CIRSE

PICTORIAL ESSAY

Endovascular Management of Extra-cranial Supra-aortic Vascular Injuries

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Abstract Supra-aortic vessel injuries are uncommon but can be life-threatening and surgically challenging. Trauma to these vessels may be blunt or penetrating, including iatrogenic trauma following the insertion of central venous lines, which may be preventable. Recent advances in technology have resulted in endovascular therapy becoming a common first-line treatment, and interventional radiologists now play a major role in the management of these vascular injuries. We review the literature on the endovascular management of these types of injuries and describe a spectrum of case-based extra-cranial supra-aortic vascular injuries managed at our institution and the range of imaging appearances, including active contrast extravasation, traumatic vessel occlusion, true aneurysms, pseudoaneurysms, and arteriovenous fistulae.

Keywords Supra-aortic · Endovascular · Trauma · Pseudoaneurysm · Stent graft · Embolization

Introduction

The extra-cranial supra-aortic arteries include the common carotid, cervical portion of the internal and external carotid, vertebral, subclavian, and brachiocephalic (innominate) arteries. Injuries to these arteries are uncommon but can lead to significant complications, including disabling neurological symptoms and death [1]. The overall mortality rates are particularly high in carotid artery injuries (up to 66%), with morbidity and stroke rates highest for internal carotid artery injuries [2]. Supra-aortic arterial injury may occur after blunt or penetrating trauma, with high-energy road traffic collisions the commonest mechanism overall [3]. Iatrogenic arterial injury is increasingly common and seen in the context of attempts on central venous access and surgery [4, 5]. Patients often present with neck swelling, which can lead to airway compromise, penetrating wound, a pulsatile mass following a history of trauma, peripheral/end organ ischaemia, neurological deficit, thrill on palpation, active bleeding, haemothorax, and sometimes tinnitus. Presentation can be either acute or delayed and diagnosis requires a high index of suspicion, rapid use of high-quality computerized tomography angiography (CTA) as first-line imaging, and an integrated multidisciplinary team approach to care. Imaging findings reflect the nature and severity of the injury and include: active contrast extravasation, pseudoaneurysms, true aneurysms, vessel occlusion, spasm and dissection, in addition to arteriovenous fistulae. Each injury must be evaluated and assessed for the risk of further complication, including hemorrhage, aneurysm enlargement, vessel occlusion, and distal thromboembolism [6].

Historically, most supra-aortic arterial injuries have been treated surgically if the lesion was suitable and accessible. Inaccessible lesions, for example aneurysms and dissections, were treated with anticoagulation and antiplatelet therapy, which rarely result in complete resolution [7, 8]. Traditional surgical approaches to supra-aortic artery trauma are associated with high morbidity and mortality rates, especially in the multiply injured and in patients with serious comorbidities [1]. Carotid artery lesions in the

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neck are particularly difficult to repair surgically, necessitating extensive exposures that may result in cranial nerve injuries [6].

Technological advances, particularly the wider availability of stent-grafts, has resulted in endovascular therapy becoming a common first-line treatment and interventional radiologists now play a major role in the management of supra-aortic vascular injuries. This minimally invasive approach offers an alternative that minimises the tissue damage, bleeding, infective complications, pain and disability, long recovery time, and in some cases reduces the high financial cost associated with surgery [1]. In some instances endovascular treatment may be delivered as a stabilizing maneuver in the knowledge that a definitive surgical procedure may be required later on. In addition, endovascular therapy can be used in combination with open surgery to treat patients with certain injury patterns.

We review the diagnosis and management of traumatic (including iatrogenic) supra-aortic vascular injuries and demonstrate the imaging abnormalities with brief discussion of the modalities, CT, MRA, and DSA. We also review treatment options with examples that illustrate reasons for choice and nuances of performance during endovascular treatment.

Diagnosis of Supra-aortic Arterial Injuries

Patients with supra-aortic arterial injury often present with airway compromise, penetrating wound, pulsatile mass

Fig. 1 Common carotid artery pseudoaneurysm. This patient was post pharyngolaryngoesophagectomy and presented with spontaneous bleeding from the surgical drain site on day 10 postoperatively. CT revealed a pseudoaneurysm (PA) from the right common carotid artery (CCA). CTA axial image (A) and sagittal reformat B show right CCA PA. Selective catheter angiography C confirming right CCA PA. A self-expanding covered stent (FLUENCY®, by BARD, 7-x 60-mm) was deployed with complete exclusion of the PA, D catheter angiogram post stent-graft insertion
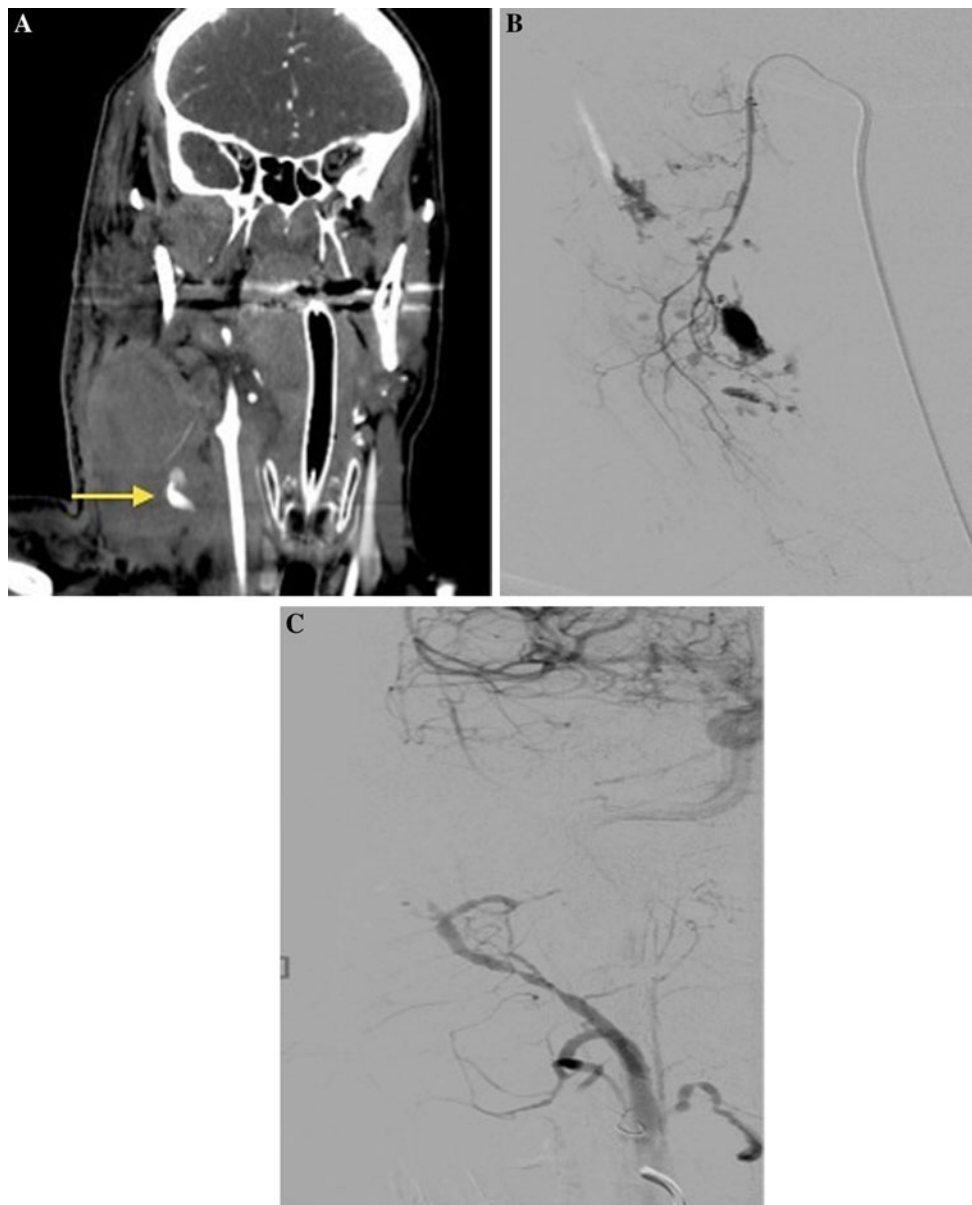
Fig. 2 ECA branch laceration with active bleeding. Motorcyclist involved in a road traffic collision (RTC) and was actively bleeding from the right ear. CTA coronal reformat **A** demonstrates contrast extravasation *(arrow)* within a large, right-sided neck hematoma. Selective catheter angiogram **B** revealed active bleeding from the descending cervical branch of the right ECA showing point of contrast extravasation. This was successfully occluded with PVA particles, **C** angiogram postembolization

following a history of trauma, peripheral/end organ ischemia, neurological deficit, active bleeding, hemothorax, palpable thrill, or tinnitus [9, 10]. Diagnosis of supra-aortic arterial injury depends on mechanism of insult, blunt or penetrating. In blunt trauma, diagnosis primarily requires a high index of clinical suspicion with cervical spine fracture and high-energy mechanism more commonly associated with vascular injury [10, 11]. CT angiography (CTA) is the most commonly available first line imaging, rapidly providing information on associated injuries, which underpins a multidisciplinary team approach to care [11–14].

Commonly, digital subtraction angiography (DSA) is performed after CTA that allows assessment of anatomy and associated injuries for planning the approach and treatment strategy.

Imaging Techniques

Computed tomography angiography (CTA). Injuries to the supra-aortic vessels are usually detected on CTA in blunt polytrauma (as part of a whole body examination) or on
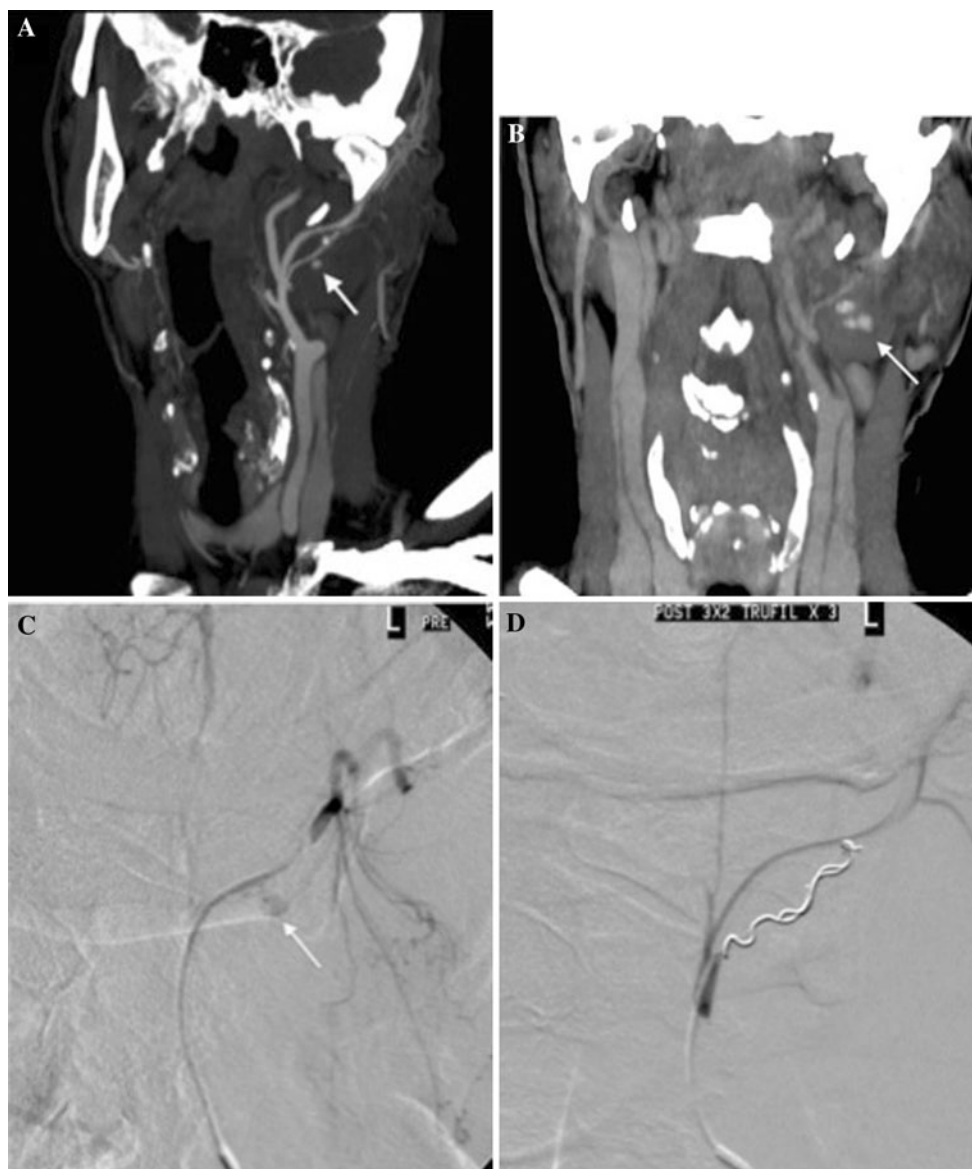
Fig. 3 External carotid artery (ECA) branch laceration. Sixty-two-year old male sustained a stab wound to the left side of the neck and presenting with neck swelling. **A** CTA coronal reformatted image shows contrast extravasation (active bleeding) from the occipital branch of the left ECA (*arrow*). **B** Delayed CTA coronal reformatted image shows continued contrast extravasation within the hematoma in the left side of the neck (*arrow*). Selective angiogram of left ECA **C** confirms contrast extravasation (*arrow*). Active bleeding was stopped after microcoil embolization using 3 microcoils. **D** Selective left ECA angiogram post embolization with cessation of contrast extravasation

multiphase CT scanning in penetrating injuries or where clinical examination suspects a supra-aortic vascular injury. CTA is performed by a 2- or 3-phase technique comprising a noncontrast, arterial and possibly a delayed phase (100 seconds). A volume of interest is selected from the skull base to the aortic arch. Iodine-based contrast agent is injected via a peripherally sited intravenous cannula, preferably in the right arm to avoid flare artifact across the origin of the great vessels. For arterial phase, a bolus-triggered technique is utilized, with a region of interest placed at the aortic arch and triggering occurring at 125 HU (usually occurs at 15-25 s from the commencement of IV contrast injection). Images are reconstructed to a 1 mm slice thickness producing a 3D dataset (isometric voxels). Thin-section axial, coronal, and sagittal reconstructions are viewed for diagnosis. Customised in plane vessel reconstructions also are utilized to provide more anatomical detail and to guide treatment planning.

Magnetic resonance angiography (MRA) is not routinely used for acute imaging but is a useful tool for
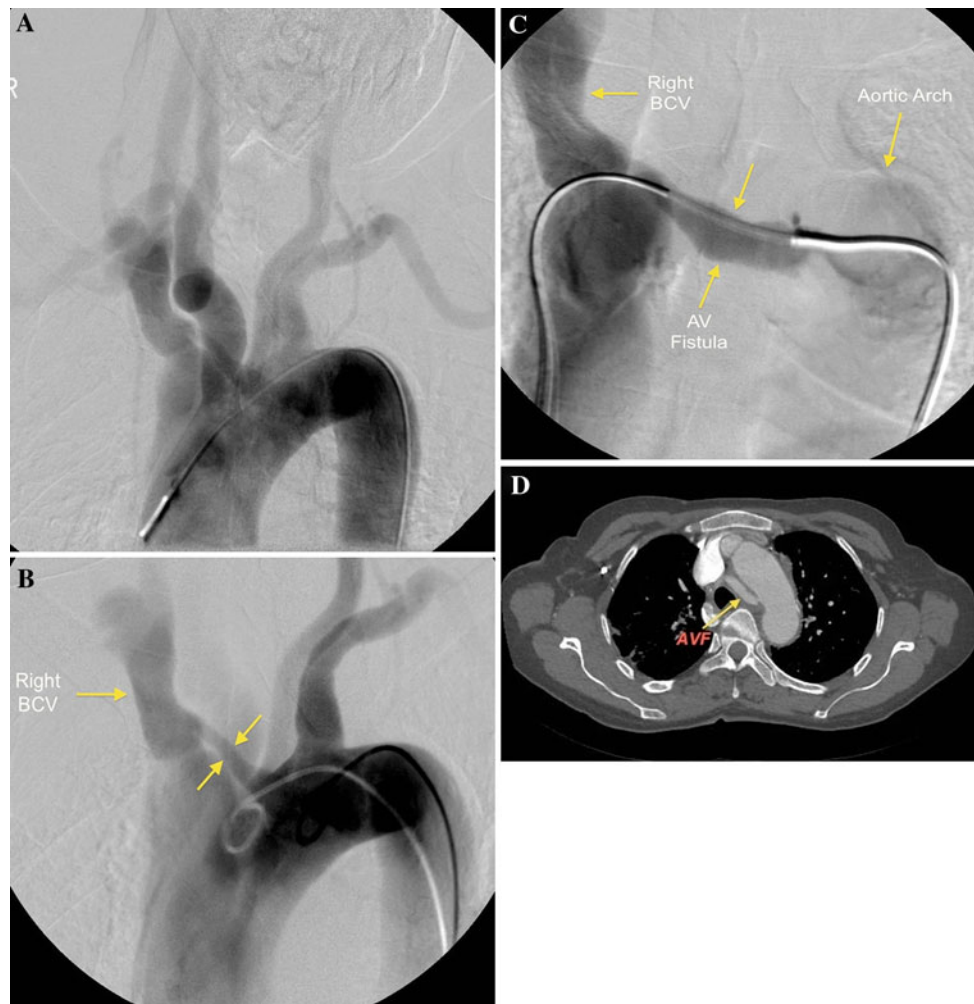
Fig. 4 Aortovenous fistula. Dialysis patient developed a right-sided neck thrill following insertion of a right subclavian dialysis line. An arch angiogram was performed and demonstrated a fistula between the right brachiocephalic vein and the arch of the aorta. Aortic arch angiogram **A** and **B** shows fistulous communication (opposing arrows) between aortic arch and right brachiocephalic vein (BCV). A guidewire and catheter were passed through the fistula to the venous side. The catheter was then withdrawn over a platinum plus wire and further angiography was performed to identify the origin of the fistula from the aorta. Fistulogram **C** confirming vascular communication between the aortic arch and right BCV. This resulted in a small amount of contrast passing into the subintimal space, creating a localized dissection. Axial CTA image **D** shows AV fistula (*arrow*) arising just distal to the left subclavian artery origin and passing anterior to the trachea into the right BCV. The consensus was to treat this AV fistula conservatively

subacute or delayed cases especially to diagnose vessel dissection, aneurysms, and pseudoaneurysms.

Digital subtraction angiography (DSA) is currently not used for diagnosis unless other tests are contraindicated or results are equivocal. This is more often with arteriovenous fistulae. DSA is essentially a part of the treatment process.

Types of Supra-aortic Vascular Injury

1. Arterial Dissection

Arterial dissection is a separation of the layers of the arterial wall with abnormal passage of blood usually beneath the intimal layer; it can be spontaneous or due to trauma. Preexisting wall abnormalities, such as atheroma or collagen vascular diseases, increase the risk of dissection. Dissection is commonest in blunt trauma and is caused by a combination of shear, traction, and obstructing forces in the vessel wall. It also may occur after penetrating and iatrogenic injury. On CTA, dissection classically appears as tapering of the lumen due to the intramural hematoma. Typically, the vessel caliber increases beyond the dissection although it may be narrower than usual due to reduced flow. Cross-sectional imaging also shows the hematoma or areas of contrast within the thrombus and may demonstrate the dissection flap. Chronic dissection may be associated with aneurysmal dilatation of the false
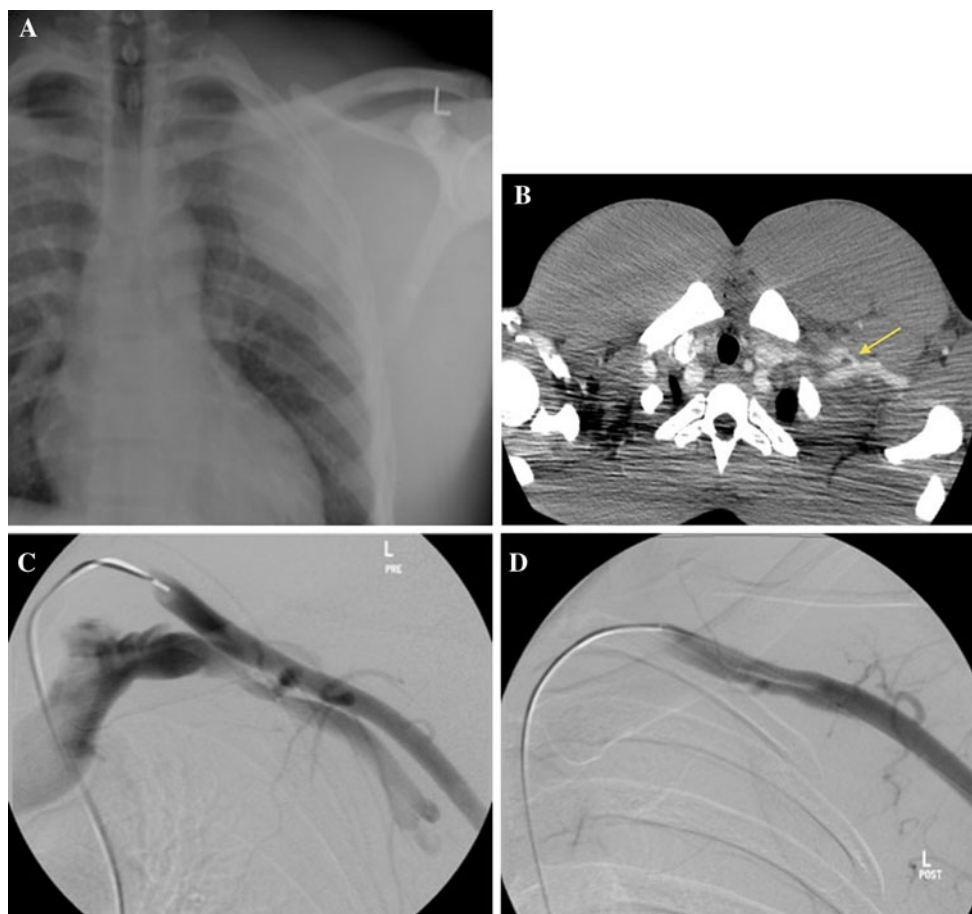
Fig. 5 Arteriovenous fistula between the left subclavian artery and vein. This patient was shot on the left upper chest with a crossbow. **A** CXR shows large opacity overlying the left upper chest and axilla. **B** Axial CTA image shows a fistula between left subclavian artery and vein (*arrow*). **C** Selective left subclavian artery angiogram confirms the fistulous communication between left subclavian artery and vein. This was treated successfully with a self-expanding covered stent graft (FLUENCY® Plus, by BARD) in the subclavian artery. Selective left subclavian angiogram after stent-graft insertion **D** with successful exclusion of the fistula

lumen typically just below the skull base. Dissection also can be associated with distal vessel occlusion due to embolism or in situ thrombosis [8, 12, 15]. Endovascular intervention, for example, in an acutely injured internal carotid artery (ICA) within 48–72 hours of the injury is associated with an increased risk of stroke from catheter manipulation and any intervention should ideally be delayed for 7 days, if clinically appropriate [16].

2. Intramural Hematoma

Intramural hematoma is usually a result of blunt trauma and is part of the dissection spectrum. Acute hematoma may form in the layers of the arterial wall. On noncontrast CT, high attenuation material may be seen, either eccentrically in the wall of the artery or circumferentially surrounding the artery. It can be associated with arterial dissection, and CTA may reveal a dissection flap and the arterial lumen may be narrowed, sometimes occluded in the region of the hematoma [9, 10, 17].

3. Thrombosis

Thrombosis within the arterial lumen may form as a result of damage to the arterial wall and subsequent activation of the clotting cascade in the region of injury. It is associated with arterial dissection, intramural hematoma, or preexisting wall abnormality, such as atheroma. The occlusion caused by the thrombus may be partial or complete. On CT, thrombosis with partial occlusion may show wall irregularity or arterial dissection with intraluminal filling defects. These appearances often are better appreciated on multiplanar reformats. Distal to the thrombus the arterial lumen may be narrowed. Thrombosis with complete occlusion may show an abrupt termination in contrast flow, truncated arteries, or absent arteries. Complete occlusion is more likely to present

Fig. 6 Internal carotid artery pseudoaneurysm. This patient was assaulted (lynched) and had a left-sided neck injury with ipsilateral Horner's syndrome. CT demonstrated an ICA pseudoaneurysm (PA) with a wide neck. **A** Axial CTA image at the level of C1 and **B** sagittal reformat show left ICA PA (*arrows*). The artery above the aneurysm was narrowed and tortuous making endovascular treatment difficult. It was not suitable for open surgical repair due to difficult surgical access. The patient was treated conservatively with anticoagulation and blood pressure control. Magnetic resonance angiogram (MRA) 15 months later **C** showed a stable left ICA pseudoaneurysm (*arrow*) following conservative management

clinically with end-organ ischemia/infarction, for example, stroke in carotid artery injury with occlusion [10, 18].

4. Arterial Laceration

Arterial laceration is a disruption of the arterial wall not involving the whole circumference of the artery [17, 18]. Arterial laceration usually occurs secondary to penetrating trauma and, increasingly, iatrogenic injury. Clinically, a pulsatile neck mass or end-organ symptoms may be present. CT angiography appearances relate to the flow of contrast through the disrupted area and whether the bleeding is contained or uncontained, as follows:

i. Pseudoaneurysm (PA) leads to hemorrhage that is contained by the vessel wall adventitia or the surrounding soft tissues. It appears as a focal out-pouching of contrast density from the native arterial lumen, in the arterial phase (Fig. 1). If the PA is due to contained flow from arterial laceration, there will be no increase in volume of the PA between arterial and delayed imaging (contained extravasation). Arterial spasm or intramural hematoma may cause luminal irregularity or narrowing in the region of the PA. An enlarging PA or contrast jet beyond the PA indicates active bleeding [17, 18]. Bleeding from a PA may be intermittent and absence of evidence of active bleeding on CT should be

Fig. 7 External carotid artery (ECA) branch pseudoaneurysm (PA). An elderly woman presented with a fall and large swelling to the right cheek. CT demonstrated two large hematomas in the right masticator space. CTA **A** revealed a PA within the right masticator space hematoma (*arrow*). A selective catheter angiogram **B** confirmed a PA from the right internal maxillary branch of the ECA showing the point of extravasation (*arrow*). This was initially treated with 300–500 micron PVA particles and embolization completed with multiple coils, **C** angiogram postembolization

metered by the patient's clinical condition. Generally, PA following a penetrating injury tends to be recognized and repaired in the immediate postinjury period, whereas diagnosis of such lesions after blunt trauma is usually more delayed [6].

ii. Uncontained contrast leakage through an arterial laceration indicates active bleeding/acute ongoing hemorrhage. High attenuation contrast material is seen outside the arterial adventitia on the arterial phase scan, with contrast pooling, periarterial hematoma enlargement, or increased contrast in the tissue planes surrounding the injured artery on delayed imaging (Figs. 2 and 3).

5. Arterial Transection

Arterial transection occurs if the whole circumference of the arterial wall is disrupted [17, 18]. This type of injury usually occurs secondary to penetrating trauma, and patients present with hypotension or an expanding hematoma and have a very high mortality rate. On imaging, they present as a truncated or absent artery with a large
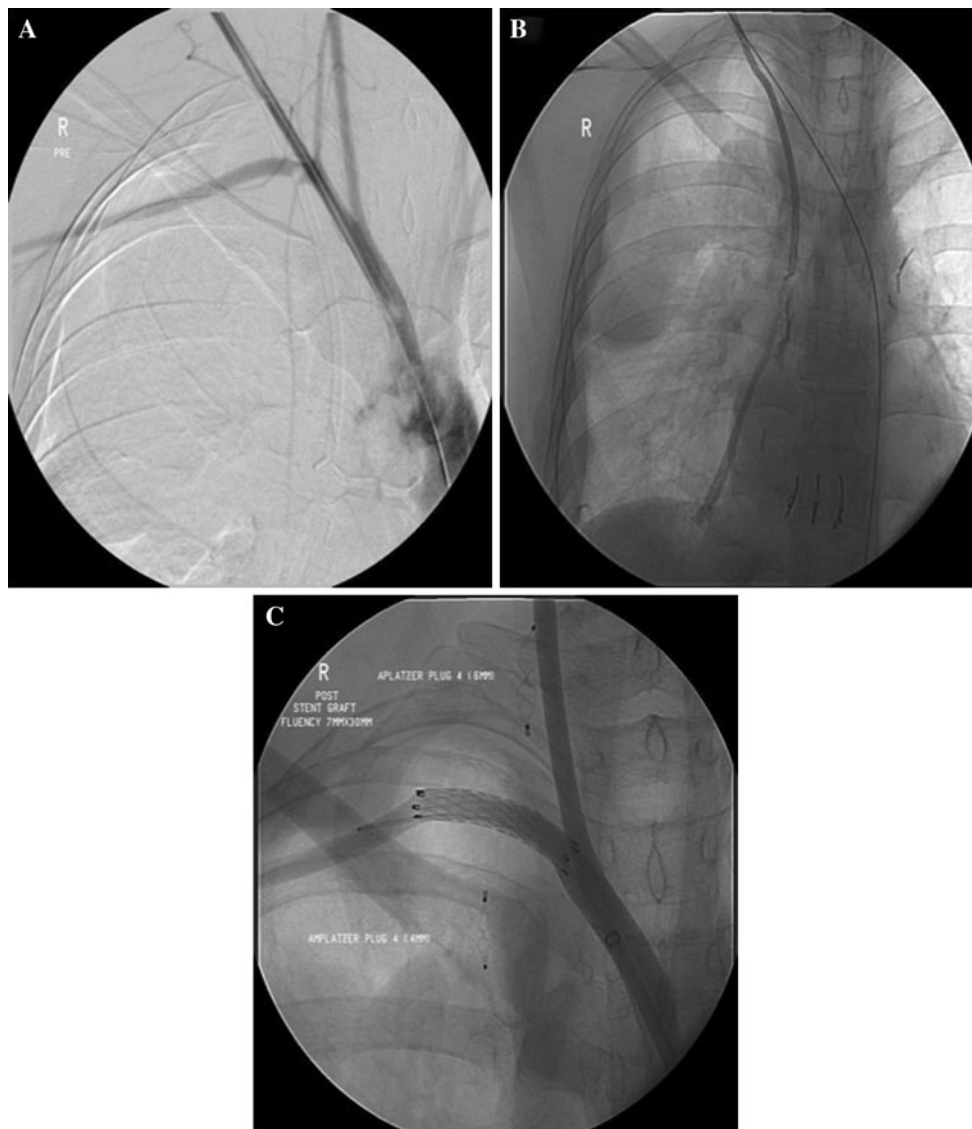
Fig. 8 Subclavian artery transection. This is an example of an iatrogenic injury with nearly complete transection of the right subclavian artery (SCA) by a Tessio line. Catheter angiogram **A** shows right SCA transection. Fluoroscopic image **B** shows the two Tessio lines, one of which is in the right pleural space. Initially, two Amplatzer vascular plugs were inserted to prevent back bleeding: one in the right vertebral and a second in the right internal mammary arteries. A self-expanding covered stent (FLUENCY®, by BARD, 7- × 30-mm) was deployed in the right SCA with successful control of arterial bleeding. **C** Catheter angiogram after stent-graft insertion in the proximal right SCA, also shows the two inserted Amplatzer vascular plugs, in the right vertebral and internal mammary arteries

hematoma, extraluminal contrast leakage, contrast in the tissue planes surrounding the artery, and/or absence of a visible distal arterial lumen [11, 17, 18].

6. Arteriovenous Fistula (AVF)

A posttraumatic communication (fistula) may form between injured arteries and adjacent draining veins, usually as a result of penetrating trauma (including iatrogenic penetrating trauma) producing adjacent partial transection of artery and vein (Figs. 4 and 5). Generally, AVF is diagnosed later than other arterial injuries. AVF is demonstrated as early filling of venous structures in the arterial phase of enhancement and similar CT attenuation in adjacent arteries and venous structures. Doppler ultrasound will show low resistance arterial flow and arterialized venous flow. Enlargement or asymmetry of draining veins also may provide a clue to fistula formation [11, 17, 18].
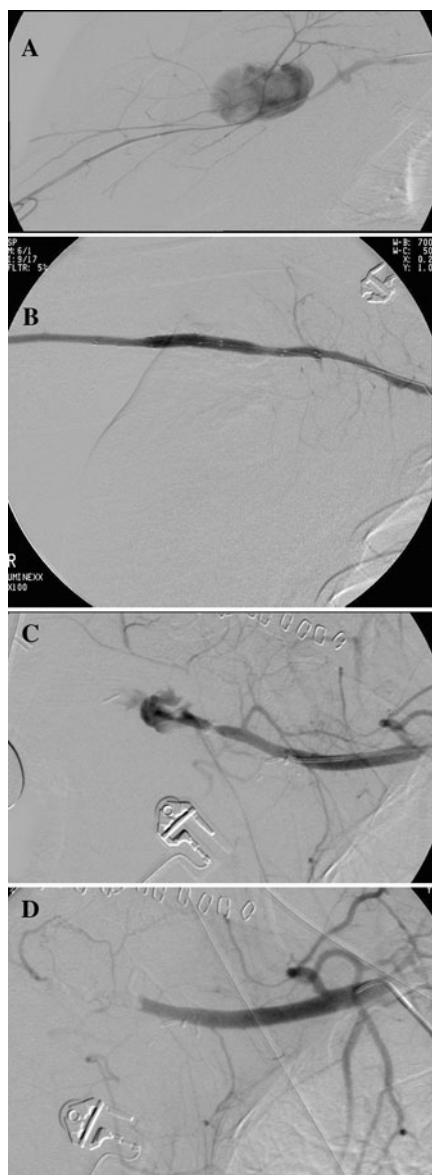
Fig. 9 Axillary artery laceration (partial transection). A 13-year-old male with Ehlers-Danlos syndrome presented with axillary hematoma and ischemic right arm with loss of sensory function, after stretching his arms 24 hr before his presentation. Selective catheter angiogram **A** shows contrast extravasation from the distal end of the right axillary artery. A bare-metal stent (LUMINEXX®, by BARD, 9 × 100-mm) was first deployed to act as a scaffold followed by a covered stent (FLUENCY® Plus, by BARD), with satisfactory obliteration of all extravasation to stop the bleeding and save the child's life. Catheter angiogram **B** after stent-graft insertion shows no extravasation. The child then underwent a trial of fasciotomy to assess recovery of ischemia and neurological function. When this was deemed futile, the arm was amputated. At this point, the previously inserted stent graft was pulled out surgically to help form the arm stump leading to profuse bleeding. Selective catheter angiogram of right upper limb stump **C** shows extravasation from right axillary artery stump after amputation. This was eventually stopped through glue plug embolization of the axillary artery stump and the child's life was saved. **D** Catheter angiogram after glue embolization with cessation of all extravasation

Management of Supra-aortic Vascular Injuries

1. Conservative Management

Nonoperative management is considered when the natural history of the arterial injury precludes operative or endovascular management or the patient's other injuries are not survivable. In the supra-aortic arteries, conservative management may be more appropriate in noncarotid injuries and is usually reserved for less complex lesions where the risk of bleeding, vessel occlusion, or thrombosis/embolization is minimal. Alternatively, if the injured artery has good collateral supply, initial conservative management may be appropriate [7]. The patient shown in Fig. 6 had a left-sided neck injury with ipsilateral Horner's syndrome following an assault. CTA demonstrated an ICA PA with a wide neck (Fig. 6A). The artery above the aneurysm was narrowed and tortuous making endovascular treatment difficult (Fig. 6B). It was not suitable for open surgical repair due to difficult surgical access. The patient was treated conservatively with anticoagulation and blood pressure control, and the PA remained stable at 15 months follow-up with no symptoms (Fig. 6C). Regular follow-up is required in conservatively managed arterial trauma, because longer-term complications, including arteriovenous fistulae, may develop.

2. Endovascular Management

a. Embolization

The use of embolization is well described with supra-aortic arterial injuries. Acutely, embolization is mainly used in cases of active life-threatening bleeding (particularly the subclavian and external carotid artery branches) where the bleeding site is to be urgently excluded from the systemic circulation [19, 20]. It also may be used in arteries supplying vital structures and when open surgical hemostasis is not feasible (e.g., internal carotid or vertebral arteries when stent-grafting is not an option). Under these circumstances, the patient's chance of survival without debilitating stroke depends on the cerebral collateral circulation. Embolization has been used previously to treat AV fistulae, disrupting the communication between arterial and venous structures; however, stent-grafts have largely replaced embolization for the treatment of AV fistulae.

A range of temporary and permanent, proximal and distal embolization agents can be deployed, including coils, plugs, particles, and liquid agents. Coils are permanent embolic agents, available in different shapes and sizes, and have tiny fibers attached to them to promote thrombosis. They act by damaging the intima leading to release of thrombogenic agents, providing a large thrombogenic surface and causing
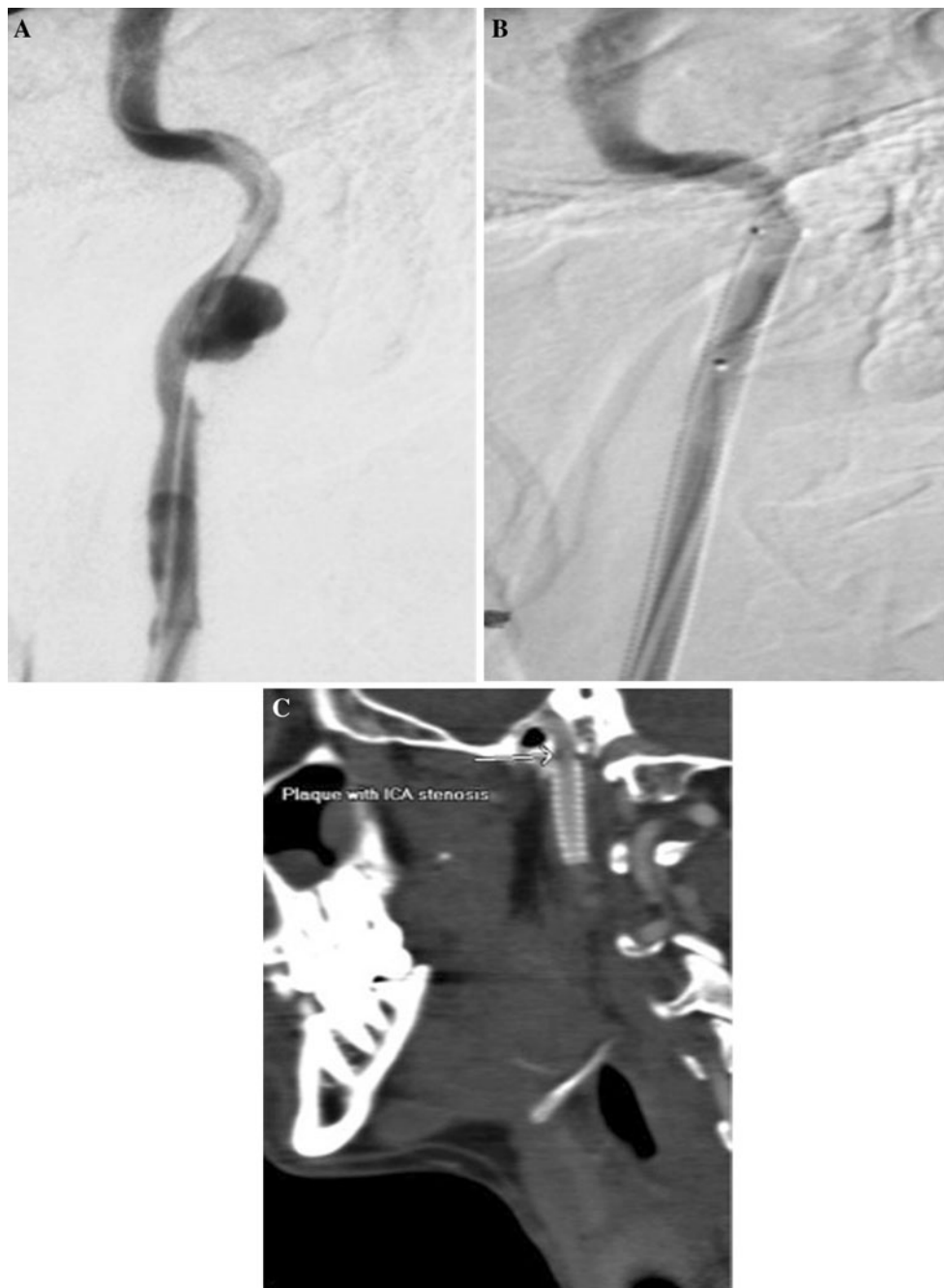
Fig. 10 Internal carotid artery (ICA) PA. Adult patient involved in an RTC. Selective catheter angiogram **A** showing the traumatic left proximal ICA PA. A stent-graft was inserted **B** with exclusion of the PA. On follow-up imaging there was mild stenosis distal to the ICA stent, which is related to intimal hyperplasia. CTA sagittal reformatted image **C** showing stent and distal ICA stenosis. The patient commenced antiplatelet therapy, including Clopidogrel (300 mg for 3 months) and aspirin (75 mg for life)

mechanical occlusion of the lumen [21]. Coil embolization is used proximally, particularly in cases of active bleeding [19] (Figs. 7 and 3). Plugs also are permanent embolic agents, e.g., Amplatzer vascular plug, which is a self-expanding Nitinol wire mesh mounted on a delivery wire by a screw thread. Plugs can be used as embolization agents on their own or with other embolization agents (Fig. 8). They are particularly useful in high-flow situations where there is a single, large vessel to occlude [21]. Particulate embolic agents are generally used for more distal bleeding sites as a temporary (Gelfoam) or permanent (Polyvinyl alcohol - PVA) measure (Fig. 2). However, particle-based embolization is not used in the treatment of AV fistulae. Liquid embolic agents can be used but only in limited cases (Fig. 9). They are divided into
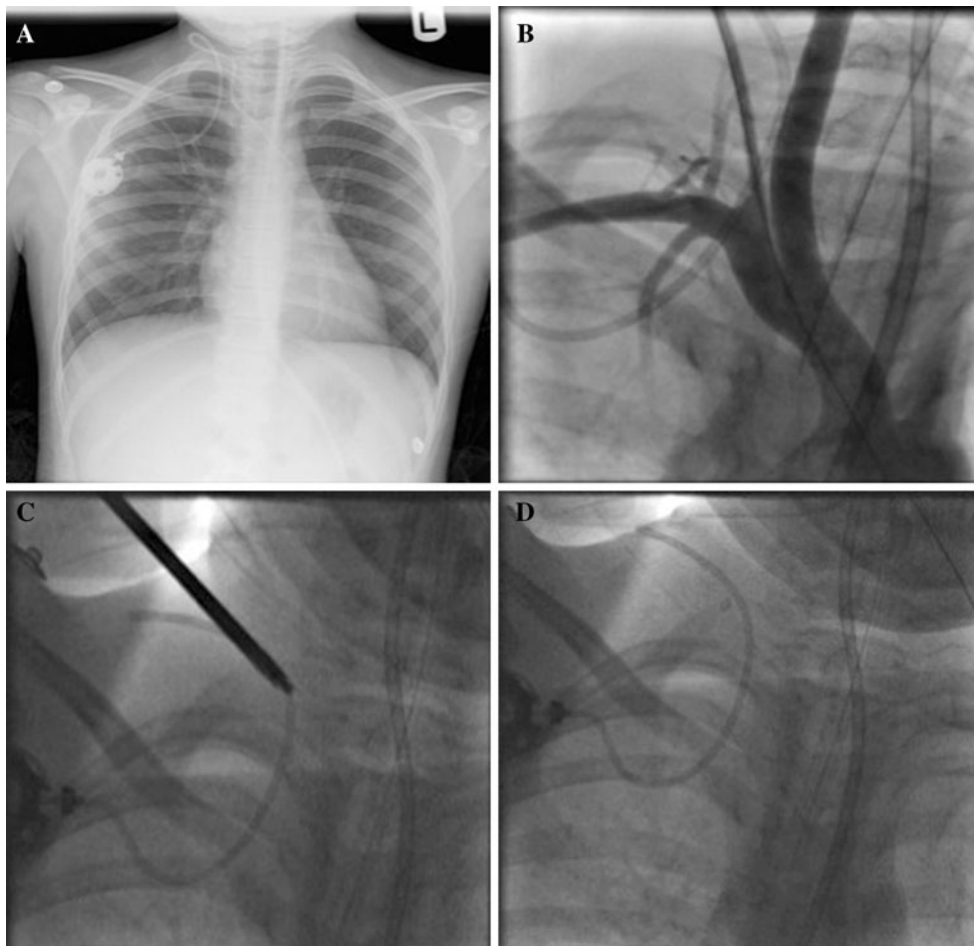
Fig. 11 Vertebral artery iatrogenic injury (laceration). This was a case of iatrogenic injury with inadvertent insertion of a tunnelled central venous catheter into the proximal right vertebral artery. **A** CXR showing tunnelled central catheter in proximal right vertebral artery. Catheter angiogram **B** before treatment shows guidewire in right vertebral artery. StarClose (Abbott Vascular) closure device was used to close the puncture in the vertebral artery. **C** Fluoroscopy image showing StarClose closure device being deployed and **D** Fluoroscopy image with closure device's nitinol clip in situ

two main categories: sclerosant and glue. Liquid embolics are the most difficult of the embolic agents to control [21]. The use of proximal embolization techniques in the acute setting often means future endovascular reconstruction options are limited due to lack of access [19, 22].

b. Stents and Stent-grafts

Stents are scaffolds used to support a vessel wall, and most are made from metal alloys (uncovered stents). They are introduced in a compressed state and then expand on delivery to line the vessel. Stent-grafts are stents covered with graft material and function as vascular conduits (covered stents) [23].

i. Uncovered stents are mainly used in arterial dissection to compress/reduce a dissection flap and restore flow to the true lumen. They also are used to treat stenotic and occlusive disease. Uncovered stents however do not prevent bleeding from lacerated arterial segments [1, 24].

ii. Stent-grafts are used for the treatment of supra-aortic arterial trauma with particular application in internal carotid and subclavian injuries [1, 22, 25]. They can be used to treat traumatic arterial PA (Figs. 10 and 1). They also are indicated in arterial laceration/transection (Figs. 8 and 9) and in AVF (Fig. 5). The advantages of stent-graft treatment include exclusion of PA, dissection flaps, AV fistulae, or lacerated arterial segments, and hence control of bleeding whilst blood flow distal to the injured arterial segment is preserved [4, 6, 25]. Overall, the indications for and use of stent-graft treatment in the acute setting is increasing and fewer complications have been reported compared with traditional surgical approaches [19, 26, 27].
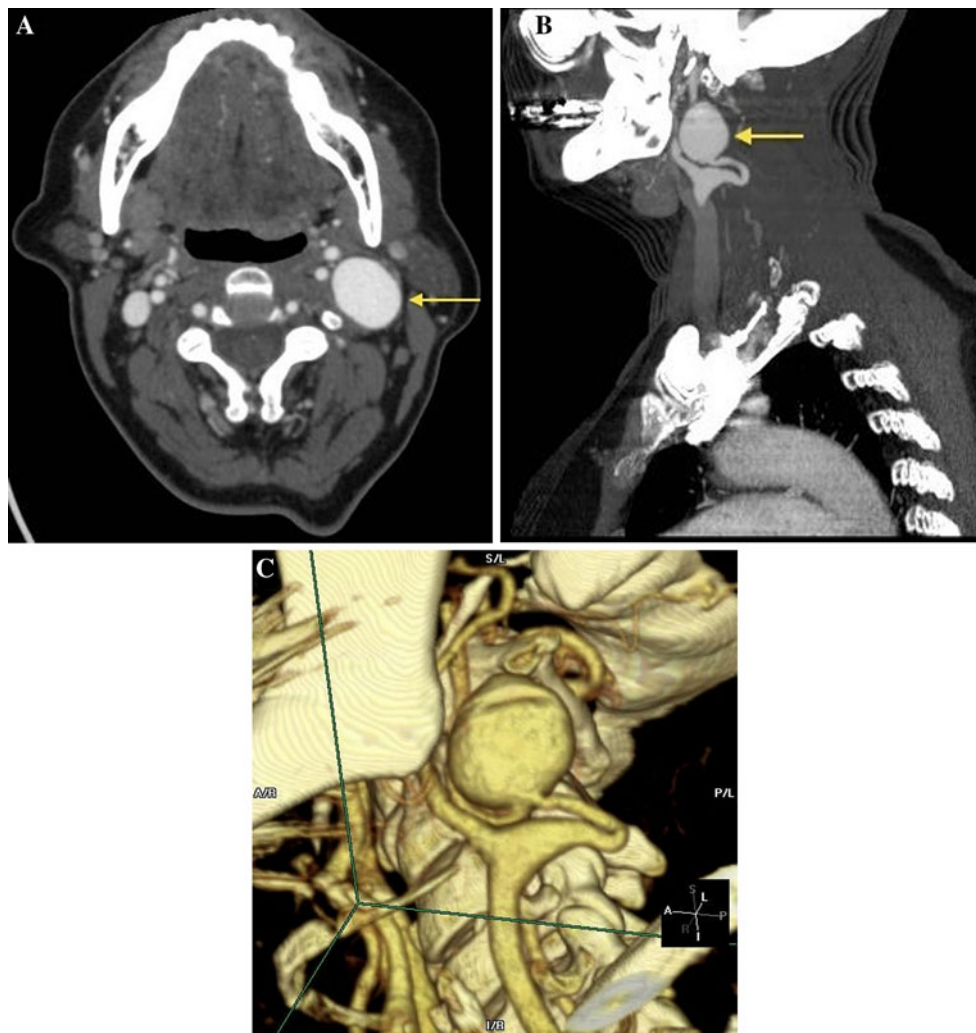
Fig. 12 True saccular aneurysm of left ICA. This patient presented with a suspected left hemisphere stroke and a lump in left side of the neck with a history of trauma some years previously. On CTA, there was a 2.5 × 2.2-cm, eccentric aneurysm just above the common carotid bifurcation, arising from a tortuous proximal left ICA. CTA axial (**A**) and sagittal reformat images **B** show left ICA saccular aneurysm (*arrows*). This is a true saccular aneurysm, and both internal and external carotid arteries are patent and there is no persistent evidence of local dissection. This was repaired surgically. Volume-rendered CTA image **C** shows the left ICA true saccular aneurysm

c. Closure Devices

Closures devices are primarily designed to achieve hemostasis of percutaneous femoral artery puncture sites and usually involve the use of procoagulant agents, plugs, clips, or sutures to seal the puncture site. The use of closure devices has been described in the treatment of small arterial lacerations with a good success rate, but it should be appreciated that this is "off-label" use and the relevant institutional protocols should be applied. Closure devices are not appropriate in larger arterial lacerations or where there is significant risk from distal emboli [4, 5, 22, 28]. Arterial closure devices have been particularly used for the treatment of iatrogenic arterial puncture during central venous catheterization where percutaneous vessel access is maintained (Fig. 11), in this case the closure device we used was StarClose (Abbott Vascular), which applies a nitinol clip to the adventitial surface of the vessel and is introduced via a dedicated sheath over a guidewire. It is deployed extraluminally; thus, there is no risk of vessel occlusion or embolization, which is extremely important in the carotid and vertebral territory.

3. Open Surgery

If endovascular techniques fail or are not feasible, traditional surgical options are still available if there is appropriate surgical access (Fig. 12). Open surgical techniques are numerous, including arteriorrhaphy, surgical patch arterioplasty, direct arterial repair, vessel ligation, and

bypass of the injured area (anatomical or extra-anatomical). Endovascular balloon tamponade followed by open surgical repair can be a useful strategy to minimize the extent of surgical intervention.

Summary

Supra-aortic vascular injuries require a precise diagnosis, which can be readily established by CT angiography. Endovascular management allows safe and effective treatment of extra-cranial supra-aortic vascular injuries. Early endovascular expertise should be available to all patients in major trauma centers to provide the best possible care.

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