

Outcomes of Traumatic Aortic Injury in a Primary Open Surgical Approach Paradigm

Jessica Forcillo¹; Michel Philie²; Andrea Ojanguren²; Soazig Le Guillan³; Alain Verdant^{1,3}; Philippe Demers^{1,3,4}; Yoan Lamarche^{1,3,4,5,*}

¹Division of Cardiovascular Surgery, Sacre-Coeur Hospital of Montreal, Montreal, Canada

²Division of Radiology, Sacre-Coeur Hospital of Montreal, Montreal, Canada

³Division of Traumatology/General Surgery, Sacre-Coeur Hospital of Montreal, Montreal, Canada

⁴Department of Cardiac Surgery, Montreal Heart Institute, University of Montreal, Montreal, Canada

⁵Critical Care Medicine, Sacre-Coeur Hospital of Montreal, Montreal, Canada

*Corresponding author: Yoan Lamarche, Department of Cardiac Surgery, Montreal Heart Institute, 5000 Rue Belanger, Montreal, Quebec, HIT 1C8, Canada. Tel: +514-3763330, Fax: +514-5932157, E-mail: yoan.lamarche@umontreal.ca

Received: February 24, 2014; Revised: June 28, 2014; Accepted: July 12, 2014

Background: Multiple classifications can be used to define the magnitude of aortic injury. The Vancouver Classification (VC) is a new and simplified computed tomography-based Blunt Aortic Injury (BAI) grading system correlating with clinical outcomes.

Objectives: The objectives of this study are: 1) to describe the severity of aortic injury in a center with a predominantly surgical approach to BAI; 2) to correlate the severity of aortic trauma to hospital survival rate and rate of adverse events according to the type of interventions performed during the hospital stay; and 3) to evaluate VC.

Patients and Methods: All patients referring to the Sacre-Coeur Hospital of Montreal between August 1998 and April 2011 for management of BAI were studied. Two radiologists reviewed all CT scan images individually and classified the aortic injuries using VC.

Results: Among the 112 patients presenting with BAI, 39 cases had local CT scans available for reconstruction. Seven patients were identified as suffering from grade I injuries (flap or thrombus of less than 1 cm), 6 from grade II injuries (flap or thrombus of more than 1 cm), and 26 from grade III injuries (pseudoaneurysm). Among the patients with grade I injuries, 57% were treated surgically and 43% medically with a survival rate of 100%. Among the patients with grade II injuries (67% treated surgically and 33% treated medically) survival was also 100%. Among patients with grade III injuries (85% treated surgically, 7% had Thoracic Endovascular Aortic Repair (TEVAR) and 8% treated medically) survival was 95%, 95% and 50%, respectively. There were no significant differences between groups as to clinical outcome. Inter-rater reliability was 0.81.

Conclusions: VC is easy to use and has low inter-observer variability. Low grades of injury were associated with low mortality related to medical treatment.

Keywords: Thoracic Aorta; Trauma; Assessment Patient Outcomes

1. Background

Blunt aortic injury (BAI) occurs in less than 1% of motor vehicle crashes, but is responsible for 16% of all related deaths (1). Traditional views have held that a sudden deceleration causes a tear at the junction between the fixed and mobile portions of the aorta, usually near the isthmus, a common injury site among survivors (2). However, injury may also occur in the ascending aorta, the distal descending aorta, and the abdominal aorta (3, 4). The typical sequence of injury in patients presenting in stable condition involves the rupture of the intimal and medial layers, followed by the rupture of the adventitial aortic wall (5, 6). Among the surviving patients admitted to the hospital, 30% will die within the first 24 hour if the BAI is left untreated (7).

For more than 40 years, aortography has been the gold standard in identifying BAI, as established by the land-

mark study by Parmley et al. (5). However, this technique is invasive. With advances in imaging techniques in the last 10 years, computerized tomographic angiography (CTA) has now been accepted as the diagnostic test of choice with a reported sensitivity between 94–100% (8, 9).

There are multiple classification systems that can be used to evaluate the severity of traumatic aortic injury including the Presley trauma center CT grading system of aortic injury (10), Simeone's classification (10, 11), and Azzadeh's classification (12). More recently, two groups from Seattle and Vancouver have developed a similar classification system for evaluating the extent of aortic injury (13, 14) (Table 1). In the two former classifications by Gavant (10) and Simeone (11), no description of patient outcomes was provided. Indeed, most classifications

are descriptive, but authors traditionally suggest potential therapeutic strategies based on the extent of injury. Guidelines tend to advocate the medical management of low-grade lesions and an endovascular or surgical treatment for patients with higher-grade lesions. Few studies have reported outcomes based on scores developed in other centers or on the application of a score followed by the implementation of a different treatment algorithm. It is in this context we sought to validate a recently developed CT score in a tertiary referral center with a primary open surgical strategy for severe traumatic aortic injuries. The Vancouver classification (VC) will be used to describe aortic injuries observed on chest CTAs done on admission after trauma.

2. Objectives

The aim of this study was: 1) to describe the severity of aortic trauma in a tertiary high volume traumatic aortic injury center; 2) to evaluate the use of VC by different radiologists; and 3) to identify predictors of adverse

outcomes based on aortic injury severity and treatment strategy (medical, open surgical, or endovascular).

3. Patients and Methods

All patients referring with traumatic aortic injuries to the Sacre-Coeur Hospital of Montreal, a level 1 trauma center, between August 1998 and April 2011, were identified by reviewing records in the hospital trauma database. Information regarding patient demographics, mechanism of injury, associated injuries, injury severity score (ISS), number of transfusions, management and outcomes were collected from medical charts and from trauma and blood bank databases. The primary outcome of interest was the reproducibility of use of VSS. Secondary outcomes of interest were intubation time, intensive care unit (ICU) length of stay (LOS), hospital LOS, number of red blood cells (RBC) transfusions, acute renal failure (ARF), myocardial infarction (MI), delirium, ventilator associated pneumonia (VAP), and new onset of paraplegia based on severity of injury.

Table 1. The Classification Systems

	Vancouver	Seattle	Azizzadeh et al. (12)	Simeone et al. (11) (Isthmus Only)	Gavant et al. (10)
Grade 1	Intimal flap, thrombus or intramural hematoma <1 cm	No aortic external contour abnormality; tear and/or associated thrombus less than 10 mm	Intimal tear	Intimal irregularity <1 cm with minimal periaortic hematoma	A: Normal Aorta, no mediastinal hematoma B: Normal Aorta, mediastinal hematoma (para-aortic)
Grade 2	intimal flap, thrombus or intramural hematoma >1 cm	No aortic external contour abnormality; tear and/or associated thrombus is more than 10 mm	Intramural hematoma	Intimal flap > 1 cm with or without pseudoaneurysm	A: Minimal Aortic injury, small (<1 cm) pseudoaneurysm, flap or thrombus, no mediastinal hematoma B: Minimal Aortic injury, small (<1 cm) pseudoaneurysm, flap or thrombus, mediastinal hematoma (para-aortic)
Grade 3	Pseudoaneurysm (simple or complex, no extravasation)	Aortic external contour abnormality: contained	Aortic pseudoaneurysm	Circumferential or near-circumferential disruption, "shattered" isthmus	A: >1 cm easily identified regular, well-defined pseudoaneurysm with intimal flap or thrombus; No ascending aorta, arch, or great vessel involvement; mediastinal hematoma present B: >1 cm easily identified regular, well-defined pseudoaneurysm with intimal flap or thrombus; Ascending aorta, arch, or great vessel involvement present; mediastinal hematoma present
Grade 4	Contrast Extravasation (± Pseudoaneurysm)	Aortic external contour abnormality: not contained, free rupture	Free rupture	Active contrast extravasation, pseudoocclusion, dissection/ischemia	Total aortic disruption; Easily identified, irregular, poorly defined pseudoaneurysm with intimal flap or thrombus; mediastinal hematoma present

3.1. Imaging Technology

Two radiologists reviewed all single and multi-detector CT scans individually and classified the aortic injuries using VC. A self-administered tutorial included in the original Vancouver report was used prior to evaluating local CTs (Figure 1; Table 1). Over a 10-year period, two different CT scanner technologies were employed: the Picker PQ 5000 (single detector) before July 2006 and the GE Ultra-light speed VCT (64 row detector) thereafter. It should also be noted that a number of patients referred from other centers were imaged with other systems. Imaging was reviewed using plain films, a workstation (GE AW workstation, GE Lightspeed), or the McKesson PACS picture archiving system. Window and level settings could be changed according to preferences. For size measurements, radiologists were required to identify the largest aortic dimension in multiplanar reconstruction (MPR) using imaging software known as 3D MPR tool. With the earlier scanners, the collimation depended on the scan range that needed to be covered with the thinner collimation reserved for CTs of the chest and the thicker collimation for the abdomen and pelvis.

3.2. Statistical Analysis

All continuous variables are expressed as mean \pm stan-

dard deviation or as median (interquartile range) for non-normally distributed variables. All categorical variables are expressed as frequencies and percentages. A one-way analysis of variance was used to compare age, ISS, time between admission/definitive treatment and time to diagnosis among the three types of treatment strategies. For all other variables in Table 2, the Fisher exact test was used. If the P value was significant, then 2×2 comparisons were done. For all continuous variables in Table 3, a two-way analysis of variance model, which included the two main effects namely type of procedure and grade, as well as their interaction term (procedure \times grade), was used to assess whether the grade differed from one type of procedure to another. The P value for the interaction term was not significant for any of these variables and was dropped from the model. Table 3 reports both P values for grade and type of intervention. For other outcomes, the Cochran-Mantel-Haenszel test was used for comparison among the grades adjusted for the type of procedure. The inter-rater agreement kappa statistic (weighed κ) was used to compare the two radiologists on their observations for the classification. The study protocol was accepted by the local Research and Ethics Board. Statistical analyses were computed using SAS version 9.2. A two-sided P value of less than 0.05 was considered significant.

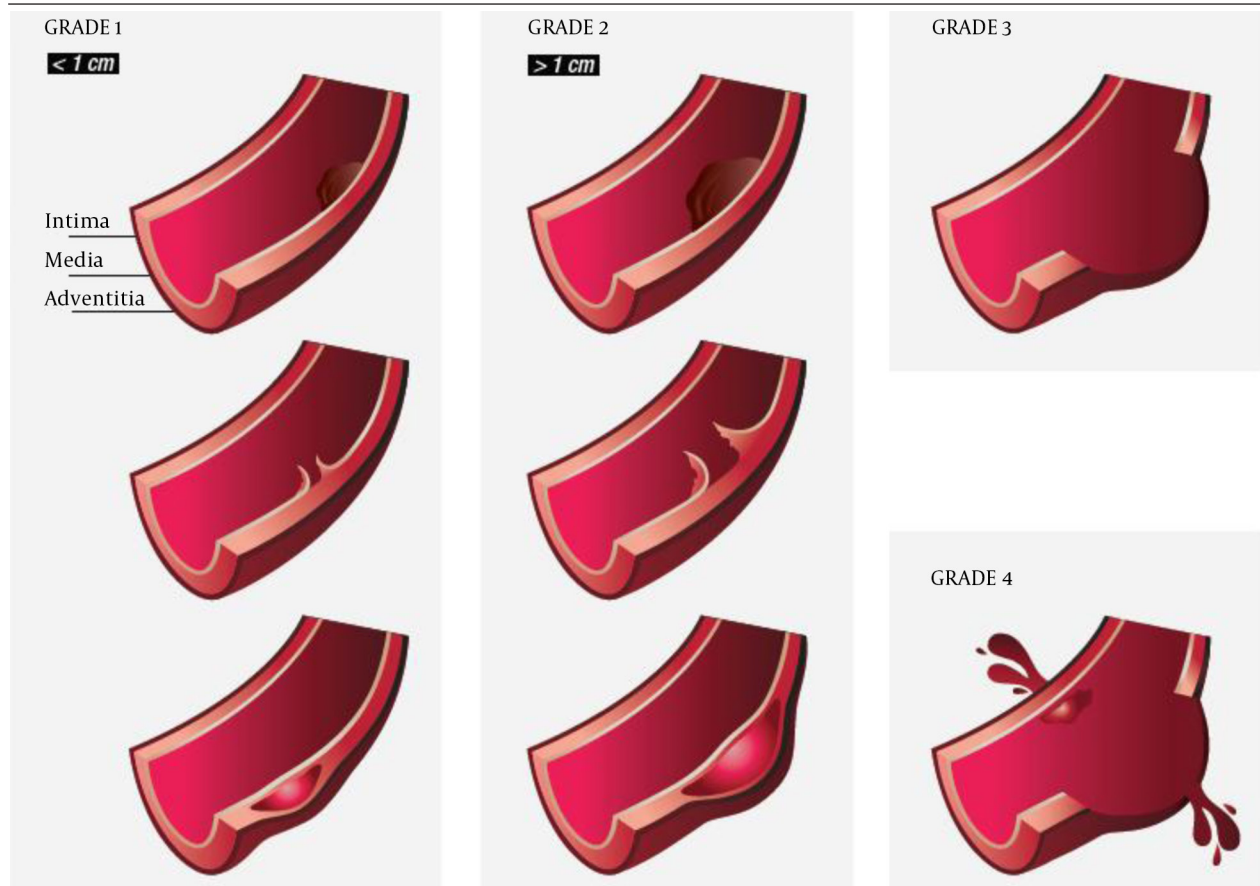


Figure 1. Illustration of the Vancouver Classification

Table 2. Demographics of Patients According to Type of Procedure ^{a,b}

Demographics	Surgery (n = 30)	Medical (n = 7)	TEVAR (n = 2)	P values
Age, y	40.43 ± 18.78	55.57 ± 13.48	21 ± 2.83	0.04 ^c
Gender, male	24 (80)	5 (71)	2 (100)	0.77
Hypertension	2 (7)	4 (57)	0	0.009
Smoking	3 (10)	3 (43)	1 (50)	0.06
Diabetes	3 (10)	1 (14)	0	1.0
Obesity	1 (3)	2 (29)	0	0.13
MVA low velocity	0	0	0	-
MVA high velocity	23 (77)	6 (86)	1 (50)	0.60
ISS	30.07 ± 9.75	31.57 ± 9.09	29 ± 7.07	0.91
Time to diagnosis, min	30 [30-180]	30 [30-45]	45 [30-60]	0.34
Hemodynamic instability	9 (30)	1 (14)	1 (50)	0.43
Time between admission and definitive treatment, min	240 [120-480]	660 [660-660]	840 [240-1440]	0.39
CI to immediate surgery	3 (10)	5 (71)	1 (50)	0.002 ^d
Paraplegia at presentation	2 (7)	1 (14)	0	0.56

^a Abbreviations: CI, contraindications; ISS, injury severity score; MVA, motor vehicle accident; TEVAR, thoracic endovascular aortic repair.

^b Data are presented as No. (%) or mean ± SD or mean [range].

^c TEVAR vs. Medical and medical vs. Surgery.

^d Medical vs. Surgery.

4. Results

4.1. Demographics

A total of 112 patients with acute traumatic aortic injury were identified. A total of 83% of patients suffered a high velocity motor vehicle accident and 29% had a concomitant head trauma. Mean ISS was 33 ± 10. Thirty-nine CTAs were available for review (those represent the local initial scanners; patients transferred from referral centers did not have scanners available for reconstruction and analysis). Supplementary Table 1 shows the Demographics for those patients according to intervention type. The demographic characteristics of patients for whom a CTA was available were comparable to those of the rest of the total cohort except for their time to admission and definitive treatment, which was shorter. Time between admission and definitive treatment was 240 [150–630] minutes. Hemodynamic instability due to associated injuries was present in 28% of patients and 23% of patients presented contraindications to immediate surgery (Supplementary Table 1).

Thirty patients underwent surgery (79%), 7 patients received medical treatment (18%) and 2 patients had a thoracic endovascular aortic repair (TEVAR) (3%).

A greater number of patients had hypertension in the medical treatment group ($P = 0.009$). Patients in the TEVAR group were younger than for the medical and surgical groups ($P = 0.04$). The principal mechanism of injury in all groups was a high velocity motor vehicle accident. Contraindication to immediate surgery was higher in the medical and TEVAR groups ($P = 0.002$). The proportion of patients demonstrating hemodynamic instability was similar between groups ($P = 0.43$) as well as time between admission and definitive treatment ($P = 0.39$), time to diagnosis ($P = 0.34$), and paraplegia at presentation ($P = 0.56$) (Table 2). Patients with grade III aortic injuries were more likely to undergo a surgical procedure (Grade I 4/7, Grade II 4/6, Grade III 22/26). For all continuous variables, the type of procedure was consistent over the different grade levels. Injury severity scores were not significantly different according to grade of injury ($P = 0.61$) or type of procedure ($P = 0.86$). Similarly, there was no significant difference in age according to grade of injury ($P = 0.73$) or type of procedure ($P = 0.08$) (Table 3). There were no significant differences among the grade levels adjusted for surgery type for all categorical variables.

Table 3. Outcomes According to Grade and Type of Procedure ^{a,b,c}

Outcomes	Grade 1 (n = 7)		Grade 2 (n = 6)		Grade 3 (n = 26)			P Values Grade/Type
	Surgery (n = 4)	Medical (n = 3)	Surgery (n = 4)	Medical (n = 2)	Surgery (n = 22)	Medical (n = 2)	TEVAR (n = 2)	
ISS	26 ± 8	39 ± 4	28 ± 7	25 ± 1	31 ± 11	27 ± 13	29 ± 7	0.61/0.86
Age, y	47 ± 20	57 ± 16	37 ± 22	52 ± 11	40 ± 19	57 ± 21	21 ± 3	0.73/0.08
Gender, male	4 (100)	2 (67)	2 (50)	1 (50)	18 (82)	2 (100)	2 (100)	0.87
ICU LOS, d	7.5 [6-9.5]	26 [6-56]	11.5 [4.5-22]	14 [14-14]	7 [5-15]	37.5 [5-70]	4.5 [4-5]	0.99/0.08
Intubation time, d	2.5 [2-4]	15.5 [6-25]	5.5 [3-12]	2 [2-2]	3 [1-9]	17.5 [5-30]	1.5 [1-2]	0.98/0.16
Hospital LOS, d	14 [10-19.5]	36 [28-58]	21.5 [13.5-30.5]	27 [24-30]	22 [12-35]	40 [5-75]	17.5 [15-20]	0.86/0.49
Hospital survival	4 (100)	3 (100)	4 (100)	2 (100)	21 (95)	1 (50)	2 (100)	0.16
PRBC	4.5 [3-6]	16 [6-26]	4 [2-6.5]	-	5 [2-9]	7.5 [3-12]	3.5 [3-4]	0.80/0.55
ARF	1 (25)	0	0	0	3 (14)	0	0	0.77
MI	0	0	0	0	1 (5)	0	0	0.57
Delirium	1 (25)	0	1 (25)	1 (50)	5 (23)	0	0	0.98
Pneumo- nia	1 (25)	2 (67)	2 (50)	1 (50)	11 (50)	1 (50)	0	0.61
New paraplegia	0	0	0	1 (50)	2 (9)	0	0	0.47

^a Abbreviations: ARF, acute renal failure; ISS, injury severity score; ICU LOS, intensive care unit length of stay; MI, myocardial infarction; PRBC, packed red blood cells; TEVAR, endovascular aortic repair.

^b Data are presented as mean ± SD or No. (%) or mean [range].

^c For continuous variables two P Values are reported (for grade and type) and for categorical variables one P value is reported (Cochrane-Mantle test).

4.2. Grades of Injury

Two radiologists rated the CT scans according to VC for aortic injury. There was perfect agreement in 29 cases (74%). The two radiologists revised the 10 discordant interpretations simultaneously and reached a consensual assessment for all patients. Grade I injury (flap or thrombus of less than 1 cm) was observed in 18% of cases (n = 7), 15% had Grade II extension (flap or thrombus of more than 1 cm) (n = 6), and 67% had Grade III injury (pseudoaneurysm of any size, with no extravasation of contrast) (n = 26). There was no aortic rupture with contrast extravasation (grade IV) in our series (Figure 1).

4.3. Correlation Between Radiologists in Classification

Agreement between the two radiologists for VC was good (weighed kappa = 0.81). There were 10 cases of disagreement. In 8 out of the 10 cases, the radiologists disagreed over a Grade I versus Grade II classification for hematomas close to 1 cm in size. There were discrepancies in measurement of the hematoma and after debate the radiologists reached a common agreement about how to

measure the hematoma. In the two remaining cases, the radiologists disagreed regarding the existence of a pseudoaneurysm and, therefore, classified the injury as Grade II or Grade III.

4.4. Outcomes

In patients with Grade I injuries, 57% of patients were treated surgically and 43% were treated medically with a survival rate of 100%. In patients with Grade II injuries, 67% underwent surgery and the remainders were treated medically with a survival rate of 100%. Among patients with Grade III injuries, 85% (n = 22) underwent surgery, 7.5% (n = 2) were treated with TEVAR and 7.5% (n = 2) were treated medically. Survival in these patient groups was 95%, 100%, and 50%, respectively (P = 0.52). Medically treated Grade III injured patients were either considered a prohibitive surgical risk (n = 1) or moribund (n = 1) (Table 3). In one case, surgery was declined because the patient had a previous coronary bypass and bilateral lobectomy with poor residual pulmonary function. This patient survived. In the second case, the patient presented with severe traumatic brain injury and herniation and became brain dead 8 hours after arrival.

One patient with Grade III injury died intraoperatively. That patient had had recent coronary artery bypasses and had suffered from unstable angina in the days prior to the trauma. On his arrival to the hospital, he was diagnosed with nosocomial pneumonia with septic shock and the aorta was found to be ruptured. The patient was brought to the OR but became unstable secondary to rapid atrial fibrillation (AF) that evolved into fatal arrhythmia. Table 3 reports that there was no statistically significant difference in hospital survival among the grades of injury adjusted for type of procedure ($P = 0.16$). Similarly, there were no significant differences for all other variables. Table 3 reports both P values for grade and type of surgery.

5. Discussion

The major findings of this study shows VC was easy to use and showed a good inter-observer correlation. There were no statistical differences in terms of outcome for any of the grades, irrespective of the treatment received. No predictors of bad outcomes became evident relating to the type of procedure received depending on grade of injuries. Patients presenting with low grades of injury were for the most part, treated medically with acceptable outcomes; and patients presenting with higher grades of injury and treated surgically had acceptable outcomes as well. However, a more liberal approach than the current TEVAR guidelines could be extended to patients deemed non-operable but treated medically. European recommendations for thoracic aneurysms state that, in certain morphologic situations that are considered prone to rupture, TEVAR may be justified at a diameter inferior to 5.5 cm. Comorbidities and age combined to surgical risk of each patient need to be considered. For traumatic aortic rupture, immediate treatment is indicated in patients with complete transection of the aortic wall and free bleeding into the mediastinum.

This study supports the use of the recently described aortic injury classification in a setting that traditionally relies on a different treatment strategy. There was good correlation between radiologists using this classification with CTs as well as good inter-observer agreement. The inter-observer reliability in this study ($\kappa = 0.81$) compared favorably with that previously reported by the Gavant, Simeone, or VC (0.44, 0.55, and 0.51, respectively) (10, 11, 14).

The two classifications described most recently by the Vancouver and the Seattle groups (13, 14) share many characteristics with this series. Survival rates of 100%, 100%, and 88% in Vancouver Grade I, II and III injuries, respectively, were similar to the survival rates reported in the initial Vancouver group (100%, 100%, and 90%) and the Seattle group (87%, 100%, and 76%). These studies also demonstrated that the hospital LOS was longer for patients with Grade I injuries compared to higher grades (13, 14). Although Azizzadeh and VC recognize 4 grades of injury, the major difference between them is that Azizza-

deh assigned a higher grade of injury to a mural hematoma (grade 2) than to an intimal flap (grade 1) (12). On the other hand, VC suggests that the extent of each of these two common findings should also be accounted for. For example, a large intimal flap should warrant more concern than a small mural hematoma and may dictate a more aggressive treatment strategy (14).

Non-operative management can be applied safely to a significant proportion of patients with polytrauma and aortic injury, which limits the risk of surgical complications from open or endovascular treatments. The non-operative approach consists in an aggressive negative inotropic treatment and an antihypertensive regimen. Caffarelli (2010) evaluated deliberative non-operative management in 53 patients with BAI and demonstrated a hospital survival rate of 93% (15). Their longitudinal analysis revealed that 78% of injuries remained stable, 18% completely resolved, and 4% progressed. In addition, multiple studies have demonstrated the safety of delayed repair in polytrauma patients, an approach used to limit complications (16, 17).

Aortic injuries of higher grades are approached by open surgical repair or TEVAR. In a systematic review of treatments of BAIs by Akowuah, 10 articles including 262 patients were identified (153 patients undergoing surgical repair and 109 endovascular repair). Postoperative results showed a higher paraplegia rate and a greater mortality rate in the surgical repair group (1% vs. 6% and 7% vs. 19%, respectively) (18). However, the mortality associated with open repair varies from one study to another and has been reported to be as low as 5% with no case of paraplegia in a previous local report (19). The combination of low morbidity and mortality with good long-term outcomes for open repair explains aggressive surgical approaches favored in this series.

The use of VC for traumatic aortic injury effectively allowed for identification of patients with varying degrees of severity of aortic injury. The classification was reproducible between observers. Patients presenting with low grades of injury were mostly treated medically, which resulted in acceptable outcomes. The use of an open surgical approach for patients with high grades of injury compared favorably with the literature. Prospective studies for treatment strategies based on severity of injury would allow for a more individualized approach for the patient with traumatic aortic injury.

5.1. Limitations

The retrospective nature of this study and sample size does not allow us to draw strong conclusions as to the optimal treatment strategy in relation to severity of injury. However, some observations can be highlighted. Patients with Grade I and II injuries had a 100% hospital survival rate in the surgically and medically treated groups. Definitive recommendations and conclusions cannot be drawn from this research project due to the small sam-

ple size. However, results of this small cohort of patients suggest that a tailored approach that takes into account comorbidities, rather than a systematic medical or surgical management, has led to optimal outcomes in this series. Patients with Grade III injuries had similar rates of survival in the surgical and the TEVAR groups, i.e. 95% and 100%, respectively. Only two patients with Grade III injury were treated medically, which resulted in 50% of mortality. Missing CT scans limited the sample size available for evaluation by radiologists. This cohort was mainly treated with the surgical approach performed by a single surgeon.

Supplementary Table 1. Demographics of the Complete Patient Population and of the Patient Subgroups with CT Scans ^{a, b}

Demographics	Total 112 Patients	39 Patients
Age, y	43.9 ± 18.62	42.2 ± 18.9
Gender, male	93 (83)	31 (79)
Hypertension	22 (20)	6 (15)
Smoking	17 (15)	7 (18)
Diabetes	9 (8)	4 (10)
Obesity	6 (5)	3 (8)
MVA high velocity	93 (83)	30 (77)
ISS	33.10 ± 10.4	30.3 ± 9.3
Time to diagnosis, min	30 [20–360]	30 [30–120]
Hemodynamic instability	37 (33)	11 (28)
Time between admission and definitive treatment, min	497.98 ± 562.88	240 [150–630]
CI to immediate surgery	19 (17)	9 (23)

^a Abbreviations: CI, contraindicated; ISS, injury severity score; MVA, motor vehicle accident.

^b Data are presented as mean ± SD or No. (%) or mean [range].

Acknowledgements

We would like to thank Anna Nozza, for her statistical contribution to this project.

Authors' Contributions

Study concept and design: Forcillo, Lamarche; Acquisition of data: Forcillo, Lamarche, Philie, Ojanguren; Analysis and interpretation of data: Forcillo, Lamarche, Philie, Ojanguren, Le Guillan, Demers and Verdant; Drafting of the manuscript: Forcillo, Lamarche, Le Guillan, Demers and Verdant; Critical revision of the manuscript for im-

portant intellectual content: Forcillo, Lamarche, Philie, Ojanguren, Le Guillan, Demers and Verdant; Statistical analysis: Forcillo, Lamarche, a statistician affiliated to our center; Study supervision: Forcillo, Lamarche.

References

- Greendyke RM. Traumatic rupture of aorta; special reference to automobile accidents. *JAMA*. 1966;**195**(7):527–30.
- Sevitt S. The mechanisms of traumatic rupture of the thoracic aorta. *Br J Surg*. 1977;**64**(3):166–73.
- Fabian TC, Richardson JD, Croce MA, Smith JS, Jr., Rodman G, Jr., Kearney PA, et al. Prospective study of blunt aortic injury: Multi-center Trial of the American Association for the Surgery of Trauma. *J Trauma*. 1997;**42**(3):374–80.
- Michaels AJ, Gerndt SJ, Taheri PA, Wang SC, Wahl WL, Simeone DM, et al. Blunt force injury of the abdominal aorta. *J Trauma*. 1996;**41**(1):105–9.
- Parmley LF, Mattingly TW, Manion WC, Jahnke EJ, Jr. Nonpenetrating traumatic injury of the aorta. *Circulation*. 1958;**17**(6):1086–101.
- Nikolic S, Atanasijevic T, Mihailovic Z, Babic D, Popovic-Loncar T. Mechanisms of aortic blunt rupture in fatally injured front-seat passengers in frontal car collisions: an autopsy study. *Am J Forensic Med Pathol*. 2006;**27**(4):292–5.
- Stemper BD, Yoganandan N, Pintar FA, Brasel KJ. Multiple subfailures characterize blunt aortic injury. *J Trauma*. 2007;**62**(5):1171–4.
- Melton SM, Kerby JD, McGiffin D, McGwin G, Smith JK, Oser RF, et al. The evolution of chest computed tomography for the definitive diagnosis of blunt aortic injury: a single-center experience. *J Trauma*. 2004;**56**(2):243–50.
- Fabian TC, Davis KA, Gavant ML, Croce MA, Melton SM, Patton JH, Jr., et al. Prospective study of blunt aortic injury: helical CT is diagnostic and antihypertensive therapy reduces rupture. *Ann Surg*. 1998;**227**(5):666–76.
- Gavant ML. Helical CT grading of traumatic aortic injuries. Impact on clinical guidelines for medical and surgical management. *Radiol Clin North Am*. 1999;**37**(3):553–74.
- Simeone A, Freitas M, Frankel HL. Management options in blunt aortic injury: a case series and literature review. *Am Surg*. 2006;**72**(1):25–30.
- Azizzadeh A, Keyhani K, Miller CC, 3rd., Coogan SM, Safi HJ, Estrera AL. Blunt traumatic aortic injury: initial experience with endovascular repair. *J Vasc Surg*. 2009;**49**(6):1403–8.
- Starnes BW, Lundgren RS, Gunn M, Quade S, Hatsukami TS, Tran NT, et al. A new classification scheme for treating blunt aortic injury. *J Vasc Surg*. 2012;**55**(1):47–54.
- Lamarche Y, Berger FH, Nicolaou S, Bilawich AM, Louis I, Inacio JR, et al. Vancouver simplified grading system with computed tomographic angiography for blunt aortic injury. *J Thorac Cardiovasc Surg*. 2012;**144**(2):347–1.
- Caffarelli AD, Mallidi HR, Maggio PM, Spain DA, Miller DC, Mitchell RS. Early outcomes of deliberate nonoperative management for blunt thoracic aortic injury in trauma. *J Thorac Cardiovasc Surg*. 2010;**140**(3):598–605.
- Paul JS, Neideen T, Tutton S, Milia D, Tolat P, Foley D, et al. Minimal aortic injury after blunt trauma: selective nonoperative management is safe. *J Trauma*. 2011;**71**(6):1519–23.
- Brinkman WT, Szeto WY, Bavaria JE. Overview of great vessel trauma. *Thorac Surg Clin*. 2007;**17**(1):95–108.
- Akowuah E, Angelini G, Bryan AJ. Open versus endovascular repair of traumatic aortic rupture: a systematic review. *J Thorac Cardiovasc Surg*. 2009;**138**(3):768–9.
- Verdant A. Contemporary results of standard open repair of acute traumatic rupture of the thoracic aorta. *J Vasc Surg*. 2010;**51**(2):294–8.