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Review

Evaluation of Subclavian, Thoracic Aorta, and Innominate Artery Injuries in Blunt Trauma Mechanisms: A Systematic Review of Case Reports and Case Series

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Abstract

Background: Blunt thoracic arterial injuries are among the rare causes for presentation at trauma centers. Most of the literature on these injuries is in the form of case reports and case series, with no significantly consolidated data available.

Methods: A systematic review of English language case reports and case series from 2000 to 2019 was carried out using the PubMed and Google Scholar search engines.

Results: The mean patient ages were 35.9, 36.4, and 44.3 years for thoracic aorta, innominate, and subclavian artery injuries, respectively. Of the innominate artery injury patients, 89.7% were male. Motor vehicle-related injuries contributed to 50.9% of thoracic aortic injuries. A blood pressure/pulse deficit was recorded in 34.8% and 20.7% of patients with subclavian and innominate artery injuries, respectively, and chest pain and hemodynamic instability were found in 23.5% and 20.5% of aortic injury patients, respectively. Clavicular fracture was the most common associated finding in subclavian artery injury patients at 42%. Computed tomography was performed in 21.7%, 47.1%, and 27.6% of patients with subclavian artery, thoracic aorta, and innominate artery injuries, respectively. An endovascular intervention was performed in 44.1% of patients with subclavian artery injuries.

Conclusion: Injury to the subclavian artery is relatively common among the older population. Blood pressure or pulse discrepancies could point to either subclavian or innominate artery injury. An endovascular intervention can be considered in all patients but must be individualized based on patient and facility factors.

Keywords: Aortic rupture; clavicular fracture; traumatic pseudoaneurysm; endovascular repair; cerebrovascular accident

INTRODUCTION

Trauma is the most common cause of mortality in children and adults under 44 years of age [1]. Blunt trauma is the leading mechanism affecting patients in most civilian trauma centers [2, 3]. Furthermore, motor vehicle accidents are the principal cause of blunt trauma, accounting for 1.3 million deaths, 20s–50 million non-fatal injuries, and 29% of all trauma cases annually [4, 5]. The overall incidence of vascular trauma is 5%, with a larger fraction contributed by penetrating trauma mechanisms [6, 7]. In fact, trauma centers report that only 5% of vascular trauma cases are caused by blunt mechanisms [8]. However, this may be an underestimation because many blunt trauma patients with major vascular injuries do not survive long enough to reach a healthcare facility. The findings of postmortem examinations of prehospital trauma deaths support this notion, placing blunt major vascular trauma as the second most common cause of death, after head injury [9, 10].

The paucity of blunt vascular injuries in trauma centers is reflected in the literature; most of the relevant publications are case reports and case series [11].

This review is intended to integrate the experiences of centers around the world through the analysis of case reports and case series concerning this issue and hopefully fill the knowledge gaps surrounding the epidemiological changes, investigative modality advancements, and management innovations for blunt vascular trauma.

METHODS

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Data source and search strategy

PubMed and Google Scholar were utilized to search for publications between January 2000 and September 2019 posing no language restrictions to the authors. The following key statements were utilized to initiate the search process: "case report/case series, subclavian artery injury," "case report/case series, thoracic aorta injury," and "case report/case series, innominate artery injury."

Inclusion criteria

All case reports and case series on subclavian, thoracic aorta, and innominate artery injuries arising from blunt mechanisms with no missing publication segments and published in English were included.
Only publications from January 2000 to September 2019 were included.

Exclusion criteria

The exclusion criteria were as follows: any blunt vascular injuries not involving the subclavian artery, thoracic aorta, or innominate artery.
All reports of vascular injury with a penetrating mechanism of trauma were excluded.
Publications that are primarily produced in a language other than English were excluded.

Data extraction and handling

From each patient report, the following information was retrieved: year of reported case, age at presentation, sex, mechanism of injury, general complaint/clinical presentations, associated injuries, specific vertebral injury, intracranial injury, associated vascular injuries (in addition to the injured vessels under study), chest wall injuries, pulmonary injuries, facial injuries, limb injuries, abdominal injuries, specific type of vascular injury for the main thoracic arterial injuries under question, diagnostic modality utilized, treatment provided, type of open surgical treatment provided, and outcome with specific complications pertaining to the vascular injury and mortality. No effort was made to communicate with authors concerning missing data from the publications.

Data synthesis and analysis

The generated data was entered into SPSS version 23 in the categories mentioned above, and the accuracy of the data was evaluated and ascertained.
After the data entry and cleanup were complete, the data analysis was conducted using the same software: SPSS version 23.

RESULTS

Subclavian artery injury

The cases of a total of 46 patients with subclavian artery injuries were reviewed (Table 1). The mean age of the patients was 44.33±21.11 years, and 73.8% were male. Motor vehicle collisions were involved in 32.6% of the cases. Motor vehicle-related injuries were reported in 13 (65%) patients younger than 45 years of age. Patients older than 45 years of age presented due to a falling accident in 36.4% of the reported cases. Of the female patients with subclavian artery injuries, half presented due to a falling accident.
Hemodynamic instability was recorded in 21.7% of the patients as a main clinical presenting sign/symptom, and polytrauma was reported in 10 (21.7%) of the patients. The most common clinical manifestations of motor vehicle-related subclavian artery injuries were blood pressure/pulse deficit (9 patients, 45%) and hemodynamic instability (7 patients, 35%). Patients presenting with subclavian artery injury after falling accidents reported progressive supraclavicular swelling in 5 (63.5%) cases. Three out of the 5 patients presenting with sports-related injuries presented with a blood pressure/pulse deficit.
Concerning associated injuries, clavicular fracture was reported in 24 (52.2%) cases. Of the patients with subclavian artery injuries and clavicular fractures, 62.5% were 45 years of age or older. Four (8.7%) of the patients had reported traumatic brachial plexopathy, and 10 (21.7%) of the patients presented with polytrauma. Of the reviewed patients, 15 (32.6%) had a pneumothorax, hemothorax, or both at presentation (Table 2).
Regarding the diagnostic modalities utilized, 44 cases reported the use of 1 or more imaging techniques. Conventional/digital subtracted angiography was utilized in 13 (28.3%) of the reported cases, and doppler ultrasonography, contrast CT, and CT angiography were used in 3 (6.5%), 10 (21.7%), and 12 (26.1%) cases, respectively. One patient had a chest x-ray as the sole imaging modality for diagnosis. A combination of CT angiography and conventional angiography with Doppler ultrasonography was conducted in 2 (4.3%) patients.
The types of vascular injuries diagnosed using imaging modalities or with intra-operative findings were reported in all 46 patients in this review. Pseudoaneurysm and dissection were reported in 20 (43.5%) and 8 (17.4%) of the cases, respectively. Rupture, laceration, and compression occurred in 4 (15.2%), 6 (13%), and 3 (6.5%) of the cases, respectively. One patient presented with a spasm of the subclavian artery.
The treatment modalities were specified in all 46 of the reviewed cases, with open surgical repair performed in 21 (45.7%) cases and endovascular and hybrid procedures performed in 17 (37%) and 5 (10.9%) cases, respectively. Three patients underwent conservative/medical therapy. Within the open surgical repair group, 11 (57%) underwent graft repair. Of the graft repair patients, 3 (27.3%), 2 (18.1%), and 2 (18.1%) underwent a prosthetic interposition graft, a prosthetic carotid-subclavian bypass, and a prosthetic carotid-axillary bypass graft, respectively. In addition, 3 (27.3%)

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Table 1. Blunt Subclavian artery injury case reports and case series.

Study(year)	age	sex	Mechanism	Main vascular presentation	Associated presentation	Cranial injury	Vertebral injury	Other Vascular injury	Chest wall injury	Lung injury	Facial injury	Limb injury	Abdominal injury	Seat belt sign	Diagnostic modality	Type of injury	treatment	Type of open repair	Type of graft	Type of repair	Complications
Fatime et al(2010)	20	M	Pedestrian MVA	Upper limb pain	polytrauma						Yes	Yes			angiography	Dissection	Open repair	Direct repair		E to E	None
Stefan'Czyk et al(2010)	10	F		Bleeding						HPN					CTA and Doppler	PA	Endovascular				None
Günday et al (2013)	31	M	Other	Chest pain	Shock				Rib fracture	PNT					Doppler and angio	Dissection	Endovascular				None
Sandiford et al (2001)	85	F	Fall	Bp/pulse deficit	None							Yes			CTA and Doppler	PA	Endovascular				None
Fuduric et al(2014)	20	M	MCI	Bp/pulse deficit	Polytrauma							Yes			CTA	Dissection	Open repair	Graft repair	PPG		ULC
Assenza et al (2012)	70	M	Fall	ASCS					Clavicle fracture						CT	Laceration	Endovascular				None
Queiroz et al (2018)	27	M	Bicycle injury	Shock						HTX					CT	PA	Open repair	NS			Dead
Serrano et al (2003)	60	F	Fall	PSCS					Clavicle fracture						Angiography	PA	Open repair	Graft repair	CAB		None
Derom et al(2008)	93	F	Fall	PSCS					Clavicle fracture						CT	PA	Endovascular				ULC
Nikolaos et al(2009)	70	M		DAE					Clavicle fracture	HTX					CT	Rupture	Endovascular				None
Weber et al (2017)	57	M	MCI	Shock	Polytrauma	Yes	Yes			HPN			Yes		CT	Laceration	Endovascular				CVA
Campfield et al (2016)	64	F	Fall	Shock	Brachial plexopathy				Clavicle fracture						CT	Laceration	Open repair	direct repair		SSR	ULC*
Yonezawa et al(2016)	55	M	MCI	Chest pain					Rib fracture	CHPN					Angiography	Laceration	Endovascular				Dead
Cheema et al(2008)	43	M	MVC	Shock	Polytrauma	Yes			C&R fracture	HPN						Rupture	Open repair	Direct repair		Ligation	None
Diaz-Gutierrez et al(2016)	20	M	MVC	Shock	Polytrauma				Rib fracture	CHPN			Yes	No	CT	PA	Hybrid				None
Elkbuli et al(2019)	30	M	MCI	Shock				SCV injury		HPN					Angiography	Rupture	Open repair	Graft repair	CAB		None
Enamorado-Enamorado et al(2011)	24	F	MVC	Shock	Polytrauma							Yes			CTA	PA	Endovascular				None
Nakada et al (2014)	41	M	MVC	Bp/pulse deficit					Clavicle fracture	PNT				No	Angiography	Dissection	Endovascular				None
Gullo et al(2012)	53	M	Fall	PSCS	Brachial prexopathy				Clavicle fracture						Doppler	PA	Hybrid				None
Hirose et al(2005)	30	F	MVC	Bp/pulse deficit					C&R fracture	HTX				Yes	Angiography	PA	Endovascular				None
Ipaktchi et al(2014)	14	M	Other	Bp/pulse deficit	None										CTA	Rupture	No treatment				

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Jaiswal et al(2018)	74	M	Fall	PSCS	Brachial plexopathy					CHPN					CTA	PA	Open repair	Direct repair		SSR	None
Ostovan et al(2017)	21	M	MVC	Bp/pulse deficit	ASCS							Yes			Angiography	Dissection	Endovascular				None
Kapetanakis et al(2006)	51	M	MVC	Chest pain	Polytrauma				R&S fracture	HPN		Yes	Yes	Yes	CT	Rupture	Open repair	Graft repair	PPG		None
Karkos et al(206)	21	M	Pedestrian MVA		Poltyrauma							Yes				Laceration	Open repair	Graft repair	SBG		RI
Noh et al(2018)	33	M	Other	Shock				SCV injury		HPN		Yes			CT	Rupture	Open repair	Graft repair	PPG		None
Kluemper et al(2017)	18	M	MVC	Bp/pulse deficit	Brachial plexopathy				C&R fracture	HPN					Doppler	Compression	Hybrid				ULC*
Knobloch et al (2006)	52	M	MCI	Bp/pulse deficit					Clavicle dislocation			Yes			CTA	Dissection	Open repair	Graft repair	CSB		None
Sabbagh et al(2016)	45	M	MVC	Bp/pulse discrepancy	Polytrauma Brachial plexopathy	Yes	Yes		Sternal fracture	PNT		Yes	Yes		CT	Rupture	Hybrid				ULC*
Mirza et al(2018)	83	F		PSCS					Clavicle fracture						CTA	PA	Endovascular				None
Faisham et al(2010)	19	M	MCI	Bp/pulse discrepancy	Polytrauma				Clavicle fracture	HPN	Yes	Yes			Angiography	Spasm	Open repair	Graft repair	SBG		None
Quinones-Baldrich (2009)	33	M	Sport injury	PSCS	None										CTA	PA	Endovascular				None
Gill et al(2013)	13	M	Sport injury	ASCS	Brachial plexopathy				Clavicle fracture						CTA	Compression	Open repair	Direct repair		CD	ULC*
Rodriguez-Merchan et al	46	M		PSCS					Clavicle fracture						Angiography	PA	Endovascular				None
Scheffler et al(2003)	58	F	Sports injury	Bp/pulse deficit	None										Doppler & angiography	Dissection	Medical/ rTPA				None
Sodhi et al (2007)	20	M	MVC	Shock		Yes			C&R fracture	HTX					Angiography	Compression	Open repair	Graft repair	CSB		None
Zaharudin et al(2016)	53	M	MVC						Sternum fracture	PC					Doppler	PA	Hybrid				None
Tachtsi et al(2011)	67	F	MVC	UL pain					Clavicle fracture						Angiography	PA	Open repair	Direct repair		Ligation	None
Tennysona et al(2018)	48	M	MVC	Shock					Rib fractures	CHPN	Yes			No	CXR	Laceration	Open repair	Direct repair		PR	None
Mandal et al(2004)	55	M	Sport injury	Bp/pulse deficit					Clavicle fracture						MRA	PA	Open repair	Graft repair	SBG		RI**
Schaik et al(2015)	52	M	Bicycle accident	Bp/pulse deficit					Clavicle fracture						CTA	Dissection	Open repair	NS			None
Watanabe et al(2005)	72	M	Fall	PSCS	Brachial plexopathy				Clavicle fracture						Angiography	PA	Open repair	Direct repair		E to E	None
Zhang et al(2015)	50	M	Engineering accident	Bp/pulse deficit	RLN palsy										CTA	PA	Endovascular				None

Butterworth et al(2001)	42	M	Sports injury	Bp/pulse deficit			SCV injury	Clavicle fracture					Angiography	Stenosis	Observation				None
Sladojevic et al(2016)	51	M	MVC					Rib fracture					CTA	PA	Open repair	Graft repair	ICS BG		
Bukhari et al(2005)	45	M	MVC	Bp/pulse deficit		Yes		Clavicle fracture	PNT			Yes	CTA	PA	Enodvascular				None

ASCS: acute supraclavicular swelling, Bp: Blood pressure, C&R: clavicle and rib, CAB: carotid axillary bypass, CD: clavicle disimpaction, CHPN: contusion with hemopneumothorax, CSB: carotid subclavian bypass, CT: computed tomography, CTA: computed tomography angiography, CVA: cerebrovascular accident, CXR: Chest Xray, DAE: decreased air entry, E to E: end to end anastomosis, HPN: hemopneumothorax, HTX: Hemothorax, ISCBG: innominate subclavian carotid bypass graft, MCI: motor cycle injury, MRA: magnetic resonance angiography, MVA: motor vehicle accident, MVC: motor vehicle collision, NS: not specified, PC: pulmonary contusion, PNT: pneumothorax, PPG: prostathic interposition graft, PR: patch repair, PSCS: progressive supraclavicular swelling, R&S: rib and sternum, RI: repeat intervention, SBG: saphenous bypass graft, SCV: subclavian vein, SSR: simple suture repair, UL: upper limb, ULC: upper limb complications.
*not secondary to the vascular injury.
**failed endovascular repair and open repair afterwards.

Table 3. Blunt thoracic aortic injury case reports and case series.

Study(year)	age	sex	Mechanism	Main vascular presentation	Associated presentation	Cranial injury	Vertebral injury	Other Vascular injury	Chest wall injury	Lung injury	Facial injury	Limb injury	Abdominal injury	Seatbelt sign	Diagnostic modality	Type of injury	treatment	Type of open repair	Type of graft	Type of repair	Complications
Matsumotoet al(2005)	69	F	MVC	Chest pain						HTX					Angiography	Arch	PA	Open repair	Graft repair	PCPB	None
Benedetto et al(2008)	19	M	MVC	shock	Polytrauma			Innominate Artery					Yes		CT	D&I aorta	Rupture	Hybrid			None
Badmanaban et al(2003)	29	F	MVC		Polytrauma				Rib fracture	HTX	Yes		Yes	Yes	Angiography	D&I aorta	Rupture	Open repair	Graft repair	PCPB	Fetal loss
Boulate et al(2018)	41	M	MVC		Polytrauma	Yes		Innominate artery	Sternum fracture	PNT					Angiography	Ascending	Dissection	Open repair	Patch repair	CCPB	None
Boulate et al(2018)	23	F	Animal injury						Sternum fracture						Angiography	Ascending	PA	Open repair	Graft repair	CCPB	None
Boulate et al(2018)	26	F	Pedestrian MVA	Alteredmentation					Sternum fracture	HTX					CT	Arch	rupture	Open repair	Patch repair	CCPB	CVA
Chock et al(2014)	25	M	MCI		Paraplagia		Yes		Rib fracture	PNT		Yes			CTA	D&I aorta	PA	Endovascular			Paraplagia
Coppi et al(2012)	24	M	MCI	Alteredmentation	Polytrauma	Yes									CT	D&I aorta	PA	Open repair	Graft repair	SCS	None
Eckhauser et al(2013)	12	M	MCI	Shock		Yes		Innominate artery	Rib fracture	HPN	Yes				CTA	Ascending	Rupture	Open repair	Patch repair	CCPB	None
Fraedrich et al(2003)	81	M	MVC					LSC&I artery	R&S fracture	PC		Yes			CT	Arch	Dissection	Endovascular			None
Ochoa et al(2011)	39	M	MVC	Altered mentation	Polytrauma	Yes			R&S fracture			Yes			CT	D&I aorta	PA	Endovascular			None

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Gombert et al(2016)	15	M	MVC	Chest pain	Polytrauma							Yes	Yes		CT	D&I aorta	PA	Hybrid			None
Ryu et al(2010)	73	F	MVC	Chest pain	Polytrauma							Yes			CT	Arch	PA	Hybrid			None
Ktenidis et al(2012)	30	M	MVC	Chest pain								Yes			Angiography	D&I aorta	PA	Hybrid			None
Kovari et al(2017)	31	F	Fall				Yes		Rib fracture	HPN		Yes	Yes		CT	D&I aorta	PA	Endovascular			None
Kovari et al(2017)	32	M	MVC	Shock		Yes	Yes		Rib fracture	CHPN		Yes	Yes		CT	Arch	PA	Endovascular			None
Mattison et al(2001)	21	M	MVC	Shock	Polytrauma	Yes			Rib fracture	HPN		Yes	Yes		Angiography	D&I aorta	Rupture	Endovascular			Dead
Moore et al(2001)	23	M	Work place injury	Chest pain			Yes			HPN		Yes			Angiography	D&I aorta	PA	Hybrid			None
Murphyvet al(2009)	26	M	Animal injury	Chest pain					C&R fracture						CTA	Arch	Rupture	Endovascular			None
Piffaretti et al(2015)	64	M	MVC	Jugular tightness	Polytrauma			RASCA injury	Rib fracture	PNT			Yes		CTA	D&I aorta	PA	Endovascular			None
Piffaretti et al(2015)	47	M	Fall	Shock		Yes			Rib fracture	CHPN		Yes			CTA	Arch	PA	Endovascular			None
Patel et al(2002)	53	M	MVC					Innominate artery							Angiography	Arch	PA	Open repair	Graft repair	CCPB	None
Gandhi et al(2003)	12	F	MVC	Altered mentation	Polytrauma	Yes					Yes	Yes	Yes	No	Angiography	D&I aorta	PA	Open repair	Graft repair	PCPB	None
Bradley et al(2006)	40	F	MVC	Chest pain		yes	Yes					Yes			CT	Arch	Rupture	Open repair	Graft repair	CCPB	None
Serna et al(2006)	28	M	MVC	Bp/pulse deficit				LSCA injury	Rib fracture					No	Angiography	Arch	Rupture	Open repair	Graft repair	CCPB	None
Propper et al(2009)	32	M	MVC		Polytrauma					HPNT	Yes	Yes	Yes		CT	D&I aorta	Rupture	Endovascular			None
Reynolds et al(2011)	21	F	MVC	Altered mentation	Polytrauma	Yes					Yes				CT	D&I aorta	PA	Endovascular			CNS insult*
Reynolds et al(2011)	40	M	MVC	Shock	Polytrauma	Yes							Yes		CTA	D&I aorta	Rupture	Endovascular			Dead
Reynolds et al(2011)	47	M	MVC		Polytrauma							Yes	Yes		CTA	Arch	Rupture	Endovascular			None
Siddiqi et al(2015)	21	M	Pedestrian MVA	Shock	Polytrauma	Yes		Innominate artery		CHPN		Yes	Yes		CT	D&I aorta	PA	Open repair	Graft repair	SCS	CNS insult*
Thompson et al(2006)	46	M	Fall		Polytrauma								Yes		CT	D&I aorta	PA	Endovascular			-

Turhan et al(2004)	31	M	MVC	Bp/pulse discrepancy									Echocardiography	D&I aorta	Dissection	Open repair	Graft repair	NS	None
Walden berger et al(2003)	81	M	MVC		Polytrauma		LSC&I artery	C&R fracture	PC		Yes		CT	Arch	Dissection	Endovascular			None
Yeo(2015)	20	M	MVC	Chest pain		Yes								Arch	Dissection	Hybrid			None

Bp: Blood pressure, C&R: clavicle and rib, CHPN: contusion with hemopneumothorax, CT: computed tomography, CTA: computed tomography angiography, CVA: cerebrovascular injury, D&I: descending and isthmus, HPN: hemopneumothorax, HTX: Hemothorax,LSC&I: left subclavian and innominate, LSCA: left subclavian artery, MCI: motor cycle injury, MVA: motor vehicle accident, MVC: motor vehicle collision, NS: not specified, PC: pulmonary contusion, PNT: pneumothorax, RASCA: right aberrant subclavian artery, R&S: rib and sternum, RI: repeat intervention, SCS: simple clamp and stitch, SCV: subclavian vein. *not secondary to the vascular injury.

Table 5. Blunt Innominate artery injury case reports and case series.

Study(year)	age	sex	Mechanism	Main vascular presentation	Associated presentation	Cranial injury	Vertebral injury	Other Vascular injury	Chest wall injury	Lung injury	Facial injury	Limb injury	Abdominal injury	Seat belt sign	Diagnostic modality	Type of injury	treatment	Type of open repair	Type of graft	Type of repair	Complications
Al-khaldi et al (2006)	35	M	MVC	DAE				RASCA injury	SCR fracture	CHPN				Yes	CTA	PA	Open repair	Graft repair	PPG		None
Dhaliwal et al(2005)	20	M	Fall	PSCS				SVC injury							Angiography	PA	Open repair	Primary repair		SLR	None
Knosalla et al (2000)	18	M	MCI	Altered mentation	Polytrauma	Yes				PC	Yes				Angiography	Dissection	NS				
Hirose et al(2004)	46	M	MVC	Bp/pulse discrepancy											Angiography	PA	Open repair	Graft repair	AIA G		None
Hirose et al(2003)	56	M	MVC	Bp/pulse discrepancy										No	Angiography	Dissection	Open repair	Graft repair	ACSG		None
Stover et al(2001)	37	M	MVC	Chest pain					R&S fracture			Yes		Yes	Angiography		Open repair	Graft repair	AIA G		NS
Stover et al(2001)	30	M	MVC	Chest pain										Yes	Angiography	PA	Open	NS	NS		NS
Axisa et al (2000)	21	M	MVC		Polytrauma				Rib fractures	PNT	Yes	Yes	Yes		Angiography	PA	Endovascular				None
Omrane et al(2014)	48	M	MVC	Bp/pulse deficit	Polytrauma	Yes									CT	Dissection	Open repair	Graft repair	NS		None
Bito et al(2014)	40	F	Fall	Shock		Yes			Rib fractures			Yes			CT	Rupture	Open repair	Graft repair	ASR		CVA
Boutayeb et al(2014)	54	M	MVC		Polytrauma				Rib fracture		Yes				CT	PA	Open repair	Graft repair	AIA G		None
Watanabe et al(2001)	36	M	Sport injury	Bp/pulse deficit	Altered mentation										Angiography	Rupture	Open repair	Graft repair	PPG		CVA

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Davidović et al(2010)	55	F	MVC	Shock					R&S fractures						Angiography	PA	Open repair	Graft repair	ACSG	None
Dias-Neto et al(2018)	41	M	Fall	Chest pain		Yes	Yes		C&R fractures	HTX	Yes	Yes			Angiography	Dissection	Open repair	Graft repair	AIA G	None
Miles et al(2003)	29	M	MVC			Yes			Rib fractures					Yes	Angiography	Rupture	Endovascular			NS
Howe et al(2017)	50	M	Fall	UL pain				RSC&RCCA injury	Rib fractures	PNT					CTA	Dissection	Open repair	Graft repair	IABG	None
Huang et al(2008)	36	M	MVC	Chest pain						HPNT	Yes	Yes			CT	PA	Endovascular			None
Lee et al(2015)	55	M	Fall	Chest pain											CT	PA	Hybrid			None
Mousa et al (2010)	51	M	MVC	Chest pain											CTA	PA	Open repair	Graft repair	AIA G	None
Ormazabal et al(2012)	21	M	MVC						Sterna fracture					Yes	CT	Dissection	Open repair	NS		NS
Chu et al(2006)	19	M	MVC	Altered mentation	Polytrauma			Aortic injury	Clavicle fracture	PC		Yes	Yes	Yes	CT	Rupture	Open repair	Graft repair	AIAG	None
Roberts et al(2000)	24	F	MVC											No	Angiography	Dissection	Open repair	Graft repair	PPG	None
Sladojevic et al(2015)	25	M	MVC	Bp/pulse deficit							Yes	Yes			Angiography	PA	Open repair	Graft repair	ACSG	None
Sladojevic et al(2015	56	M	MVC						R&S fractures						Angiography	PA	Open repair	Graft repair	ACCG	None
Symbas et al (2005)	32	M	MCI	Shock	Polytrauma		Yes		Rib fracture	CHPNT	Yes		Yes		CT	PA	Open repair	Graft repair	AIAG	None
Symbas et al (2005)	32	M	MCI	Chest pain	Polytrauma				Rib fracture	PC		Yes			Angiography	PA	Open repair	Graft repair	AIAG	None
Symbas et al (2005)	40	M	MVA	Bp/pulse deficit					Rib fracture	CHPNT					Angiography	PA	Open repair	Graft repair	AIAG	None
Boulate et al(2018)	18	M	MCI		Polytrauma				Rib fractures	HPNT	Yes				Angiography	PA	Open repair	Graft repair	PPG	CVA
Boulate et al(2018)	30	M	MVA						R&S fractures	PNT					Angiography	PA	Open repair	Graft repair	AIAG	RI

ACSG: Aorto-right common carotid and right subclavian bifurcated graft,ACCG: ascending to common carotid bypass graft, AIAG: ascending to innominate artery graft repair, ASR: ascending to subclavian graft, Bp: Blood pressure, C&R: clavicle and rib, CHPN: contusion with hemopneumothorax, CT: computed tomography, CTA: computed tomography angiography, CVA: cerebrovascular accident, DAE: decreased air entry, E to E: end to end anastomosis, HPN: hemopneumothorax, HTX: Hemothorax, ISCBG: innominate subclavian carotid bypass graft, IABG: innominate axillary bypass graft, MCI: motor cycle injury, MVA: motor vehicle accident, MVC: motor vehicle collision, NS: not specified, PC: pulmonary contusion, PNT: pneumothorax, PPG: prostathic interposition graft, PR: patch repair, PSCS: progressive supraclavicular swelling, R&S: rib and sternum, RI: repeat intervention, RCCA: right common carotid artery, RSC&RCCA: right subclavian and right common carotid arteries, SCR: sternum, clavicular and rib fracture,SCV: subclavian vein,SLR: simple laceration repair, SSR: simple suture repair.

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patients underwent a saphenous bypass graft, 8 (42.1% of the open repair cases) patients had direct repairs with end-to-end anastomosis, a simple suture and ligation were performed in 2 (25%) patients, and 1 patient underwent a patch repair.
The outcomes and complications were reported in 45 of the 46 cases, with 73.9% of patients experiencing total resolution and 6 (13%) experiencing upper limb complications, of which 4 were confirmed brachial plexopathy at presentation rather than vascular injury-related complications. Repeat intervention was needed in 2 (4.3%) patients, and 2 (4.3%) patients died. Furthermore, 1 patient was diagnosed with a cerebrovascular accident related to the subclavian artery injury.

Thoracic Aorta injury

The data for a total of 34 aortic injury patients was retrieved from the literature between 2000 and 2019 (Table 3). The mean age of the patients with aortic injuries was 35.9±18.9 years, and 26 (76.5%) of the patients were male. Of the patients examined, 23 (67.6%) presented after a motor vehicle collision, and 28 (82.4%) had injuries related to motor vehicles (including pedestrian motor vehicle accidents and motorcycle injuries). Hemodynamic instability (hypotension) and chest pain were the chief clinical features in 7 (20.6%) and 8 (23.5%) of the cases, respectively. Polytrauma was reported in 17 (50%) of the patients. Twenty-one (84%) of the patients aged under 45 years had motor vehicle-related injuries, compared to 7 (77.7%) of the patients aged 45 years or older. Female patients presented after motor vehicle accidents in 87.5% of the cases, compared to 80.7% in male patients.
Rib fracture was the most common associated chest wall injury, presenting in 9 (26.9%) of the cases overall and in 3 (8.8%) and 1 (2.9%) cases with sternum and clavicle fractures, respectively. Hemopneumothorax alone was reported in 5 (14.7%) patients, and with lung contusion in 3 (8.8%) patients. Five (14.7%) patients had an abdominal-associated innominate artery injury, and 13 (38.2%) patients had an associated traumatic brain injury (Table 4).
The most common imaging modalities utilized were contrast CT scanning and CT angiography, which were used in 16 (47.1%) and 7 (20.6%) cases, respectively, and conventional/digital subtracted angiography was used in 10 (29.4%) cases. The most common sites of injury were the isthmus and the descending aorta, accounting for 18 (52.9%) of the examined cases. The aortic arch and the ascending aorta were injured in 13 (38.2%) and 3 (8.8%) cases, respectively. A pseudoaneurysm was discovered in 18 (52.9%) of the patients using an imaging modality or intraoperative findings. Rupture was diagnosed in 11 (32.4%) cases and dissection with or without thrombosis in 5 (14.7%) cases. Regarding treatment, 13 (38.2%) patients underwent open surgical repair, with endovascular repair performed in 15 (44.1%) and a hybrid method in 6 (17.6%) cases. In the open repair group 10 out of 13 (76.9%) of the patients underwent a repair using a prosthetic graft, and 3 (23.1%) underwent a patch repair. The majority of the open procedures—7 cases (53.8%)—were performed under a complete cardiopulmonary bypass with deep hypothermic arrest and a centrifugal pump (3 cases, 23.1%). Two patients underwent a simple clamp and stitch procedure with no bypass.
In terms of the outcomes and complications in the aortic injury patients, 76.5% experienced complete resolution, with 2 deaths out of the 34 patients reported. Three (9%) patients had chronic cerebral sequele, with 2 of the 3 cases caused by traumatic brain injury.

Innominate artery injury

The data of a total of 29 patients was retrieved from reports from 2000 to 2019 (Table 5). The mean age of the patients with innominate artery injuries was 36.4±12.8 years, and 26 (89.7%) of the patients were male. Motor vehicle collisions contributed to 19 (65.5%) of the innominate artery injury cases, with motor vehicle associated-injuries accounting for 79.3% of the cases. Regarding the clinical presentations of the innominate artery injury patients, chest pain and blood pressure/pulse deficit were reported in 7 (24.1%) and 6 (20.7%) cases, respectively. Polytrauma was reported in 8 (27.6%) cases.
Rib fracture alone was reported in 9 (31%) patients and with sternum fracture in 4 (13.8%) patients. Lung contusion alone was reported in 3 (10.3%) patients and with hemopneumothorax in another 3 (10.3%). Eight (27.6%) of the cases included facial injuries. Extremity injuries were reported in 8 of the 29 patients (27.6%), and 6 (20.7%) had a seatbelt sign (Table 6).
Regarding diagnostic imaging and treatment modalities, angiography (conventional/digital subtracted) was utilized in 18 (62.1%) cases. A contrast CT scan and CT angiography were performed in 8 (27.6%) and 3 (10.3%) cases, respectively. A pseudoaneurysm was identified using imaging modalities or intraoperative findings in 58.6% of the reported cases, whereas 24.1% of the cases had dissection with or without intravascular thrombosis, and rupture was present in 13.8% of the cases.In 1 case, the type of innominate injury was not further specified. Twenty-four (82.8%) patients underwent open surgical repair: 3 patients were treated with an endovascular technique, and 1 patient was treated with a hybrid method. Twenty-one of the 24 (87.5%) patients treated with open repair underwent a graft repair, and 1 patient was treated with a direct suture repair. Two cases did not specify the method of open repair used. Among the patients in the graft repair group, 10 (47.6%) had an ascending aorta to innominate artery bypass graft, whereas 3 (14.3%) had an aorto-right common carotid and right subclavian bifurcated bypass graft. An interposition graft was

performed in 4 (19%) patients, and ascending aorta to common carotid artery bypass, innominate to axillary artery bypass graft, and ascending aorta to subclavian artery bypass procedures were performed in 1 patient each.

Among the patients with innominate artery injuries, 69% experienced complete resolution and were symptom free at follow-up, 10.3% of the patients had a cerebrovascular accident pertaining to the arterial injuries, and 1 patient required a repeat intervention.

DISCUSSION

Subclavian artery injury

Subclavian artery injuries were more common in males, corresponding with the results of a report by Sturm et al. in 1984, which included 80% (12 out of 15 patients) male patients [108]. The mean age of the patients examined in this review was relatively older than that of the report of 26.2 years by Sturmet al.but relatively younger than a case series published in 2001 from cases treated before 1998, which reported a mean age of 57 years [107, 108].

Motor vehicle-related injuries were reported in almost half of the reviewed cases as a mechanism of trauma, which is low compared to other studies [107–109]. Motor vehicle-related injuries were found to be more common among males than females in this review, corresponding to a significantly higher rate of motor vehicle-related fatalities among males than among females [110]. A point worth mentioning is the high proportion of fall-related subclavian artery injuries in older patients, which has never been previously reported in systematic reviews.

The most common clinical presenting signs and symptoms in the reviewed cases were blood pressure/pulse deficit and hemodynamic instability. This is certainly not an outlier in the context of blunt subclavian artery injuries. Katras et al.reported that 7 out of the 15 patient cases they reviewed included hypotension (unstable hemodynamic status), and 7 out of 15 included diminished or absent pulse [107]. Patients with subclavian artery injuries after a fall had a less dramatic, but more progressive presentation of progressive supraclavicular swelling, pointing toward the necessity for a more vigilant follow-up in these cases.

Clavicular fracture was the most common associated fracture in patients with subclavian artery injuries, with more than half of patients presenting with this fracture. This finding has been replicated by multiple reviews articles published by other authors [107–109].

Concerning imaging modalities, conventional/digital subtracted angiography was the most commonly utilized technique, followed by CT angiography and standard contrast CT scanning. In the present review, conventional angiography was used less frequently than in previous reviews.This is consistent with a review by Sturm et al., in which 14 of the 15 patients underwent conventional diagnostic angiography before operative management was performed. In addition, Costa and Robbs reported that conventional angiography was performed in all 11 patients for whom operative management was provided [108, 109]. Investigative modalities have found that most vascular lesions are pseudoaneurysms. However, this was not exhibited in a review by Katras et al.,in which only 2 of the 7 patients had pseudoaneurysm of the subclavian artery [108].

Endovascular and hybrid methods of treatment together have contributed to managing 48% of subclavian artery injuries, which certainly demonstrates a significant shift from the previous reports from the end of the past century. In all 3 of the reports examined from this period—those of Strum et al., Katras et al.,and Costa and Robbs—only open repair was reported in all of the patients [107–109]. In the present review, the open repair group underwent more graft repairs than primary/direct sutures, which is similar to Costa and Robbs' report [109].

Regarding patient outcomes, 6 out of the 46 patients in this review experienced upper limb complications due to either vascular or non-vascular causes. This outcome was significantly rarer than in the 7 out of 15 patient cases with limb complications in Costa and Robbs' report [109]. This may be due to recent improvements in operative techniques and the advent of endovascular and hybrid techniques.

Thoracic aorta injury

More than 3/4ths of the patients with blunt thoracic aortic injury in this review were male, with motor vehicle-related injuries being the most common mechanism. This corresponds to a larger study from Germany, in which 77.5% of the patients with blunt thoracic aorta injuries were male, and high-speed motor vehicle accidents caused 78% of the blunt thoracic aortic injuries [111].

The most common clinical manifestations in this review were chest pain and hemodynamic instability (hypotension). Hemodynamic instability was more common in a German study, appearing in 35.6% to 70.1% of cases depending on the vascular lesions in question [111]. Polytrauma was reported in the present review in half of patients, and cervical and thoracic vertebral injuries were reported in significant number of patients at, 14.7%, although no prior data is available for comparison.

Rib fracture is the most common chest wall trauma associated with blunt thoracic aorta injury. There is also a high rate of associated traumatic brain injury among blunt thoracic aorta injuries. An autopsy report by Burkhart et al.showed higher rates of rib fracture and traumatic brain injury (69% and 68%, respectively) than this review (26.9% and 38.2%, respectively) [112]. This may be because autopsy cases have an expected higher severity of injury than the patient cases examined in the present review. In addition, in the present review,

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Table 2. Demographics, mechanism of injury and clinical manifestations of patients with Subclavian artery injuries.

Category	Subcategory	Number	Percentage(%)
Age category	1-17 years	3	6.5
	18-44 years	18	45.7
	45 years and above	25	54.3
Sex	Male	36	78.3
	Female	10	21.7
Mechanism of injury	Pedestrian motor vehicle accident	2	4.3
	Motor vehicle collision	15	32.6
	Motor cycle injury	6	13.0
	Falling down accident	8	17.4
	Sports injury	5	10.9
	Bicycle	3	6.5
	Workplace injury	2	4.3
	Other and non specified	5	10.9
Clinical presentation	Blood pressure or pulse deficit	16	34.8
	Hemodynamic instability	10	21.7
	Progressive supraclavicular swelling	8	17.4
	Decreased Air entry	1	2.2
	Upper limb pain	2	4.3
	Acute supraclavicular swelling	2	4.3
	Chest pain/dyspnea	3	6.5
	External bleeding	1	2.2
	Non-specified	3	6.5
Associated injuries			
Chest wall injuries	Chest wall injury		
	Clavicle fracture alone	19	41.3
	Rib fracture alone	5	10.9
	Sternum fracture alone	2	4.3
	Rib and clavicle fracture	5	10.9
	Rib and sternum fracture	1	2.2
	None/not reported	14	30.4
Lung/intrathoracic injury	Lung parenchymal/intrathoracic injury		
	Pneumothorax alone	4	8.7
	Hemothorax alone	4	8.7
	Hemopneumothorax	7	15.2
	Lung contusion alone	1	2.2
	Lung contusion with hemopneumothorax	3	6.5
	None/Not reported	27	58.7
Other area injuries	Face injury	3	6.5
	Subclavian vein injury	1	2.2
	Extremity injury	11	23.9
	Abdominal injury	4	8.7
	Traumatic brain injury	5	10.9

Table 4. Demographics, mechanism of injury and clinical manifestations of patients with Subclavian artery injuries.

Category	Subcategory	Number	Percentage(%)
Age category	1-17 years	3	8.8
	18-44 years	22	64.7
	45 years and above	9	26.5
Sex	Male	26	76.5
	Female	8	23.5
Mechanism of injury	Pedestrian motor vehicle accident	2	5.9
	Motor vehicle collision	23	67.6
	Motor cycle injury	3	8.8
	Fall from height	3	8.8
	Animal related injury	2	5.9
	Workplace injury	1	2.9
Clinical presentation	Chest pain	8	23.5
	Hemodynamic instability	7	20.6
	Altered mentation	5	14.7
	Blood pressure or pulse deficit	2	5.9
	Other	3	8.8
	Non-specified	9	25.6
Related complaint	Polytrauma	17	50
Chest wall injury	Rib fracture alone	9	26.9
	Sternum fracture alone	3	8.8
	Sternum and rib fracture	3	8.8
	Rib and clavicle fracture	1	2.9
	None/not reported	18	52.9
Lung parenchymal/ intrathoracic injury	Pneumothorax alone	3	8.8
	Hemothorax alone	3	8.8
	Hemopneumothorax	5	14.7
	Lung contusion alone	2	5.9
	Lung contusion with hemopneumothorax	3	8.8
	None/Not reported	18	52.9
Associated vascular injury	Innominate artery	5	14.7
	Left subclavian with Innominate artery	2	5.9
	Left common carotid artery	1	2.9
	Right aberrant subclavian artery	1	2.9
	None/Not reported	25	73.5
Other area injuries	Face injury	5	14.7
	Extremity injury	17	50
	Abdominal injury	13	38.2
	Traumatic brain injury	13	38.2
	Vertebral injury	5	14.7

Table 6. Demographics, mechanism of injury and clinical manifestations of patients with Innominate artery injuries.

Category	Subcategory	Number	Percentage(%)
Age category	18-44 years	20	69.0

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	45 years and above	9	31.0
Sex	Male	26	89.7
	Female	3	10.3
Mechanism of injury	Motor vehicle collision	19	65.5
	Motor cycle injury	4	13.8
	Fall from height	5	17.2
	Sports injury	1	3.4
Clinical manifestations	Chest pain	7	24.1
	Blood pressure or pulse deficit	6	20.7
	Altered mentation	2	6.9
	Hemodynamic instability	3	10.3
	Progressive supra-clavicular swelling	1	3.5
	Ischemic limb pain	1	3.5
	Decreased air entry	1	3.5
	Other	1	3.5
	Non-specified	7	24.1
Related complaint	Polytrauma	8	27.6
Chest wall injury	Rib fracture alone	9	31.0
	Sternum fracture alone	1	3.4
	Clavicle fracture	1	3.4
	Sternum and rib fracture	4	13.8
	Rib and clavicle fracture	1	3.4
	Rib, clavicle and sternum fracture	1	3.4
	None/not reported	12	41.4
Lung parenchymal/ intrathoracic injury	Pneumothorax alone	3	10.3
	Hemothorax alone	1	3.5
	Hemopneumothorax	2	6.9
	Lung contusion alone	3	10.3
	Lung contusion with hemopneumothorax	3	10.3
	None/Not reported	17	58.6
Associated vascular injury	Aorta	1	3.5
	Right subclavian and right common carotid artery	1	3.5
	Right aberrant subclavian artery	1	3.5
	Superior vena cava injury	1	3.5
	None/Not reported	25	86.2
Other area injuries	Face injury	8	27.6
	Extremity injury	8	27.6
	Abdominal injury	3	10.3
	Traumatic brain injury	4	13.8
	Vertebral injury	3	10.3
Seatbelt sign	Yes	6	20.7
	No	3	6.9
	Not reported	21	72.4

nearly half of the patients had 1 or more pulmonary injuries. This high occurrence is still lower than that of the autopsy reports of patients with thoracic aorta injuries [112].

Innominate artery injuries were most commonly associated with aortic injuries, and although prior studies linking aortic and innominate artery injury are not available, this association is logical. Similar trauma mechanisms and anatomic proximity make both vessels vulnerable simultaneously.

CT scanning was the diagnostic modality of choice in nearly half of the patient cases in the present review [113]. This is consistent with the recommendation from Mirvis et al., who argue that, given its sensitivity and specificity of greater than 90%, the CT scan is a good option for traumatic aortic injury diagnosis. In fact, an additional 1/5th of patientsin the present review underwent CT angiography, further decreasing the need for conventional/digital subtracted angiography.

In the present review, most patients (52.9%) had injuries either at the isthmus or the descending aorta.This is slightly lower than in other studies. For instance, Williams et al. reported that 65% of the reviewed injuries occurred at the isthmus or the descending aorta [114]. Pseudoaneurysm was the most common vascular lesion in this review. This is similar to other findings in the literature, including those of Starnes et al., in which pseudoaneurysm was reported among 71% of the blunt aortic injury patients [115].

Endovascular repair was the most common modality of thoracic aorta repair in the present review. In fact, with the introduction of the hybrid method, close to 2/3rds of patients underwent a minimally invasive corrective procedure with either total endovascular or hybrid techniques. This data is similar to the findings of Gombert et al.,in which 62.8% of patients underwent an endovascular procedure. However, contrary to what Gombert et al. reported, this review did not find patients who underwent conservative management with no surgical intervention [111]. Graft repair was the most common method of open repair in the present review.

The present review revealed a 6% mortality rate, which is significantly lower than the rates reported by large reviews, such as that by Gombert et al.,in which a 40.8% rate of total mortality was reported [111]. This level of staggering difference may be attributed to the fact that the case reports and case series in the present review are those of living patients rather than fatalities.

Innominate artery injury

The mean ages of the thoracic aorta and innominate artery injury patients are quite similar. The high male predominance (89.7%) identified in this review is consistent with the results of an older review by Hirose and Gill, which showed a male predominance of 86.3%. Motor vehicle related-accidents were the mechanism of injury in more than 80% of the patients in this review, which is similar to the 88.9% reported by Hirose and Gill. Chest pain and blood pressure/pulse discrepancies were the 2 dominant manifestations, occurring in almost half of the patients in the present review. Hirose and Gill reported that 20 out of 132 patients (15.15%) experienced blood pressure/pulse deficits even though thy didn't report on Chest pain [90].

On the subject of associated injuries, this review found rib fractures in almost half of the reported cases, polytrauma in 1/4th of the reports, and a significant number (41.4%) of instances of at least 1 pulmonary injury. Hirose and Gill reported a significantly lower rate of rib fractures (16 out of 132 cases, 12.1%). Similarly, Hirose and Gill reported only 28 out of 132 patients experiencing pulmonary complications, which is also significantly lower than the rate obtained in this review. The reason for these discrepancies is unknown. The rate of head injury, at 13.8% in this review, is comparable to that in the report from Hirose and Gill, in which 15 out of 132 patients (11.4%) experienced a traumatic brain injury [90]. The seatbelt sign status was reported in 8 patients in the present review, of which 6 had a seatbelt sign, which can indicate a sudden deceleration injury that may have caused the innominate artery injuries.

Although 62% of patients in this review underwent a diagnostic angiography, this invasive modality seems to be decreasing in popularity. Hirose and Gill reported that in all of their reviewed cases with a reported imaging modality, diagnostic conventional angiography was used, which caused the authors to conclude that angiography is the gold standard modality. This shows a slow yet steady increase in the utilization of noninvasive diagnostic modalities such as CT with contrast and CT angiography.

The present review found pseudoaneurysm in more than half of the cases. This correlates well with similar review findings on thoracic aorta and subclavian artery injuries [90].

In the innominate artery injury cases examined in the present review, open repair was the most common management modality (in contrast with the for aortic and subclavian artery repair, for which endovascular intervention was preferred more often). Hirose and Gill did not report any endovascular procedures in the case reports reviewed prior to 2003. Although the progress towards endovascular and hybrid techniques may be slower compared to aortic and subclavian artery injury repairs, more and more surgeons have been utilizing endovascular interventions in recent years [90].

In the present review, complications with cerebrovascular accidents occurred in 10% of the patient cases, and all of these complications occurred in the open surgical repair group and none in innominate artery injury patients treated with endovascular interventions. This could be due to selection bias because more stable patients may have been more likely to be managed with endovascular techniques than those undergoing

open repairs.

CONCLUSION

In subclavian artery injuries, clavicular fracture can point to arterial injuries, especially in older patients. Blood pressure/pulse deficits were the most common clinical indicators of these injuries.Investigations using CT with contrast, CT angiography, or conventional angiography are typically performed in these cases, with no clear preference of any one over the others. Open repair is still the most common treatment modality, with an increasing use of endovascular techniques.

Blunt thoracic aortic injuries are common among high-speed deceleration injuries. Chest pain in a patient with a significant trauma mechanism is a good indicator that further investigation is needed, especially when associated with head trauma or polytrauma. A CT scan can be the first and even the modality of choice for this investigation. Endovascular procedures can be considered regardless of the type of vascular lesion.

Innominate artery injury is a predominantly motor vehicle-related injury. Chest pain and blood pressure/pulse deficits are the most common clinical features of this injury. Suspected innominate artery injuries may need conventional/digital subtracted angiography, and the threshold for performing these tests should be lower. Open surgical management is still the procedure of choice, and until further knowledge is gained, there can be no recommendation to replace this time-tested technique.

DECLARATIONS

Conflicts of interest

All authors declare that there are no conflicts of interest.

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