an established diagnosis of a deceleration thoracic aortic rupture, SP is higher in those that have undergone endovascular stent grafting [1, 22]. Most ruptures are located in the aortic arch and descending aorta; therefore, it may be difficult to anchor the stent graft, due to the risk of possible obstruction of arterial branches that stem from the aorta. As a result of accumulated experience, these complicated indications could be treated at our facility. Two patients in our sample underwent combined surgical and endovascular treatment. In the first case, a rupture in the dorsomedial aspect of the aortic arch required a more proximally placed stent graft; therefore, a left subclavian-to-left common carotid artery transposition was performed first. After stenting, which covered the arteria lusoria, and based on the patient's good overall condition, the surgeons decided to transpose the arteria lusoria to the right common carotid artery. The patient survived without complications from the aortic injury or from the surgical intervention. In the second case, stenting was followed by left subclavian artery (LSA) transposition only. An additional six patients also received stenting with LSA coverage, after monitoring, these patients showed no signs of ischemia, innervation disorders, or impaired left upper limb mobility.

Continual improvement in the quality of diagnostic and therapeutic procedures has led to reduced mortality among patients with deceleration thoracic aortic traumas; however, mortality has not been eliminated. Eleven patients that were transported to the ED died an average of 16 h and 30 min after admission (range 0:52–115:29). The longest admission-to-death interval was observed in a patient that died of severe cerebral contusion. The remaining ten patients died due to traumatic hemorrhagic shock. Of these, five died as a direct result of severe thoracic aortic injuries and died shortly after admission, during permanent CPR (three had undergone an emergency thoracotomy), and had a mean injury to death interval of 1 h and 46 min (range 0:52–2:49). The other five had been diagnosed with severe associated injuries, particularly in the abdomen, and we found only one patient who died, despite a SP > 50% (SP = 85%). This patient died due to a retroperitoneal hematoma that burst into the left pleural cavity; the hematoma occurred due to massive bleeding from an aberrant renal artery, and it had not been detected on the admission CTA. In this case, the thoracic aortic injury was not life threatening, and it was not visible on the admission CTA, or even during surgical exploration of the left hemithorax. An autopsy showed a 1.5-cm partial aortic arch rupture. Another patient, with an SP of 49%, had extensive injuries of the liver and right adrenal gland. This patient was admitted nearly 3 h after injury, and after sequential treatment from four different ground ambulance crews. Finally, the patient was transported via air ambulance to our trauma center. Based on the CT results, he was transported to the operating room, where he was repeatedly resuscitated, but subsequently died. A third patient, with an SP of 31%, died of a severe cerebral contusion 5 days after admission (see above paragraph). The admission CTA did not detect an aortic rupture, but the autopsy revealed a 2.5-cm partial descending aortic dissection, located 5 cm distal to the arch. The remaining two patients in this group had a mean SP of 1.56% (range 0–6.6%).

Previous studies have reported that 71–88% of deceleration thoracic aortic injuries resulted in deaths at the incident scene [1, 23–25]. Post-admission mortality rates were reported to be up to 33%, but a prospective study, conducted in 2007 in the USA, reported only 13% mortality [1]. A detailed analysis of that study revealed very strict inclusion criteria. When we applied those criteria to our sample, we had to exclude 4 patients transported during uninterrupted CPR; the resulting lethality rate was then 22% (7 fatalities out of 32 patients hospitalized). If we also excluded the 4 patients who did not die as a result of thoracic aortic injury (determined by autopsy), the lethality rate would have been even further reduced to 11% (3 of 28 patients). The decreasing trend in mortality due to this type of trauma was also evident in other studies, and it is largely associated with the use of endovascular therapy. Surgical intervention has been recommended for patients that are hemodynamically unstable, has complicated ruptures that are incompatible with endovascular therapy, or requires a combined procedure with extensive stent grafts [1, 2, 22, 26, 27]. Our experience supported these recommendations.

Conclusion

The present study, and comparisons with data from earlier studies in our facility, showed that clear progress has been made in the diagnosis and therapy of traumatic thoracic aortic ruptures and survival (even in patients with severe associated injuries). During the previous study from 1994 to 1997, all patients died but they were not diagnosed with or treated for thoracic aortic rupture. In our study sample, there were no deaths due to unrecognized thoracic aortic injury.

Our findings suggested that death from thoracic aortic injuries might be minimized by providing patients that are triage-positive primary transportation directly to appropriate trauma centers. Accurate diagnoses and treatments were supported by admission chest X-rays, a massive transfusion protocol, and particularly CTA, which are not routinely included in primary surveys. Another prognostic parameter was clinical collaboration between an experienced trauma surgeon, an interventional radiologist, and a vascular or thoracic surgeon. It can be assumed that continued improvement of trauma systems will lead to an increase in primary transportation directly to trauma centers for patients with severe injuries (including those with thoracic aortic trauma). However, an increase in patient numbers in the ED will increase the demands placed on experienced trauma teams, and it will increase the demand for quality diagnostics and treatments that require medical equipment and qualified staff.

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Compliance with ethical standards

Conflict of interest The author(s) declare that they have no competing interests.

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