Research Article

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Journal of Vascular and Endovascular Therapy
ISSN-2634-7156

2021
Vol. 6 No. 3: 15

Decision Making Based on Clinicoanatomic Criteria to Select Open Versus Endovascular Repair for In nominate Artery Pseudoaneurysms Management

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Citation: Raherinantenaina F, Andrianandraina MCG, Avotsihoarana TH, Rabemanantsoa R, Mampiadana ML, et al. (2021) Decision Making Based on Clinicoanatomic Criteria to Select Open Versus Endovascular Repair for In nominate Artery Pseudoaneurysms Management. J Vasc Endovasc Ther. 6 No. 3: 15.

Abstract

Background: The quality of present data on the effectiveness of endovascular repair (EVR) or open surgery (OS) to treat in nominate artery pseudoaneurysms (IAPs) is poor. The use of EV might simplify the procedure and provide a meaningful alternative for this condition, but it remains to be proved. We analyzed all IAP cases handled by OS or EVR from the literature to affect the decision-making for OS or EVR, basing the choice of intervention on clinicoanatomical data analysis.

Methods and results: All relevant literature reports of EVR and OS management of IAP were analyzed comparatively. Evidence-based data were extracted from the literature using Medline and Embase database resources. We totally recorded 73 cases, 50 from OS repair and 23 received EVR. Most patients who displayed hard signs or stable vital signs have been significantly managed by OS (94% *vs.* 57%) or EVR (43%*vs.* 8%) respectively. There was a significant predominance of iatrogenic injuries in the EVR group compared with those handled by OS (39%*vs.* 26%) except for patients who underwent endovascular stenting. OS was performed in the large majority of patients with severe blunt traumas (50%*vs.* 22%)(p=0.0328). Many patients classified as having cardiothoracic comorbidities benefited from EVR therapy (52%*vs.* 20%). Some cases in which arterial wounds were limited to the mid segment of the IA underwent EVR with significant proportion compared to the OS group (26%*vs.* 24%) (p=0.004). Patients in the EVR group had more operative failure and complications rates (39%) rather than those in the OS group (20%) ($p<$ 0.05). Of the 23 patients managed by EVR, two had premature mortality (8.7%); of the remaining cases that received OS, the early mortality rate represented 6%. The significant causes for OS-related morbimortality were multiple organ failures, acute right heart insufficiency, pneumonia, deep vein thrombosis and hemorrhagic shock. Overall events for EVR-related death included stroke complications and massive hemorrhage from endoleak. The mid-term follow-up rate was significantly higher for the EVR group (57%) compared to the OS group (30%).

Conclusion: Compared with OS repair, EVR might represent an attractive alternative strategy for managing IAPs. The most primary option for OS included unstable patients, suffered from endovascular stenting, free of comorbidities and when the arterial wound is located at the distal portion of the IA.

Keywords: Endovascular repair; Innominate trunk; Brachiocephalic artery pseudoaneurysm; Open surgery revascularization

Received: February 19, 2021, **Accepted:** March 24, 2021, **Published:** March 31, 2021

Introduction

False aneurysm, also known as pseudo aneurysm, occurs when a damaging force is applied to the arterial wall, allowing persistent extravasations of blood into the surrounding connective tissues. Innominate artery (IA) injuries are rare and accounted for roughly 0.4% of vascular wounds and 9% of chest penetrating vascular traumas [1]. In the past 30 years, less than a hundred cases of IA pseudo aneurysm (IAP) have been published since 1990. As detailed in **Table 1**, the vast majority of papers on this subject are case reports. Currently, open surgery (OS) remains the treatment of choice [2,3]. However, this surgical strategy possesses a considerable risk of operative morbidity and mortality. Adaptation of the endovascular repair (EVR) modality to supra-aortic vessels

Table 1 Baseline data from published case reports regarding brachiocephalic artery pseudo aneurysms management (n=84).

Authors /Year	Sex/age	Etiology	Delay Follow-up	Clinical presentation	Imagery Location	Treatment Outcomes
Lovelock et al 2020 [39]	M/36	Blunt trauma Motor vehicle	Emergency 6 months	Polytrauma, shock, arm ischemia	CTA Proximal	MS, CPB, AI prosthetic graft
Pawar et al 2020 [33]	M/20	Tracheostomy	2 days 1 month	Severe bleeding, oozing (Peritracheostomy)	CTA+ART Mid	Failed primary repair Covered stent graft
Dapratiet al. 2020	M/49	Aortic surgery (Anastomotic)	6 months 1 month	Mass	CTA AI junction	MS, CPB, aorto-carotid bypass
Volpe et al. 2019 [59]	M/62	Blunt trauma	Emergency 24 months	Unstable patient Hemorrhage shock	CTA+ART Proximal	Covered stents (FA) Endoprothesis (DTA)
Safran et al. 2019 [17]	M/46 M/90	Central vein catheterization Tunnel catheter (hemodialysis)	3 hours 5 years 3 weeks 1 month	Chest and neck pain Shock, swelling Pulsatile neck	ART Proximal CTA+ART Proximal	Iliac leg extension stent grafts Stent grafts. BAA
Chen et al. 2019 [11]	F/63	Aortic surgery (anastomotic)	4 months 4 days	Asymptomatic	CTA Proximal	Covered stent AA + FA accesses
Choudhryet al. 2019 [9]	F/58	Lung cancer (CRL), mycotic	3 months 1 month	Bleeding (from chest wall wound), shock	CTA Proximal	Stent grafts + carotid-carotid bypass PTFE
Li et al. 2018 [52]	F/60	Meniere's disease	----- 1 year	Pulsatile mass, dysphagia Dyspnea. Rupture	CTA+ART Distal	Kissing covered stent FA+BA access
Sibilleet al. 2017 [53]	F/60	Blunt trauma Motor vehicle	14 days 1 month	Chest pain	CTA, BAA Proximal	Stent graft + bypass
Choufaniet al. 2016 [58]	M/28	Penetrating injury (shrapnel)	Emergency 1 month	Dyspnea Asymptomatic	CTA+ART Proximal	Covered stent FA open access
Terceros-A et al. 2016 [6]	M/43	Blunt trauma	Emergency ------	Multiple trauma Unstable patient	CTA Proximal	Conservative survey
Machado et al. 2016	M/76	Tracheostomy	2 weeks 1 month	Bleed	CTA Proximal	Bifurcated bypass
Lee et al. 2015 [8]	M/55	Anastomotic	25 years 6 months	Chest pain	CTA Distal	Stent + PTFE
Rahimiet al. 2015 [48]	M/60	Carotid surgery	----- 10 months	Stroke, hemiparesis, arm ischemia	ART Mid	Covered stent
Roussel et al. 2015 [10]	F/42	SVC stenting	4 years 18 months	Hemoptysis	CTA+ART AIJ	Covered stent graft + Axilloaxillary bypass
Galanteet al. 2015 [13]	M/64	Blalock-Taussig shunting	----- 2 months	Headache, coma Stroke	CTA+ART Proximal	Stent graft Died (stroke)
Koorakiet al. 2015 [51]	F/74	Hemodialysis catheter	19 days 3 months	Hematoma, thrill, dysphagia, hoarseness	CTA+ART Mid	Covered stents FA access
Hodjatiet al. 2015	F/29	Blunt trauma	1 month 3 months	Dyspnea, stridor, respiratory failure	CTA Proximal	Open repair, bypass Synthetic graft
Liu et al. 2014 [30]	M/45	Blunt trauma	61 hours 8 months	Back pain, dyspnea Respiratory distress	CTA, BAA Proximal	Quadrifurcated graft CPB, sternotomy
Boutayebet al. 2014 [38]	M/54	Blunt trauma	Emergency 1 month	Multiple trauma	CTA Origin	MS, CPB Prosthetic graft
Brahmbhattet al. 2014 [44]	M/57	Tracheostomy (Dilatation)	Emergency Weeks	Bleeding	CTA Mid	Open repair. Died
Azarconet al. 2014 [16]	M/25	Blunt trauma Motorcycle	2 days 5 days	Asymptomatic	CTA+AOT Distal	Covered stent-Viabahn, endoleack
Greene et al. 2014 [26]	F/3	Explosion (metal fragment)	6 days 1 week	Fragmentation injuries Hemothorax	CTA Distal	Manubriotomy, vein patch angioplasty
Fukuda et al. 2014 [54]	M/59	Anastomotic	2 weeks 8 months	Back pain	CTA+AORT Proximal	Covered stent BA access
Alagappanet al. 2014	M/20	Blunt trauma	1 hour 1 month	Ischemic stroke Hemiparesis	CTA Proximal	Open surgery ETE anastomosis

Mosqueraet al. 2013 [40]	M/49	Blunt trauma	2 weeks 1 year	SVCS, respiratory distress Pulsatile swelling	CTA Distal	Pericardial patch CPB, sternotomy
Roan et al. 2013 [28]	M/76	Infection	2 weeks 5 years	Fever, sepsis	CTA Distal	MS, CPB, Extra-anatomic bypass
Philip et al. 2012 [42]	M/0.3	Subclavian vein catheterization	8 days 7 days	SVCS, respiratory failure	DUS+CTA Mid	Suture 7/0 Prolene
Durieuxet al. 2012 [43]	M/59	Endocarditis *Staphylococcus*	6 weeks 1 month	Mitral endocarditis	USD+MRA Proximal	Cryopreserved arterial homografts
Scantleburyet al. 2012 [56]	F/46	Lymphoma surgery	7 years 3 months	Painful pulsatile mass (anterior chest wall)	AORT Proximal	Covered stent FA access
Darkoet al. 2012	M/23	Blunt trauma Motor vehicle	Emergency 2 weeks	Neck and chest wall tenderness	CTA Proximal	MS, Bypass Dacron Aorto-innominate
Miliauskaset al. 2012	M/58	Chest traumas and surgery	1 year 1 month	Dyspnea, massive hemoptysis	CTA+AORT Proximal	Aneurysmectomy
Takigushiet al. 2011	M	Traumatic injury	------ 1 month	-------	CTA Mid	Open repair, CPB Artificial vessel
Caballero V et al. 2011 [5]	F/26	Blunt trauma	3 years	Mass, dyspnea	CTA	Non-mentioned
de Troiaet al. 2011 [45]	F/71	Subclavian vein cannulation	Emergency 16 months	Acute chest pain Anemia	CTA Mid	Covered wall graft stent, FA access
Cordovaet al. 2011 [37]	M/32	Blunt trauma	Emergency 30 days	Multiple trauma	CTA+ART Mid, BAA	AI Bypass (Dacron) + aortic stent graft
Mousaet al. 2010 [27]	M/51	Blunt trauma Motor vehicle	28 years 1 month	Cough, chest pain Acute dyspnea	X-Ray CTA	Sternotomy Dacron graft
Salcuniet al. 2009	F/71	Subclavian vein catheterization	6 hours 16 months	Neck pain	CTA+ART	Wall stent
Kanwaret al. 2009 [47]	M/17	Blunt chest trauma (football)	3 months 2 years	Stroke (weakness) Pulsatile mass	CTA+ART Mid	Open repair
Ahmed et al. 2009 [49]	M/53	Mediastinoscopy (biopsy)	3 months 1 month	Asymptomatic	CTA+AORT Proximal	Covered stent grafts FA access
Wang et al. 2009 [62]	F/39	Dilatational tracheostomy	2 days 18 hours	Acute bleeding (tracheostomy)	ART Mid	Wallgraft stents Embolization. Died
Elahiet al. 2009	M/79	Coronary surgery	10 years 1 month	Acute onset hoarseness Dysphagia	CTA (giant) Proximal	Bypass (Dacron) + Stenting graft
Guilbertet al. 2008	F/79	Jugular vein catheterization	3 hours 1 month	Pulsatile blood return	------	Ministernotomy Suture
Rabuset al. 2008 [41]	F/27	Blunt chest trauma	4 years Weeks 1 month	Lung symptoms pneumonia	CTA+MRA Proximal	Sternotomy- bypass (Aorto-carotid-subclavian Dacron)
Rispoliet al. 2008 [35]	M/71	Innominate artery stenting	12 years 20 months	Chest pain, dyspnea Cough	CTA (giant) Proximal	Median sternotomy CPB, Bypass Dacron
Petrocheilouet al. 2008 [15]	F/65	Hickman line insertion	6 hours Death	Dyspnea, stridor, shock Instable patient	CTA Proximal	Median sternotomy Died (Hemorrhage)
Choi et al. 2008 [14]	M/49	Blunt trauma	14 months 1 month	Dyspnea, hoarseness	CTA (BAA) Proximal	Open surgery, CPB Prosthetic graft
Huang et al. 2008 [57]	M/36	Blunt trauma Motor vehicle	Emergency 1 year	Severe chest back pain	CTA+ART Distal	Covered stent graft FA access
Vanhuyseet al. 2008 [29]	F/49	Blunt trauma Clavicle luxation	----- 1 month	Chest pain	CTA Mid	Open surgery Bypass
Ito et al. 2007 [18]	M/86	Atherosclerotic ulcer	4 months 1 month	Hemoptysis, hoarseness Neck pain	CTA+ART Mid	Large MS, Prosthetic graft (Dacron)
Augoustideset al. 2006 [34]	M/16	Tracheostomy	7 months 5 days	Hemoptysis	Giant IAP	Endovascular coiling FA, CPB

Sakamoto et al. 2006 [20]	M/64	Endovascular stenting	34 years 3 weeks	Dyspnea, cough, fever Repeated pneumonia	CTA+ART Mid	CPB, Prosthetic graft
Szetoet al. 2006 [46]	M/16	Fistula (trachea and innominate)	7 months 3 months	Bleeding, RDS Rupture	ART Proximal	Stent graft via carotid artery
Maddaliet al. 2006 [61]	F/50	Jugular vein catheterization	3 years 1 month	Pulsatile swelling, bruit	ART Distal	Thoracotomy, CPB Patch, Stent Gore-tex
Zoffoliet al. 2006 [60]	F/35	Blunt trauma Vehicle crash	Emergency 1 year	Multiple trauma Respiratory insufficiency	CTA+AORT Distal	Laparotomy Stent graft via aorta
Tsutsumiet al. 2005	M/62	Innominate catheterization	3 months 1 month	Intermittent chest pain	CTA+MRA Mid	Median sternotomy Prosthetic graft 8mm
Okubo et al. 2005 [31]	F/68	Radiation Mediastinitis	65 months 18 months	Chest skin ulceration Rupture	ART Proximal	Median sternotomy Bypass Dacron
Wells et al. 2005 [36]	M/20	Blunt trauma	Emergency 6 days	Severe blunt injury	ART (BAA) Proximal	Median sternotomy Bypass grafting
Symbaset al. 2005 [3]	M/32 M/32 M/40	Blunt trauma Blunt trauma Blunt trauma	Emergency 23 days Emergency 8 days Emergency 9 days	Multiple trauma, shock Multiple trauma Multiple trauma Chest and back pain	CTA+ART Proximal AORT AI junction ART Proximal	MS, AI PTFE graft interposition Failed EVAR MS, AI PTFE graft MS, AI PTFE graft interposition
Dhaliwalet al. 2005 [12]	M/20	Blunt trauma	5 months 3 weeks	RDS, SVCS, swelling Stridor	ART (giant) Distal	Thoracotomy + CPB Suture 4/0
Reddiet al. 2005 [21]	M/46	Stab injury wound	26 years Months	Stridor	CTA + ART (giant) Mid	Large sternotomy Suture
Cothrenet al. 2005 [25]	M/35	Blunt trauma Motor vehicle	Emergency 33 days	Severe chest injury	ART Proximal	Sternotomy Bypass PTFE 12 mm
Kaushalet al. 2005	M/62	Mycotic *Staphylococcus*	4 months 6 weeks	Embolic stroke Hemiparesis, hoarseness	MRA Proximal	Median sternotomy CPB, Patch pericardia
Moise et al. 2004 [32]	F/46	Blunt trauma Motor vehicle collision	Emergency 6 months	Multiple trauma Stable hemodynamics	CTA+AORT Proximal BAA	MS, CPB, graft interposition.
Bielbet al. 2003	M/45	Mediastinoscopy	----- 1 month	------	Proximal	Failed Stent graft Aorto-carotid bypass
Walter et al. 2003 [19]	M/68	Balloon angioplasty	3 weeks 3 weeks	Recurrent laryngeal nerve palsy	MRA Distal	Open bypass + CPB Bifurcated Dacron
Amondet al. 2002 [7]	M/80	Subclavian vein catheterization	----- -----	Thoracic pain	-------	Thrombosed spontaneously
Pruitet al. 2002 [23]	F/74	Mycotic stenting	2 weeks Death	Distal septic emboli	CTA	Sternotomy + CPB Died
Axisaet al. 2000 [50]	M/21	Blunt trauma Road accident	Emergency 18 months	Flail chest, hemothorax Severe injuries	CTA+AORT Mid	Cervicotomy Covered stent graft
Sommer et al. 2000	M/19	Blunt injury	3 years 1 month	Stroke, hemiparesis	MRA+ART Distal	Surgical removal, saphenous vein graft
Chandler et al. 1999 [55]	M/20	Blunt trauma Road accident	Emergency 1 month	Flail chest Hemopneumothorax	CTA + ART Proximal	Palmaz stent via FA and CCA
Harvey et al. 1999	M	Penetrating injury (gunshot)	2 months 1 month	Bilateral hemiparesis Hemiplegia	ART Distal	Carotid-brachial bypass
Ihayalet al. 1999	M/69	Subclavian vein catheterization	7 months 1 month	Hoarseness	CTA + ART	Sternotomy Patch Gore-Tex
Boulahyaet al. 1999	M/33	Jugular vein catheterization	1 year 23 months	Hemoptysis, swelling	USD + CTA + ART	Cervicosternotomy Shunt, patch Dacron
Yamashiroet al. 1998	F/28	Trauma traffic accident	Emergency 1 month	Blunt chest trauma	AORT Proximal	Open surgery Bifurcated Dacron
Ruebbenet al. 1997	M	Polytrauma	Emergency 1 month	Polytraumatized patient	Trunk Mid	Open surgery Stent graft placement

Lobo et al. 1997	M/17	Penetrating injury (rifle)	3 hours 1 year	Hemoptysis	CTA+AORT Proximal	Extended MS, Dacron graft
Souryet al. 1995	F/63	Subclavian vein catheterization	2 days 1 month	Asymptomatic	CTA + ART Mid	Open surgery Suture
Maria et al. 1995	M/25	Blunt chest trauma	Emergency 18 months	Resuscitated patient (cardiac arrest)	CTA Proximal	MS, AI bypass (PTFE)
Kraus et al. 1993	F/40	Blunt chest trauma	Emergency 14 months	Multiple trauma Cutaneous wound	CTA+ART Mid	SCI+MS ETE anastomosis
Folliset al. 1992	F/55	Subclavian vein catheterization	2 months 1 month	Dyspnea	CTA + ART	Sternotomy + CPB ETE anastomosis
Abbreviations: AA: Axillary Artery; AIA: Aorto-innominate Artery; AIJ: Aorto-innominate Junction; AORT: Aortography; ART: Arteriography; BA: Brachial Artery; BAA: Bovine Aortic Arch; CCA: Common Carotid Artery; CPB: Cardiopulmonary Bypass; CTA: Computed Tomography Angiography; DTA: Descending Thoracic Aorta; DUS: Doppler Ultrasound; ETE: End-to-End; FA: Femoral Artery; MS: Median Sternotomy; PO: Postoperative; PTFE: Polytetrafluoroethylene; RDS: Respiratory Distress Syndrome; SCI: Supra-Clavicular Incision; SVCS: Superior Vena Cava Syndrome						

injuries has become popular in the recent decades [4]. EVR is a more practical technique than OS and effective as a lifesaving approach [1,4]. Awarding to our knowledge, no update with robust data has been previously established in this setting. The management continues unstandardized and there is no consensus concerning the optimal treatment, as to indications for EVR or OS techniques. For instance, the benefits of endovascular treatment, like short operative time and less trauma, shorter hospital and intensive-care unit stays, have typically been evaluated only with limited data on the basis of small samples [2,4]. Recently, a series study reported excellent results with mid-term follow-up (6-12 months), but only in a few young patients [4]. Accordingly, without a comparison of OS and EVR results in treating IAPs, it was premature to conclude that EVR technique is better than OS at dealing with these patients. We therefore conducted a systematic review of IAPs treated by EVR or OS repair in the literature to analyze comparatively characteristic differences between the both groups and identify valuable clinicoanatomical criteria for better decision-making of the therapeutic management.

Methods

Study Identification

Articles published between 1990 and May 2020 in the MEDLINE and EMBASE databases were searched online. The descriptors used to find titles of possible interest were «post-traumatic innominate artery pseudo aneurysm», «surgical and endovascular brachiocephalic artery repair», «supra-aortic vessels injury», «covered stent and in nominate artery pseudo aneurysm». After reading the abstracts online, 81 articles were downloaded for complete reading. All papers referenced were read selectively, and the review finally included 78 articles (81 cases). These selected reports covered a period of 30 years, while 14 (17.3%) were published from 1992 to 2000, 32 (39.5%) from 2001 to 2009, and 37 (45.7%) between 2010 and May 2020.

Criteria for inclusion and data extraction

We included relevant papers with comprehensive information on the following criteria: patient demographics including age, gender; etiology and mechanism of vascular trauma like catheterization and surgery, blunt trauma, inflammatory or infectious disease and penetrating injury; most comorbidities; clinical presentations and symptoms; concurrent injuries; radiological findings and details of treatment; arterial wound characteristics; perioperative complications and mortality; follow-up and outcomes. Abstracts and case series without specified information according to the stated selection criteria were excluded. All data were extracted from the article texts.

Statistical analysis

Patient data were collected in a Microsoft Excel database. The exploratory data analyses checked the distribution of values and presented the results as the mean and standard variation for numerical variables. Nominal data were presented in the form of frequencies and associated percentages. Differences between patients receiving OS and EVR were checked using the chi-squared test or Fisher's exact test for categorical variables. All statistical tests were tailed, and $p<0.05$ was considered statistically significant. All statistical analyses were performed with Epi Info 7^{TM} software, version 7.2.2.6.

Results

Eighty four cases were recorded. Eight patients receiving hybrid techniques were reviewed separately because we have not identified any significant difference for this group compared to the OS or EVR group. Among them, 50% were male, 87.5% had comorbidities and hard signs, 62.5% suffered from iatrogenic injuries, 25% presented with bovine arch anatomy (Figure 1), 75% underwent endovascular stenting and prosthetic bypass grafting concomitantly with minor complications in 50% of cases, no deaths occurred. Additionally, we excluded three cases, two of which seems to support no specific management and the other recovered without any surgical intervention [5-7]. The latter was observed in an elderly patient who complained of chest pain after percutaneous subclavian vein catheterizations, in which the pseudo aneurysm has thrombosed spontaneously [7]. Overall baseline clinical characteristics of the 73 patients evaluated are indicated in **Table 2**. The study included 52 (71%) men and 21 (29%) women with a mean age of 46 ± 21 years (ranges 3 months-90 years). Fifty patients underwent OS (68.5%) and 23 received EVR (31.5%). The primary OS techniques used included graft interposition or prosthetic bypass (70%) (**Figure**

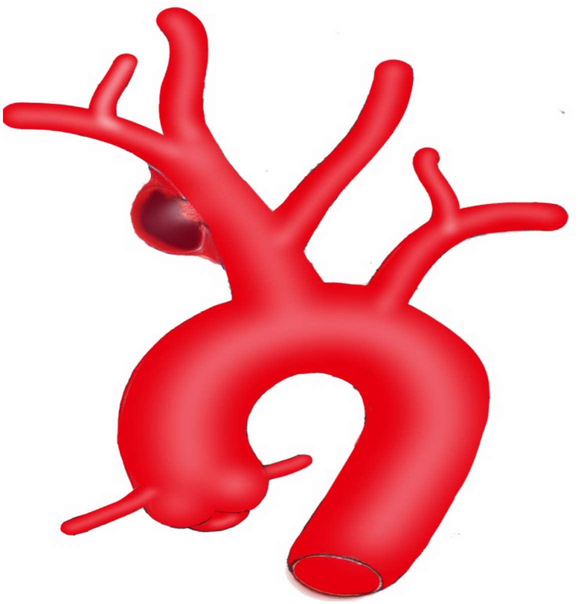

Figure 1 Typical variant of bovine aortic arch anatomy (common origin of innominate artery and left common carotid artery) [30].

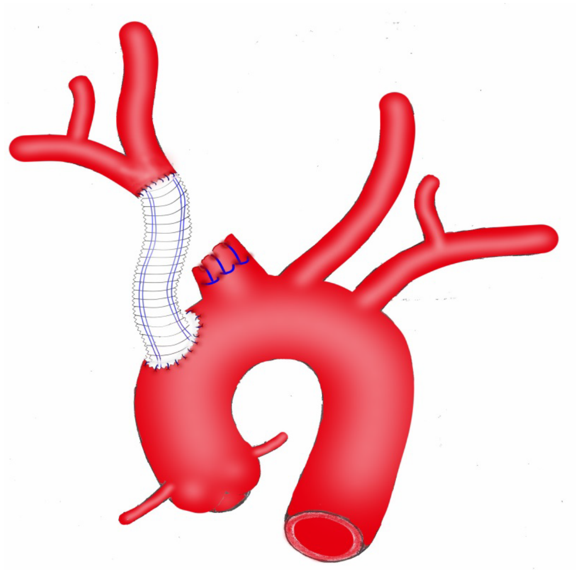

Figure 2 Aorto-innominate prosthetic bypass grafting [39].

Table 2 Baseline clinical characteristics in the 81 cases evaluated.

Variables	Open repair (50)	Endovascular repair (23)	Hybrid repair (8)	*p* value
	N (%)	N (%)	N (%)	
Mean age	45.6 ± 20.9	46.7 ± 21.5	53.7±14.8	0.084395
Gender				
Male	37(74)	15(65.22)	4(50)	NS
Female	13(26)	8(34.78)	4(50)	0.000993
Diagnostic delay (month)				
< 1	28(56)	14(60.87)	2(25)	0.009237
[1-12]	13(26)	4(17.39)	1(12.5)	0.056948
> 12	8(16)	1(4.35)	4(50)	0.176482
Imprecise	1(2)	4(17.39)	1(12.5)	0.025492
Hard signs	47(94)	13(56.52)	7(87.5)	0.000177
Superior vena cava syndrome, respiratory distress syndrome, dyspnea, stridor	10(20)	2(8.7)	2(25)	0,099655
Pulsatile bleeding, hemoptysis, pulsatile hematoma (chest, neck), pulsatile mass, thrill, audible bruit, shock, instable patient, polytrauma, severe injury, multiple trauma, neck and chest tenderness (enlarging hematoma)	24(48)	9(39.13)	5(62.5)	NS
Stroke (hemiparesis, headache, coma), arm ischemia, nerve palsy	7(14)	2(8.7)	---------	0.024815
Endocarditis, pneumonia, mediastinitis, septic emboli, sepsis	6(12)	--------	---------	
Soft signs	4(8)	10(43.49)	1(12.5)	0.010421
Asymptomatic patient, stabilized patient **Isolated pain (chest, neck, back)** **Stable hematoma or non-pulsatile swelling, anemia** **Hoarseness, dysphagia**				
Etiology of the pseudoaneurysm				

Iatrogenic injury	13(26)	11(39.13)	5(62.5)	0.000182
Open surgery	2(4)	4(17.39)	2 (25)	0.000438
Vascular catheterization	7(14)	5(21.74)	2(25)	0.000005
Endovascular stenting	4(8)	----------	---------	
Medical intervention (tracheostomy, mediastinoscopy)	2(4)	4(17.39)	1(12.5)	0.000438
Blunt trauma	25(50)	5(21.74)	2(25)	0,032873
Penetrating injury	5(10)	1(4.35)	---------	0.055547
Inflammatory disease	------	1(4.35)	---------	
Infection	3(6)	----------	1(12.5)	0.219944
Atherosclerotic ulcer (spontaneous perforation)	1(2)	----------	----------	
Comorbidities	10(20)	12(52.17)	7 (87.5)	0.000001
Tetralogy of Fallot	--------	1(4.35)	----------	
Coronary artery disease, ischemic cardiomyopathy, diabetes mellitus, dilative cardiomyopathy	2(4)	----------	----------	
Aortic arch replacement, aortic regurgitation/dissection	1(2)	1(4.35)	1(12.5)	
Chronic obstructive pulmonary disease	------	1(4.35)		
Coronary heart disease, coronary surgery, left cardiac failure, chronic renal failure	------	---------	1(12.5)	
Mediastinal lymphoma/carcinoma, chemoradiation	1(2)	2(8.7)	1(12.5)	
Tracheostomy, thymoma, sternotomy	1(2)	---------	2(25)	
Lung carcinoma, chemoradiation, lobectomy	1(2)	---------	1(12.5)	
Cerebral palsy, cerebral tumor (meningioma)	-----	2(8.7)	---------	
End stage renal insufficiency, hemodialysis	1(2)	1 (4.35)	---------	
Meniere's disease	-----	1(4.35)	---------	
Type-2 diabetes, heavy smoking, multi-drug treated hypertension	2(4)	1(4.35)	1(12.5)	
Laryngeal cancer, laryngectomy, chemoradiotherapy	1(2)	1(4.35)	---------	
Hemicolectomy (adenocarcinoma), chemotherapy	-----	1(4.35)	---------	

2), lateral sutures (14%) patch angioplasty (10%) and end-to-end anastomosis (6%). The two groups were approximately similar in age, gender and diagnostic delay. Sixty patients (82.2%) presented with hard signs. Of these, 47 cases received OS procedures with significant predominance (94% *vs.* 57%) especially for patients whose evident symptoms of stroke or infections were present. Some patients were asymptomatic or displayed stable vital signs (19%). The overwhelming majority of them were managed endovascularly (44%*vs.* 8%) (p=0.0104). Regardless of the injury mechanism, iatrogenic (30%) and blunt (41%) traumas attended the most prominent events of all etiologies. Notably, many iatrogenic injuries were repaired by EVR (39%*vs.* 26%) with $p<$ 0.05. Blunt traumas were significantly more frequent in the OS group (50%*vs.* 22%). OS repair was performed in the large majority of patients with penetrating injury (18%*vs.* 9%) (p=0.003). Most comorbid patients (30%) benefited from EVR procedure (52%*vs.* 20%) with p<0.001. Other perioperative data and outcomes are outlined in **Table 3**. Concurrent injuries were present in 34 patients (47%) with no significant difference between the two groups (48%*vs.* 46%). Giving to the radiologic findings obtained from CTA, arteriography and operative views, OS had handled many patients who developed loco regional complications without statistical significance (60%*vs.* 48%) especially for those experienced giant pseudo aneurysms. There were more injuries with contained rupture and thromboembolism events in EVR (30%*vs.* 22%) and OS (12%*vs.* 9%) groups respectively (p<0.02). Several patients in whom arterial tears were limited to the mid segment of the IA benefited from EVR procedure with significant proportion compared with those underwent OS repair (26% *vs.* 24%). Injuries to the distal portion of the IA have been typically managed by OS (16%*vs.* 13%) (p<0.05). In the OS group, the cardiopulmonary bypass (CPB) using was significantly more frequent in the management of proximal injuries (18%*vs.* 8%). The length of arterial tears was available in 35 patients (48%), in which no significant difference was discovered between the two groups (54%*vs.* 35%). A bovine arch anatomy was encountered in nearly 7% of patients, of which all arterial tears were located within the proximal IA segment, and most of them underwent OS repair (80%). Patients in the EVR group had more operative failure and complications rate (39%) rather than those in the OS group (20%) (p<0.002). The early reoperation rate was also significantly higher in the EVR group (13%*vs.* 4%). The length of hospital stay was stated in 18 patients (25%), which was longer in the OS group compared with the EVR group (p<0.007). The mean follow-up was 5 months in the OS group versus 9 months in the EVR group (p=0.5285). The mid-term follow-up of EVR was significantly higher than those of OS (57%*vs.* 30%). There were 5 mortalities totally (7%), including 4 early within 30 days after operations and 1 late over 30 days following procedures. The mortality rate was higher in the EVR procedure (9%) compared with the OS (6%) (p<0.05). The 3 early mortalities of OS were caused by multiple organ failures, acute right heart insufficiency and hemorrhagic shock. The other early death occurred from a massive bleeding as a result of failed EVR processes. A late

Table 3 Other perioperative data and outcomes.

Variables	Open repair (50)	Endovascular repair (23)	Hybrid repair (8)	*p* value
	N (%)	N (%)	N (%)	
Radiologic data				
CTA	20(40)	----	----	
CTA + Arteriography	14(28)	17(73.91)	7 (87.5)	0.000052
MRA	6(12)	----	----	
Arteriography	9(18)	6(26.09)	1(12.5)	0.000052
Concurrent injuries	23(46)	11(47.83)	4(50)	NS
Left common carotid artery occlusion	2(4)	----		
Superior vena cava fistula, superior vena cava compression	2(4)	1(4.35)	----	
Airway obstruction, tracheal compression, tracheal deviation	4 (8)	----	1(12.5)	
Tracheal obstruction, repeated pneumonia, tracheal fistula	6(12)	3(13.04)	1(12.5)	
Common carotid artery–internal jugular vein fistula	------	1(4.35)	-----	
Common carotid artery laceration/thromboembolism	3(6)	----	-----	
Innominate artery dissection/transection/obstruction	2(4)	2(8.7)	-----	
Subarachnoid hemorrhage, spinal cord contusion, paralysis	------	1(4.35)	-----	
Aortic dissection, aorto-innominate junction injury	2(4)	2(8.7)	2(25)	
Descending thoracic aorta transection/cardiac injury	2(4)	1(4.35)		
Locoregional complications of the pseudoaneurysm	30(60)	11(47.83)	2(25)	NS
Giant pseudoaneurysm (diameter ≥ 6 cm) Contained rupture Thrombosis/embolism	13(26) 11(22) 6(12)	2(8.7) 7(30.43) 2(8.7)	2(25) ------ ------	0.211608 0.000263 0.011076
Arterial wound localization				
Proximal portion	25(50)	11(47.83)	4(50)	NS
Mid portion	12(24)	6(26.09)	2(25)	0.004623
Distal portion	8(16)	3(13.04)	2(25)	0.009237
Imprecise	5(10)	3(13.04)	------	0.000065
Arterial tear length				
≤ 10 mm	17(34)	6(26.09)	1(12.5)	0.098553
>10 mm	10(20)	2(8.7)	------	0.099655
Bovine-type aortic arch anatomy	4(8)	1(4.35)	2(25)	0.025492
Cardiopulmonary bypass use	16 (32)	1(4.35)	1(12.5)	0.520998
Perioperative complications	8(16)	6(26.9)	4(50)	0.000002
Pneumonia, deep vein thrombosis, sepsis, respiratory failure	3(6)	1(4.35)	-------	
Bleeding and massive amounts blood transfusion	2(4)	-----	1(12.5)	
Type-II endoleak blush	-----	2(8.7)	1(12.5)	
Endovascular stenting or coil embolization failure	-----	2(8.7)	1(12.5)	
Hemorrhage, cardiac arrest, acute renal insufficiency	3(6)	1 (4.35)	-------	
Fistula between trachea and innominate artery	------	-----	1(12.5)	
Reoperation	2(4)	3(13.04)	1(12.5)	0.000005
Stent restenosis from intimal hyperplasia (2 months) Endoleak (18-hour, 4-day, 19-day)	---- ----	1(4.35) 2(8.7)	 1(12.5)	
Unstable sternum (6 days), failed primary repair (bleeding)	2(4)	-----	-------	
Perioperative death	3(6)	2(8.7)	-------	0.000005
Stroke complications	----	1(4.35)		
Multi-organ failure	1(2)	-----		
Acute right heart failure	1(2)	-----		
Hemorrhagic shock and electromechanical dissociation	1(2)	1(4.35)		
Hospital stay length(days) *< 10* *≥ 10*	 6(12) 7(14)	 5(21.74) -----	 ------- 1(12.5)	 NS

Follow-up (month)				
Short-term < 2	31(62)	9(39.13)	4(50)	NS
Mid-term [2-24]	15(30)	13(56.52)	4(50)	0.000001
Long-term (5-year)	1(2)	1(4.35)	-------	NS
CTA: Computed Tomography Angiography; NS: Non-Significant; MRA: Magnetic Resonance Angiography.				

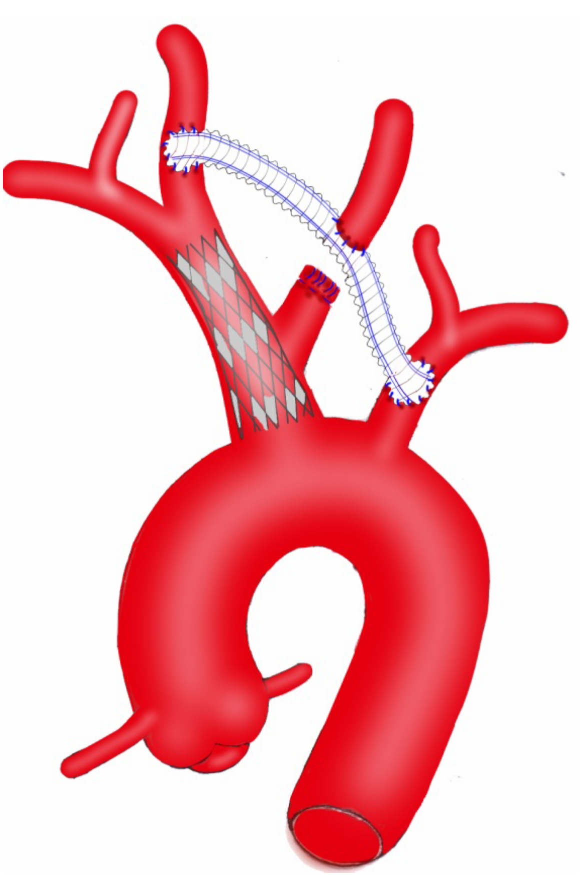

Figure 3 Hybrid repair of an in nominate artery pseudo aneurysm associated with a bovine aortic arch anatomy [53].

mortality was observed in an EVR patient who died from stroke complications. The main EVR-related morbidity consisted of early reintervention, endovascular stenting and coil embolization failures, type-II endoleak, and pneumonia and stent restenosis.

Discussion

This review documented that OS and EVR techniques maintained their critical potential purpose and usefulness, as both were advantageously effective and complementary. Hybrid techniques combining extra-anatomic cervical bypass and endovascular stenting have been successfully used in both symptomatic and comorbid patients [8-10]. The general objective of these repair methods is to avoid thromboembolism, bleeding from rupture and nerve compression from mass effects secondary to massive hematoma. The specific indications were to alleviate compressive symptoms of surrounding vital structures such as trachea, esophagus and superior vena cava (SVC) [15-17]. The decision whether to treat with open, endovascular, or both measures should be guided by surgeon experience and the patient's overall symptomatology and comorbid conditions. The utmost criteria should include aortic arch anatomy patterns (bovine aortic arch) and other supra-aortic vessels involvement, location of the arterial wound, and diameter and length of the IA. Granting to the outcomes as mentioned above, OS was reported to be morbid and fatal procedure in some patients. The reason is mostly resulted from the surgical technique itself requiring aggressive median sternotomy, from which extension into the right cervical region is generally [3,18]. This technique has already been associated with sternum instability resulting in an early reoperation [19]. Sometimes, when the CPB is unavailable, other accesses such as concomitant cervicotomy or supra-clavicular incisions and anterolateral thoracotomy have been needed to get better the operative view and to upgrade the quality of control procedures intraoperatively [2,12,20-26]. A maximal vascular exposure also required dislocation of the sternoclavicular joint and resection of the proximal portion of clavicle [27]. Markedly, all patients with thoracic surgery antecedents may be exposed to hazardous events due to vascular dissection and control gesture, which became difficult and hemorrhagic because of multiple fibrous adherences as a result of inflammatory surrounding structures and chronic hematoma [9,18,21,23,28]. The operative length may also be longer particularly in the bifurcated or quadrifurcated prosthetic bypass carrying out (215 – 224 min) [24,29-32]. Rarely performed, lateral suture and end-to-end anastomosis techniques are swift but unsafe in the large arterial substance loss length (> 10 mm), which is frequently associated with high risk of tension, stenosis and stitches dehiscence [33]. Aortic clamping also figures among the incursive patterns of the OS approach. To reduce the operative risks, some investigators employed protective measures for cerebral perfusions, like passive aorto-carotid shunting, electroencephalogram monitoring and CPB using with deep hypothermia and circulatory arrest for management of associated aortic arch injury, large pseudo aneurysms, bovine aortic arch anatomy, and proximal and complex injuries [12,14,18-20,23,28,30-39]. The purpose of the CPB, further, facilitated the subclavian and carotid arteries control with rupturing the pseudo aneurysm [12,40]. Even so, any intempestive maneuver leading to excessive handling of the pseudo aneurysm must be avoided before making a distal clamping to prevent the cerebroembolic risk [24]. Despite the disadvantages of the OS, several situations and patient characteristics benefited from it, as the EVR failed or unavailable [3]. Kieffer et al reported their experience with the most previous cardiovascular OS techniques of 27 IA aneurysms over a 7-years interval. Overall operative morbidity (22%) and mortality (4.3%) rates appear acceptable, and no recurrence or infectious complications has been reported [24]. Also, du Toit et al had good or excellent results in 34 patients who suffered from penetrating IA injuries and treated by OS repair [2]. There were 79% and 6% of survival and operative complications rates respectively. The successfulness of the OS may be explained by achievement of manifold repairs working side- or cross-clamping technique without CPB [2-4,9,10,21,24-26,36,37,41,42]. Nevertheless, cross-clamping the IA with no cerebral perfusion assistance is not recommended in elderly populations because they are likely to have insufficient cerebral artery communications [18]. In addition, pediatric populations and absence of adequate landing zones represent an argument for OS therapy [8,20,26,27,30,37,41,42]. The most primary option for this surgery should include hemodynamically unstable patients, iatrogenic injuries resulting particularly from iterative endovascular maneuvers, free of major comorbidities, youthful populations, mycotic pseudo aneurysms, presence of bovine aortic arch, and injuries to the mid or distal portion of the IA [3,4,14,18,23,28,30,32,35,37-39,43]. In this group, perioperative hypotension, respiratory complications, systemic infection, serious bleeding, and anemia were all linked to the postoperative cardiac morbimortality [2,15,23,24,44]. Hazardous management of a bovine trunk and emergency surgery for a ruptured aneurysm were also reported as a fatal condition with high postoperative mortality rate (> 50%) [2,24]. The top two factors of significant mortality included coma at presentation and associated injuries [2]. Generally foreseeable, intraoperative exsanguinations, irreversible hypovolemic shock, cardiac tamponade, respiratory difficulties necessitating artificial ventilation, extensive cerebral infarction, neurologic deficit and multiple organ failures accounted for the principal perioperative complications reported [2,3,15,23,24,33,45,46]. Vascular complications and large hemorrhage volume are associated with prolonged hospital stay and increased morbidity risks [3]. The most common reported large hospital stay length ranged from 5 to 35 days [3,20,25,26,30,35,37,39,41,42]. Although there is insufficient evidence for follow-up, the mid-term results were satisfactory in terms of survival and free-relapse [2-4,21,30,31,32,35,39,40,47]. Otherwise, surgical repair is so fraught with complications, and despite continued advances in medicine and critical care, morbidity and mortality events may occur. Such constraint is presumably at the origin of motive way and reason to support EVR techniques [4]. Currently, several authors have reported the results of EVR for the management of IAP, and it has subsequently been accepted widely as a therapy option [2,4,15,16,17,33,34,45,48-58]. Adaptation of EVR principles is similar to those employed in the management of supra-aortic vessels injuries, and successful intervention has been advocated. This repair is minimally invasive and faster than OS; however, it is crucially dependent on several criteria including the likelihood of stent infection, and the surgeon's endovascular experience [4,17,33]. Many diagnostic conditions were handled by EVR techniques in patients with complex anatomy setting and history of multiple surgical procedures in the mediastinum, and in the presence of concomitant injuries and mediastinal carcinomas [33,37,46,49,53]. The remaining indications should include incomplete vascular rupture or transection confirmed by angiography, and compatible anatomy with stable landing zones which were commonly achieved within the proximal and mid portions of the IA [2,4,9,10,17,20,38,57]. Another basic option for EVR approach has been suggested to treat large or ruptured aneurysms with erosion of the sternum that was a contraindication to sternotomy because of the potential catastrophic hemorrhage risk [10,13,24,56]. With the technical difficulty and resulting danger of OS approaches, EVR offers an appealing solution, as it allows rapid control of hemorrhage with minimal physiologic impact on the patient [1,4,9,10,17,33,59]. In emergency situations, the decision-making could be performed in stabilized patients and in cases of high surgical risks, for which an eventual OS repair should be considered afterward [3,9,10]. To prevent a delicate dissection, a few studies have reported successful management with covered stent-grafts, wall-graft endoprosthesis, balloon-expandable covered stent, Palmaz stent, Amplatzer device, iliac leg extension stent grafts, bare stent, and kissing stent-grafts [2,4,10,15,16,17,33,34,45,48-60]. The fully percutaneous apical access is often associated with lower blood loss and a shorter hospitalization (1–8 days) in appropriately selected patients [4,15,48,56,59] compared with the surgical approach requiring sternotomy or thoracotomy (5–45 days) [2,3,12,19,20,25,26,28,37,39,41]. Beforehand, overstenting of common carotid artery (CCA) origin has been unsafe in more distal lesions [2,20]. Currently, this was successfully challenged by the report of Li et al, which described the use of kissing stent-grafts for the treatment of focal lesions within the IA bifurcation [52]. In the other extremity, percutaneous device closure of pseudo aneurysm arising from the junction of the IA and the aorta might now be able to be performed safely [56]. The effectiveness of EVR is also associated with distinguished technical success and possibility to treat concurrent injuries such as arteriovenous or tracheo-innominate fistula, IA obstruction and transection of the descending thoracic aorta (DTA) [2,13,33,37,59]. In some cases, EVR procedures may be facilitated by exposure of the arterial access in advance, especially for CCA, and brachial and femoral arteries [33,34,46,50,58]. At intervals, EVR management could be achieved via aorta during laparotomy for abdominal damage control [60]. Whatever the surgeon's ability, this technique is typically exposed to endoleak risk as well as isolated coil embolization failure that was already unable to ensure any IAP exclusion [3,9,34,61,62]. At mid-term follow-up, the pseudoaneurysm exclusion is consistently observed without a significant incidence of endoleak or conversion to open repair [2,4]. As aforementioned, EVR can be reserved as a bridge to open repair once patients have stabilized and local infection control is established [3,9]. It is, in addition, an acceptable treatment modality for patients with a limited life expectancy who would benefit from a short hospital stay and earlier discharge and will be unexposed to the long-term risks. EVR, however, may be complicated by enlargement of the arterial tear leading to a patent sac, requiring subsequently coil embolization and coverage for successful exclusion [9,46,56,61]. The present review supported as well the latest relative contraindication to the EVR therapy for managing IAPs [2]. In fact, injuries in close proximity to the aortic arch or innominate bifurcation should be managed by extra-anatomic crossover bypass with carotid-subclavian transposition and stent graft placement [2,9,10]. EVR was also not compatible with arterial tear length superior or equal to the diameter of the IA, and in the patient diagnosed as having a bovine aortic arch with life-threatening airway compression and severe hemorrhage [30,32,37,61,62]. Actually, the management of the bovine aortic arch trends to be achieved consistently by EVR or hybrid fashion (Figure 3) even in the presence of hemorrhagic shock and transection of the DTA [17,53,59]. Potential concerns with stent-graft placement include stenosis within the stent, despite the antiplatelet therapy, and the possibility of requiring lifelong surveillance, particularly in the trauma setting, in which the patients tend to be young and often not compliant [23,57,58]. At last, vascular access site complication is one of the important and most frequent causes of morbidity following EVR but it was undescribed in this review. Earlier reports on EVR have disseminated promising results; however, only a few case reports and limited series with restricted follow-up were published. Some authors documented excellent results with long-term patency (70-98%), but only in patients who underwent percutaneous transluminal angioplasty for atherosclerotic stenoses and occlusions [63,64]. The crucial question of durability, therefore, remains unanswered. Whatever, it is evident that the presence of a stent graft could complicate a later surgical repair in many ways, and primary OS is preferable for patients considered eligible for this therapy [23,26]. Endovascular treatment positively represents a therapeutic alternative, particularly in emergency and in polytraumatized patients [4,33]. Nevertheless, this process was associated with higher technical failure and morbimortality rates compared with those observed in the OS repair. Therefore, surgical repair continues the preferred treatment because of the lack of long-term data [3,39,65].

Limitation

Some useful information details were unavailable in old data and images articles such as operative technique, hospital stay length, and follow-up.

Conclusion

This review showed that IAPs management can be achieved safely and effectively by EVR or OS regarding 30-day and mid-term morbimortality rates. Hemodynamically stable patients, iatrogenic injuries, antecedent of comorbidities, contained rupture and wound located at the middle portion of the IA were suitable for EVR procedure. OS repair may be proposed in young patients, displayed hard signs, suffered from endovascular stenting and blunt trauma, free of cardiothoracic comorbidities, diagnosed with a bovine aortic arch anatomy, and when the arterial tear is located at the distal segment of the IA. Proximal traumatic injuries are also best treated with a bypass from the ascending aorta to the involved IA, especially when not anatomically suitable for EVR. Hybrid repair with an extra-anatomic cervical bypass may be an ideal fashion for complex injuries or in high-risk patients [8-10,53,61].

Conflicts of Interests

We stated no conflicts of interests and funding on this article.

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