The Neurointerventional Toolkit

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Introduction

Neurointerventional procedures employ the use of various specialized products and devices. This chapter presents an overview of the contrast agents, catheters, coils, flow disruption devices, liquid and particulate embolic materials, stents, clot retrievers, and closure devices commonly used by neurointerventionalists. An understanding of the basic differences in the uses and actions of these products is intended to assist providers in choosing from the many options.

Contrast Agents

Nonionic Contrast Agents

Iohexol, trade name Omnipaque, is currently the most widely used contrast media for neurointerventional procedures. Iohexol is a low-osmolality contrast agent available in various concentrations ranging from 140 to 350 milligrams of iodine per milliliter. Iohexol is safer and less allergenic than ionic preparations. Patients with normal renal function can tolerate as much as 5–8 cm^3/kg of contrast for the duration of the interventional procedure for a maximum of 400–800 cm^3 [1]. Patients with impaired renal function should have reduced contrast load and periprocedural precautions taken to reduce the risk of contrast-induced nephropathy.

Femoral Artery Sheath Types

Smaller access 4- and 5-French catheters and sheaths are used in diagnostic cerebral angiography (4 French in children). For interventional procedures, larger catheters are used, which therefore require a larger femoral sheath, usually 5 French to 9 French [2] (Fig. 1.1). A longer sheath is needed for cases of significant iliofemoral artery tortuosity to facilitate catheter navigation. Similarly, in interventional cases with significant vascular tortuosity, in which more support is necessary, a long sheath (80–90 cm) can be placed distally into the carotid or vertebral artery, and then a guiding catheter or intermediate catheter is coaxially inserted to create a "triaxial" support system. Once a sheath is inserted into the groin, it is usually continuously flushed during the procedure with a solution of 2000 U heparin in 500 ml of normal saline [3].

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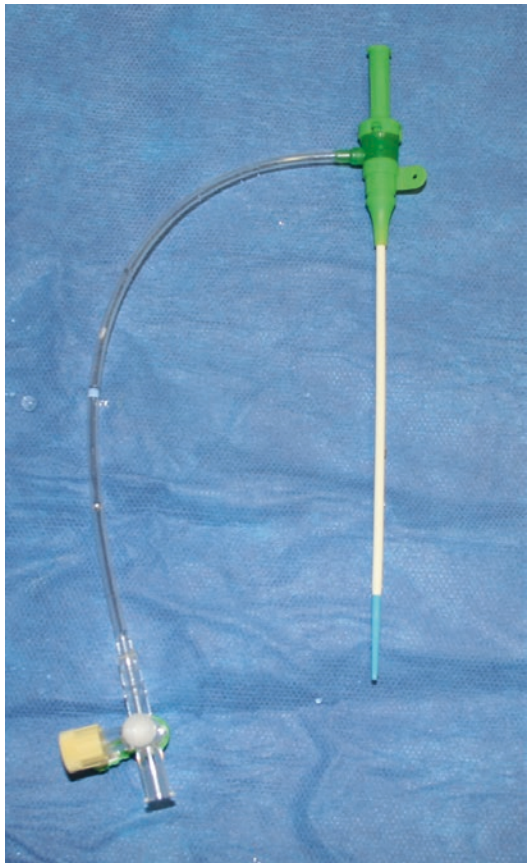

Fig. 1.1 6F femoral sheath

Radial Artery Sheath Types

Coronary catheterization and intervention has largely moved from the transfemoral approach to the transradial approach [4]. This approach is associated with reduced risk of major access site bleeding, vascular injury causing limb ischemia, and is generally preferred by patients as it does not require lengthy periods lying flat. It is also preferred for its efficiency on a systems level as patients can be discharged to home more quickly after elective procedures. Adoption within the neurointervention community has been more gradual, but is gathering momentum [5].

Transradial access platforms have been developed by multiple neuroendovascular vendors. These sheaths allow access to the radial artery over a microwire rather than an 0.035-inch wire. They are designed to minimize the outer diameter while maximizing the inner diameter. This is achieved by thinner wall construction which may be associated with greater fragility and less support. Despite these limitations, the transradial approach is now being used for an expanding number of therapeutic procedures and has largely supplanted the transfemoral approach to diagnostic angiography in many centers [6].

Wires and Catheters

Diagnostic Cerebral Angiography

Diagnostic catheters are usually advanced over a hydrophilic wire. The wire acts as a guide to prevent the catheter tip from damaging vessel walls and/or causing a dissection.

Hydrophilic wires vary from soft and flexible to slightly stiffer. Selection of the wire for a procedure depends on how much wire support is needed to navigate the catheter. With stiffer catheters, there is a greater risk of vessel dissection [1]. Arterial dissections are an uncommon complication with prevalence reported in the literature at around 0.4% [7].

Typically, a 5-French standard catheter is used for cerebral angiography (4 French in children). Catheters should have good torque control, be soft and nontraumatic, be radiopaque, and have a smooth surface to prevent thrombus formation. A standard angled catheter is the workhorse of most diagnostic cases. However, in cases of tortuous anatomy, more complex-shaped catheters such as Simmons II shaped, Headhunter, or Mikaelsson can be used [8].

Guide Catheters, Intermediate Catheters, and Microcatheters

For intracranial aneurysm embolization procedures, a large-lumen 6-French guide catheter (Fig. 1.2) or long 6-French sheath is typically used. Once the guide catheter is in position, a microcatheter is advanced under road-mapping

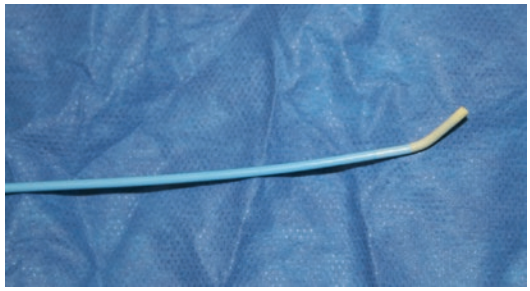

Fig. 1.2 6F Envoy guide catheter. (Credit: DePuy Companies, used with permission)

guidance over a micro-guidewire into the aneurysm. Subsequently, coils are advanced and detached inside the aneurysm [9]. In tortuous anatomy, a long sheath may be used, in coordination with a guide catheter or an intermediate distal access catheter, and a microcatheter. This system is termed a triaxial system.

A new catheter category came into vogue in the mid-2010s: the intermediate catheter [10]. These catheters are placed telescopically through a guide sheath or guide catheter. They have a large enough inner lumen to accommodate commonly used microcatheters, but are flexible/atraumatic enough to be navigated intracranially into the proximal branches of the circle of Willis. These devices have the advantage of providing greater support in the delivery of large and stiffer devices such as flow disruptors or for very distal catheterization as in tortuous arteriovenous malformation pedicles. The current crop of suction thrombectomy catheters (see below) also are of a similar size and construction and may be considered members of this family.

Microcatheters can be hydrophilic or nonhydrophilic, but only hydrophilic microcatheters are recommended since they are proven to be less thrombogenic [11]. Microcatheters come in different sizes, and in general, the smallest catheter for the desirable coils should be used [1] (Fig. 1.3). The inner diameter of the microcatheter may range in size for coil delivery from 0.015 to 0.025 in.; hence, close attention must be paid to coil size compatibility during aneurysm embolization.

Coils

Platinum coils for the treatment of brain aneurysms were introduced in the 1990s as an alternative to surgical clipping [12]. Platinum coils consist of a platinum thread looped around a thicker platinum wire. Once deployed inside the aneurysm, they regain their original shape and are subsequently detached from the wire by a low current (Fig. 1.4) or other mechanism.

Coils can be "filling," "framing," or "finishing." They have different diameters, stiffness pro-

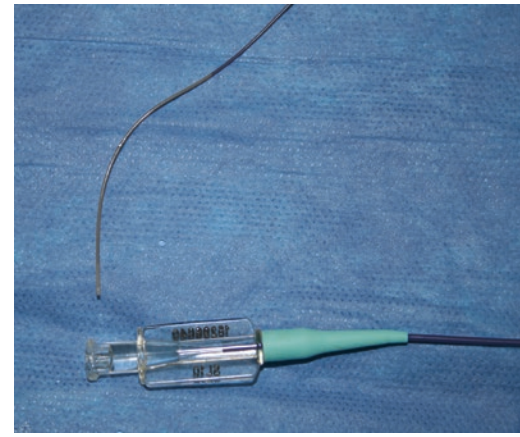

Fig. 1.3 Excelsior® SL-10® microcatheter. (Credit: Stryker, used with permission)

Fig. 1.4 Low-current detachment system. (Credit: Boston Scientific, used with permission)

file, and geometry that influence their stability within the aneurysm [13].

Framing coils are three-dimensionally designed coils to frame the circumference of the aneurysm, while *filling coils* pack the aneurysm once it has been framed. *Finishing coils*, on the other hand, are soft coils designed for final packing of the aneurysm and neck [1].

Achieving an adequate packing density of the coils within the aneurysm is one of the most important factors in avoiding aneurysm recanalization [14]. Recanalization and coil compaction are determined by many factors; however, notably, smaller and softer coils generally have a higher risk for coil compaction.

An effort to minimize recanalization led to the introduction of *bioactive coils.* Bioactive coils consist of bare platinum coils with adjunctive polymers polyglycolic acid (PGA), polyglycolic/polylactic acid (PGLA), or hydrogel that have the properties of affecting thrombosis, inflammation, and healing processes within the aneurysm [15]. Theoretically, bioactive coils were expected to produce a more prominent healing response within the aneurysm that resulted in less recanalization. While trial results have been mixed, hydrogel coils have been associated with lower recanalization rates in several well-designed randomized studies [16].

Liquid Embolic Materials

Liquid embolic material is mainly used for embolization of cerebral or spinal arteriovenous malformations (AVMs) and pial or dural arteriovenous fistulas (AVFs). Most of these materials are supplied in a liquid state and delivered using microcatheters. Currently, there are few liquid embolic agents commercially available.

Ethylene-vinyl alcohol copolymer (Onyx) is supplied by the manufacturer in a liquid form dissolved in an organic solvent, dimethyl sulfoxide (DMSO), with tantalum powder added for radiopacity. Onyx is nonadhesive and has an even flow pattern. When Onyx contacts blood, the DMSO rapidly diffuses causing precipitation and solidification of the polymer [17]. The solidification occurs more slowly than cyanoacrylates, and it usually does not adhere to the walls of the microcatheter, thereby allowing a slower injection and better AVM nidus and/or fistula penetration [17]. Reflux of the Onyx around the distal microcatheter, however, is often encountered the longer the injection of the copolymer, which can make the microcatheter difficult to retrieve.

Cyanoacrylate (*n*-BCA TRUFILL) is an acrylic agent that polymerizes when it contacts blood or saline solutions. Due to its strong adhesive characteristics, it is possible to cause adhesion between the tip of the microcatheter and the vessel or glue cast [18]. The polymerization rate can be adjusted by varying the concentration of the monomer in Ethiodol or by adding glacial acetic acid to the mixture.

Particulate Embolics

Polyvinyl alcohol particles are small solid particles of various sizes which are radiolucent and need to be mixed with contrast material to make them radiopaque. Particles are commonly used for tumor embolization. They produce occlusion by thrombus formation, and when the particles are too large, they can clog the microcatheter. Particles can be carried out by flow; this means that flow can take them to the lesion or may cause them to land more distally than intended. For this reason, particles are not effective for high-flow fistulas. Embospheres (BioSphere Medical, Rockland, MA) of various sizes may also be used for deliberate small-vessel occlusions in hypervascularized tumors and epistaxis.

Stents

Stent-assisted coiling is used in the setting of a wide-neck aneurysm. Stent-assisted coiling requires the use of dual antiplatelet therapy, and therefore, they are generally used for unruptured cases. Their use in the setting of subarachnoid hemorrhage (SAH) has been described as a viable option in the literature but remains controversial [19]. Stents or vascular remodeling devices

designed for aneurysm treatment are self-expandable nitinol meshes of thin-strut density deployed across the neck aneurysm and followed by coil packing of the aneurysm [20]. They provide more stability to the coil mass by holding it in place, and theoretically, they reduce the possibility of recanalization [20]. Early complications include thromboembolism, and, in a late setting, stent stenosis and occlusion of the parent vessel can rarely occur [21] (Fig. 1.5). These come in open-cell and closed-cell designs. The open-cell design has somewhat more vessel conformity in small vessels, on a turn, and allows for a Y-stent configuration. The closed-cell design has somewhat more protection from the stent herniating into aneurysm or coils herniating through the stent.

Intracranial stents for atherosclerotic stenosis (ICAD) are rarely used at present due to the superior results seen with aggressive medical management in the SAMMPRIS trial [22]. The device utilized in this trial, the *Wingspan Stent* (Boston Scientific, Boston MA), remains the only FDA-approved device for the treatment of ICAD refractory to aggressive medical management. It is based on the Neuroform platform and is also of a self-expanding nitinol construction. The device has since been studied in the WEAVE prospective registry which showed low complication rates when used on-label, but conversely high complications when used off-label [23]. The use of coronary stents and aneurysm scaffolding stents for ICAD has also been described, but the lack of rigorous randomized studies makes efficacy unproven.

Flow diverters are self-expandable, flexible stent-like devices with a dense mesh that once expanded covers a large surface area. Flow diverters are mainly used for the treatment of wide-neck, fusiform, large, and giant aneurysms and are typically constructed of nitinol and cobalt chromium. They are designed to offer aneurysm occlusion due to flow disruption, and for large and giant side-wall aneurysms, the preliminary angiographic results have been superior to coil embolization alone [21, 24]. This occlusion is delayed following treatment, based on the size and location of the aneurysm. With this device, most patients demonstrate very good long-term angiographic results [21]. The potential complications reported have been embolic events, stent thrombosis, delayed aneurysm rupture, and in-stent stenosis [21, 25].

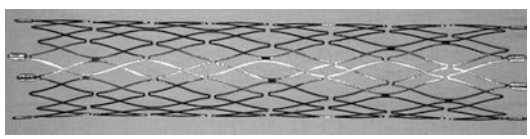

Fig. 1.5 Neuroform Atlas® stent system. (Credit: Stryker, used with permission)

Endosaccular flow disruptors are part of a new family of devices designed to be deployed within the aneurysm sac rather than the parent vessel. Like flow diverters, they are constructed of a woven wire mesh but they are basket-like devices rather than being cylindrical. They are particularly effective in bifurcation aneurysms where coil recanalization is a common problem. The first device to market in the USA is the Woven EndoBridge (WEB; Microvention) [26]. At present, these devices, while effective, are delivered through relatively large and stiff microcatheters. They will undoubtedly become more easily delivered over time, and their applications will likely expand to other aneurysm types.

Cervical carotid stenting is a stage procedure for reestablishing luminal diameter in high-grade carotid atherosclerotic disease. Following access and placement of a 6-French sheath in the common carotid artery, an embolic protection device is advanced past the stenotic area and then deployed. This is followed by an over the wire angioplasty procedure performed to the stenotic area of the vessel to permit the advancement of the stent. The third stage is insertion of the stent. Once the stent is deployed, it can be followed by a second angioplasty procedure to fully expand the stent if needed [1]. Carotid stents are also commonly constructed of nitinol and often taper, with the proximal end conforming to the larger common carotid diameter, while the distal end is smaller to better match the diameter of the internal carotid artery.

Mechanical Clot Retrievers

Mechanical clot retrievers and aspiration catheters are used as an alternative or in combination with pharmacological thrombolytic agents in the setting of acute ischemic stroke. This is an established treatment for large-vessel occlusion strokes. There are currently multiple devices available commercially, and they can be categorized according to their mode of action into two main groups, aspiration or retrieval devices.

Aspiration devices use a proximal approach and act by applying a vacuum force to the proximal aspect of the thrombus. These systems use a large bore catheter which is attached to a power aspiration pump. A major advantage of these devices is that they work at the proximal edge of the clot, and therefore, there is no need to pass through the thrombus. They are effective with soft or intermediate clots but could have more difficulty with firm fibrinous clots.

Retrieval devices, on the other hand, consist of a microcatheter containing a stent retrieval device which is passed distal to the thrombus. The microcatheter is then retracted, and the stent retrieval device is unsheathed. The stent device traps the clot within its struts and when pulled out removes it from the vessel [27]. The use of a balloon guide catheter in association with this technique can reduce the risk of clot embolization during retrieval to otherwise unaffected vessels. These devices can be used independently or in combination to achieve clot retrieval.

Trevo (Stryker, Kalamazoo, Michigan) and Solitaire (Medtronic, Irvine, California) are examples of available stent retrievers in the USA. Trevo is a stent-like device designed to integrate the clot into its structure, allowing it to retract both the device and clot from the blood vessel. The Solitaire is also a self-expanding nondetachable stent that acts in a similar way, incorporating the clot and allowing to completely retrieve it [28]. In 2012, Mendonca et al. published their results comparing both devices, and their study showed no significant differences between them [28].

Fig. 1.6 Perclose closure device. (Credit: Abbott, used with permission)

Closure Devices

Percutaneous femoral artery closure devices are commonly used to close the punctured artery in the groin after endovascular cases. These closure devices allow patients to ambulate sooner than when standard compression techniques are used. Two of these products are Perclose (Abbott Vascular, Redwood City, CA) and Angio-Seal (St. Jude Medical, St. Paul, MN).

Perclose places a Prolene stitch, which is placed in the arteriotomy site percutaneously (Fig. 1.6). There are 6-French and 8-French varieties.

Angio-Seal places a mechanical seal, produced by a bioabsorbable anchor and a collagen sponge, which dissolves within 60–90 days. With this device, the same artery can be re-punctured [1].

For radial access procedures no endovascular closure devices are available. However, hemostasis can generally be effectively achieved through the application of external pressure over the arteriotomy using a bracelet-like device with an inflatable bladder. After initial application, the bladder is slowly deflated over time until the device can be removed.

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