Subclavian and Vertebral Arterial Interventions

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ABSTRACT

Endovascular treatment of supra-aortic atherosclerotic arterial stenoses and occlusions using percutaneous transluminal angioplasty (PTA) and stent placement is an accepted first-choice procedure. Technical success, primary success, and midterm patency after PTA and stent placement for the treatment of stenosed or obstructed brachiocephalic arteries are promising and complication rates are low. Permanent miniaturization and device improvement makes treatment of atherosclerotic obstructive disease by endovascular means in brachial and cephalic arteries a safe procedure showing promising midterm patency rates.

KEYWORDS: Arteries, innominate; arteries, subclavian; carotid arteries, stenoses or obstruction; stents and prostheses; percutaneous transluminal angioplasty

Objectives: Upon completion of this article, the reader should understand the indications and technique for treatment of brachial and cephalic arteries.

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Percutaneous transluminal angioplasty (PTA) was first described by Dotter and Judkins¹ in 1964. Initially, PTA was performed for the treatment of stenosed and nearly occluded femoral and iliac arteries. Grüntzig et al² established the treatment for renal and coronary arteries in 1978. The first percutaneous intervention in the carotid artery was performed in an experimental study of stenoses in dogs and results and published in 1977 by Mathias.³ The first interventional maneuver in a human carotid artery of a high-risk patient was reported by Kerber and coworkers in 1980.⁴ Here a high-grade stenosis of the common carotid artery was dilated in collaboration during a

thromboendarterectomy procedure of the carotid bifurcation.

Since the 1980s, interventional radiologists have been evaluating and refining the use of transluminal techniques for revascularizing stenotic and occlusive lesions in supra-aortic vessels.⁵ Vascular insufficiency of the upper limb and the cervical arteries must be differentiated from that of the lower limb because it is not as closely associated with cardiovascular disease and long-term survival is higher. Atheromatous disease is relatively uncommon in the great vessels of the aortic arch when compared with lower limb arteries and the carotid bifurcation. Fields et al showed in a large study

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that only 17% of patients with extracranial arterial disease had stenoses of $>30\%$ of either the subclavian or innominate arteries, pointing out that subclavian and innominate arterial disease is slowly progressive.⁶

Additionally, the pattern of disease in the upper limb is somewhat different from that in the lower. In the arm, atheromatous disease tends to be more focal, typically affecting the origin and the proximal portions of the innominate and subclavian arteries. The left subclavian artery is more often affected than the right.⁷ Such disease results in a "subclavian steal," which was first described in 1961 by Reivich et al.⁸ Occlusive disease proximal to the left vertebral artery causes reversal of left vertebral flow from the right vertebral via the circle of Willis, and subsequently into the left subclavian artery. The most common cause of stenotic lesions in these vessels, similar to other vessels, is atherosclerotic disease. However, other causes, such as dissection, fibromuscular disease, and various vasculitides, are not infrequent.⁶

The diagnosis of clinical subclavian steal (as opposed to angiographic, which is often asymptomatic) is based on the combination of upper extremity ischemic symptoms (arm claudication, paresis, and atheroembolic digital ischemia) and is a blood pressure difference between the arms of 20 mm Hg. Less commonly, there is vertebrobasilar insufficiency, which includes symptoms of ataxia, diplopia, syncope, vertigo, dizziness, nausea, and vomiting. Another syndrome, more recently seen and increasing in frequency, is coronary steal syndrome, in which a stenosis proximal to internal mammary-coronary artery bypass may cause ischemic symptoms. The more frequent use of the left internal mammary artery (LIMA) for coronary bypass procedures has resulted in greater surveillance and treatment of the left subclavian artery.⁹ Controversially there are interventionists who consider a high-grade proximal subclavian arterial stenosis in a relatively asymptomatic patient as suitable for endovascular treatment to maintain the capacity to construct a LIMA graft if necessary.⁸ PTA for significant stenosis involving the origin of the vertebral artery is also a well-established treatment for selected patients when posterior cerebral arterial circulation is compromised.¹⁰ Before an interventional procedure is considered, adequate imaging is mandatory.

IMAGING

Noninvasive imaging modalities such as magnetic resonance imaging/angiography (MRI/MRA) or contrast-enhanced computed tomography (CECT) should be considered as first-line investigations when clinical signs indicate diseased supra-aortic arteries to give an overview of vascular anatomy and disease extent.^{11,12} Color-coded duplex ultrasound is often performed initially. Currently we prefer contrast-enhanced MRA for the aortic arch

and the circle of Willis. Based on this imaging the interventional procedure can be planned (access route, equipment, risk assessment of potential complications). If there are any contraindications to MRA, contrast-enhanced CT angiography serves as an excellent imaging alternative.¹¹

ACCESS ROUTES

Current equipment (sheaths, wires, balloons, and stents) has such a low profile that it allows access that does not exceed a crossing profile $>6F$. However, the common femoral route is generally preferred because of the lower risk of hematoma and other complications that can occur from brachial approaches. We do not routinely use the radial approach, although some occasionally do. Usually a 5 to 6F short sheath provides safe initial femoral access; then the short sheath is exchanged for a long 45-cm (brachial approach) or 90-cm sheath (femoral approach). An approach from the groin and the arm is necessary only in cases where the first-choice approach fails.

In occlusions of the subclavian and innominate artery, especially when the occlusion is flush with the arch with no characteristic nipple in the proximal segment of the artery, the primary approach has to be brachial. Other reasons for a brachial approach is if the origin of the subclavian or innominate artery is at such a sharp angle to the aorta that traditional femoral access would be very difficult. Also, if severe aortoiliac disease is present, the brachial approach is preferred. Brachial artery puncture should be low near the olecranon fossa because of difficulty in achieving hemostasis with a high approach in the upper arm. A micropuncture system is helpful to gain clean access into the brachial artery, introducing a 0.035-inch Terumo wire (Terumo, Tokyo, Japan) and then a short 5F sheath. The axillary approach should only be used in exceptional circumstances because of the high risk of the brachial plexus injury that can result from an expanding hematoma.

EQUIPMENT

Recent device improvement such as miniaturization, resulting in lower outer crossing profiles of interventional instruments, has resulted in much safer PTA as well as stent procedures. Access technique has already been described. We prefer to work with long 90-cm sheaths placed proximal to the lesion. Endovascular technique remains the same for left or right subclavian, innominate, axillary, or vertebral arteries. The insertion of a 6F 90-cm-long sheath is usually combined with a 0.035-inch hydrophilic Teflon coated wire (Terumo, Tokyo, Japan). Catheterization and crossing of the target stenosis or occlusion is achieved with a combination of a 5F diagnostic catheter (125 cm long) in vertebral arteries and an 0.014-inch wire (Spartcore;

Guidant, Indianapolis, IN) for stenosed lesions or the 0.035-inch Terumo with or without an 0.018-inch wire (V18 control; Boston Scientific, Natick, MA) for occluded lesions. However, any catheter configuration can be chosen, depending on operator's preference and the anatomy. Once the lesion is crossed, our preference is direct stenting of the lesion to fix the plaque material and avoid embolic events by dislodging debris during multiple crossings and predilation (stent-protected

angioplasty¹³). A balloon-expandable stent is preferable due to lower crossing profiles. Monorail-stent-balloon rapid exchange systems, such as the Herculink (Guidant, Indianapolis, IN), make the procedure much more efficient.

As in the axillary artery and the subclavian artery, lesions at the origin of the vertebral artery should be stented once the lesion is crossed successfully with a guidewire.^{14,15} Specific stents such as low-profile and

Figure 1 (A) Intra-arterial digital subtraction angiography from the aortic arch demonstrating concentric stenoses within the proximal part of the innominate artery and at the origin of the left common carotid artery. (B) After successful stent placement in the innominate artery (Palmaz 204; Cordis, Miami Lakes, FL) (expanded diameter, 8 mm), the stenosis of the left common carotid artery is better seen because the angiographic angle is now more favorable. (C) Fluoroscopy after stenting the left common carotid artery (Palmaz-Corinthian; Cordis, Miami Lakes, FL) (expanded diameter, 7 mm; length, 15 mm) shows deployed stents (arrows) in a good position. (D) Final digital subtraction angiography shows simultaneous filling of the stented arteries.

small-diameter coronary stents might be useful when stenting the vertebral artery.¹⁶ The use of a cutting balloon¹⁷ or cerebral-protection devices are not used routinely.¹⁸

ANTICOAGULATION AND FOLLOW-UP

Patients should receive a bolus of heparin (5000 IU) intra-arterially during the intervention followed by therapeutic low-molecular-weight heparin for 24 hours. The partial thromboplastin time should be two to three times control. Patients should take lifelong aspirin (100 mg/d). In patients with vascular comorbidities, clopidogrel, 75 mg/d, should be prescribed for at least 6 weeks. Both of these antiplatelet agents should be prescribed at least 48 hours in advance of the procedure. Late loading doses of clopidogrel have little effect. Cilostazol might be a promising option in the future.

The follow-up protocol should include clinical examination and color-coded duplex ultrasound at 3 months, 6 months, and after 1 year. If restenosis is suspected, an intra-arterial digital subtraction angiography should be performed immediately to redilate the lesion.¹³ Due to severe susceptibility artifacts at the site of stent placement, MRI should not be considered as a follow-up imaging procedure.

SUBCLAVIAN LEFT/RIGHT AND INNOMINATE ARTERY INTERVENTION (FIGS. 1–4)

Once arterial access is obtained, a left anterior oblique projection with the 5F pigtail catheter in the aortic arch is first performed. Using road mapping with favorable image angles, the target lesion is crossed. Guidewire and sheath/guide catheter selection depends on the lesion characteristics. Traditionally, for a moderate stenosis of the left subclavian, a 0.035-inch hydrophilic wire (260 cm long) will work well and can be used to provide adequate support throughout the procedure. The diagnostic catheter used for support is usually a 5F 120-cm-long hockey stick-shaped catheter. For higher-grade stenoses, a 0.035-inch regular-angled hydrophilic wire is used, followed by a suitable diagnostic catheter, which is then exchanged for a metal-braided 90-cm sheath. Equally well tolerated are the 0.014-inch support coronary wires (Spartacore; Guidant, Indianapolis, IN). With the guidewire beyond the stenosis, the diagnostic catheter is removed leaving the long sheath (6F) in a stable position just proximal to the lesion. It is important to choose the right guiding catheter or sheath because contrast injection to visualize the target lesion at all stages is vital. Some interventionists cross the stenosis with the guide catheter without predilation, allowing positioning of the stent with no risk of the stent being stripped from the balloon catheter.

However, others leave the guide catheter proximal to the ostium and cross with the balloon-mounted stent catheter. Once crossed and before deployment, it is important that vessels such as the internal mammary and the vertebral arteries not be compromised. The balloon-mounted stent is usually 7 to 8 mm in diameter and 15 mm to 20 mm in length. If the stenosis is close to the origin of the vertebral artery (putting that artery at risk), a 0.014-inch guidewire can be positioned in the vertebral artery as a safety wire during subclavian stenting. The balloon should be carefully held because of aortic arch pulsations, and then the stent should be deployed quickly to ~8 atm. Stent apposition to the vessel wall and position can then be checked by angiography. Unlike other major arteries, the origin of the subclavian artery is somewhat fragile, so caution is advised not to overdilate this vessel to avoid rupture, which can have catastrophic results.

Self-expandable stents are not chosen because of their inability to be exactly precise in a region where millimeters count. Furthermore, there is the possibility of stent migration with the self-expandable stents.¹³

DISTAL SUBCLAVIAN AND AXILLARY ARTERY

The number of patients, especially those on hemodialysis, who present with mid and distal subclavian stenosis is rising. Angioplasty alone without stenting is the procedure of choice for these lesions, particularly between the first rib and clavicle, as well as at the subclavian/axillary junction where there is bending and compression. When the lesion does not respond to angioplasty or results in flow-limiting dissection, self-expanding nitinol stents are a bailout option. Balloon-mounted stents should not be used because they are too compressible in these sites.

COMPLICATIONS

Minor complications such as an arteriovenous fistula and bleeding/hematoma may occur. Vessel rupture resulting in a major complication is rare and said to occur in ~1%.^{19,20}

Cerebral hyperperfusion after angioplasty and stenting of a totally occluded left subclavian artery is also rare, although this complication has been described in the literature, particularly after vertebral artery recanalization.²¹

RESULTS

Minimally invasive PTA for symptomatic stenoses of the subclavian, common carotid, and innominate

Figure 2 (A) Intra-arterial angiography after Wallstent (Boston Scientific, Natick, MA) (length, 39 mm; diameter, 10 mm) deployment into the innominate artery. One year later, blood pressure of both arms had decreased significantly. (B) The proximal concentric stenosis within the Wallstent (arrow) was assumed as hemodynamically relevant now. (C) An additional balloon-expandable stent (arrows) was implanted (Palmaz Corinthian; Cordis, Miami Lakes, FL) (length, 20 mm; diameter, 8 mm) to ensure a complete covering of the stenosis by the Wallstent. (D) A newly developed concentric stenosis of the left subclavian artery was stented using a Palmaz Corinthian (length, 15 mm; diameter, 7 mm).

and vertebral arteries is superior to open surgery due to lower complication rates and comparable results.²²⁻²⁷

In cases of failed PTA, stent implantation should be considered.²⁸ Angioplasty with stenting of focal stenotic and occlusive lesions of supra-aortic trunks are relatively safe procedures that seem to produce satisfactory immediate and midterm success and acceptable long-term patency rates.^{5,29} The insertion of stents into supra-aortic arteries represents an effective adjunct to PTA of atherosclerotic stenoses in these vessels, although primary stent placement may be an effective treatment alternative for selected lesions such

as stenoses at the origin of the vessel or primary dissections.³⁰ Risks of stent implantation are possible misplacement and early re-occlusion; however, this is very uncommon.³¹

A multicenter study, with follow-up still under way in Japan, has studied 320 patients with 340 lesions treated. Wallstents (Boston Scientific, Natick, MA) and Palmaz stents (Cordis, Miami Lakes, FL) were implanted, resulting in a 99.1% technical success rate. One major complication occurred due to subclavian artery rupture with mediastinal hemorrhage. No embolic complications were reported. The primary angiographic patency was 99% at 5 years.²⁰

Figure 2 (Continued) (E) The final digital subtraction angiography demonstrated no remaining stenoses.

Since 1989, the equipment used to perform subclavian interventions has improved dramatically, improving technical success, which is reflected in the high technical success rates, lower complication rates, and lower restenosis rates. Angioplasty alone had a restenosis rate ranging from 5 to 22%.¹³ With the development of endovascular stenting, there has been a reduction in the restenosis rate ranging from 0 to 16%.¹³

The author's group has treated 55 symptomatic lesions with PTA and stent placement and were technically successful in all patients (100%).¹³ According to Kaplan-Meier life-table analysis, the cumulative primary and assisted primary patency rate was 69.5% (patients at risk, $n = 15$; standard error, 9%) and 90.6% (patients at risk, $n = 16$; standard error, 6.3%) at 20 months; primary and assisted primary patency rate for stenosed lesions is 76.9% (patients at risk, $n = 15$; standard error, 8.6%) and 95.5% (patients at risk, $n = 16$; standard error, 4.4%) at 20 months.¹³

The primary technical success rate of 100% in this series is comparable to that of other studies, with results ranging between 74 and 100%.³²⁻³⁶ Other studies have

shown that PTA of the subclavian arteries is a safe, highly effective procedure and should be considered as the treatment of choice for symptomatic subclavian artery stenoses.³⁷⁻³⁹

Clinical results might be influenced by the design and material of the stent implanted. The optimal stent has a high expansion efficacy and good flexibility to align to tortuous vessels. Stents should also show good visibility and minor shortening to facilitate safe positioning. Because the deployment of self-expanding stents progresses from distal to proximal, there is a certain protection against embolization of bigger particles. However, small particle embolization through the wire mesh of the stent is still an issue. Previous data from the authors group indicates that 35% of lesions treated with self-expanding Wallstent (Boston Scientific, Natick, MA) became stenotic (6/17 vessel segments), whereas none of those treated with balloon-expandable stents did.¹³

In the author's series, all occlusions of the brachial and cephalic arteries were treated successfully (100%). Mathias et al³⁴ reports a successful recanalization rate of 83%, whereas Motarjeme³⁶ reports a success rate of 46%. This may be a function of case mix.

Chronic occlusions of the subclavian artery are far more difficult to treat than stenoses. A transbrachial recanalization approach is preferred.^{40,41} Staikov et al⁴² successfully used a simultaneous transbrachial and transfemoral approach for angioplasty of high-risk subclavian or combined vertebral artery stenosis and occlusions.

The technical success rates following open surgery such as carotid-subclavian bypass, subclavian-subclavian bypass, and subclavian-carotid transposition show primary success rates of 86 to 100%, which are comparable to PTA. The restenosis rates after surgery, however, are lower, showing cumulative patency rates of up to 90 to 100% after 5 to 10 years.⁴³⁻⁴⁵ However, surgery is associated with a 30-day mortality rate of 3%,⁴³ which exceeds the mortality rate of PTA. In 5.6 to 23% of cases complications such as bleeding, neural lesions (especially of the phrenic, laryngeal recurrent, and sympathetic nerve), lymphatic fistulas and cerebral ischemia may occur in addition to the general perioperative complications.^{24,46} Given the right information, most patients would choose the less invasive procedure, especially when elderly patients with multiple comorbidities are considered. The authors did not observe any cases of peripheral embolization, a complication documented in the literature with rates of 3.3 to 5% for PTA in the subclavian artery and the brachiocephalic trunk.

Stenoses of the origin of the vertebral arteries account for ~90% of all vertebral stenoses. Contrary to the stenoses of the carotid bifurcation, vertebral stenoses are ulcerated only in 4%.⁴⁷ Because of its smooth morphology, the risk of angioplasty is low. Success rates of 92% and 96% were quoted by Motarjeme and

Figure 3 (A) Intra-arterial digital subtraction angiography performed by injecting contrast media via a long sheath from the groin demonstrates a high-grade short stenosis of the innominate artery; a 0.014-inch wire is already in place (B). (C) The balloon-stent device (8 × 20 mm) is placed in the correct position as shown by control angiography. (D) The final angiogram shows accurate stent placement without any residual stenosis.

Courtheoux et al,^{36,48} and no complications are reported.⁴⁸ As always, but especially in the vertebral artery, a clear indication for intervention is important; and only definite vertebrobasilar and posterior fossa symptoms justify interventional therapy.

Only small numbers of stenoses of the brachiocephalic trunk and common carotid artery have been reported in the literature. However, most reports record

good primary success rate. Motarjeme³⁶ reported a significant complications with a resulting stroke.

Cumulative patency rates at these sites demonstrate 90.6% primary patency rate and 95.5% assisted primary patency rate for stenosed lesions at 20 months. Hüttl et al, after angioplasty of the innominate artery in 89 patients, reported primary and secondary patency rate of 98% and 100%, respectively, at 6 months.⁴⁹

Figure 4 An unusual case of *right* subclavian steal syndrome caused by a proximal subclavian artery stenosis (A); the right vertebral artery supplies the distal subclavian artery (B). A long sheath is placed in the innominate artery where there is an eccentric plaque (C). The position of the stent (6 × 13mm) is checked by an angiogram via the long sheath (D) before deployment. The stents are well seen on unsubtracted images (E). Final control angiography reveals antegrade flow into the right subclavian and right vertebral artery (F).

CONCLUSION

In conclusion, PTA and/ or stent implantation can be regarded as a standard interventional procedure for the treatment of atherosclerotic arterial stenoses and occlusions in supra-aortic vessels with high technical success and low complication rates. Midterm results are promising. Much of the success depends on improved technology, patient selection, and operator skills.

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