19 On the Horizon: Innovative Techniques and Procedures

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Introduction

In 1927, Moniz was the first to use a radiopaque substance and X-rays to image the cerebral vasculature in living human subjects. A few decades later, in 1953, Ivar Seldinger was the first to describe a percutaneous approach to access and visualize peripheral arteries. Seldinger's technique brought on a revolution in angiography and avoided the need for surgical cutdown in order to access vessels. It remains a foundational technique for both vascular and nonvascular access to this day [1]. The remainder of the twentieth and first decades of the twenty-first centuries has been marked by steady advances in neuroendovascular techniques such as the introduction of the Guglielmi detachable coil in the 1990s. More recently, the tremendous effect size of mechanical thrombectomy in improving patient outcomes has revolutionized the way in which ischemic stroke patients are treated [2, 3]. The future is bright with new therapies emerging and promising to continue the revolutionary impact of the field on neurovascular diseases and the nervous system more broadly.

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Beyond Femoral Access

The neurointerventional community is increasingly turning to non-femoral access for diagnostic and interventional procedures. The radial approach has been gaining more widespread use and benefits from the growing cardiology literature showing safety and improved morbidity and mortality. Clinical trials such as RIVAL show that transradial access (TRA) is associated with reduced morbidity, mortality, length of hospital stay, and cost. There are limitations to TRA due to the size of the vessel and anatomical considerations which make its catheterization challenging in some cases. The left-sided supra-aortic vessels, specifically the left carotid, present a challenge through the transradial approach [4].

While not a novel technique, transcervical access of the intracranial circulation through direct carotid puncture has the potential to allow faster recanalization times and to offer therapy to those with complex anatomy of the aortic arch or its branches. This approach to access has become particularly attractive for mechanical thrombectomy (MT). The MT population is often older and has a high incidence of severe vessel angulation and redundancy. This can sometimes make transfemoral or transradial access of the intracranial clot difficult, time-consuming, and sometimes impossible. In these cases, direct carotid puncture has proven successful but is associated

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with its own challenges such as iatrogenic carotid injury and postoperative access site bleeding with hematoma formation [5]. The development of carotid access sheath and arteriotomy closure systems may overcome these challenges in the future. A second arena in which direct carotid access is gaining adoption is in transcarotid artery revascularization (TCAR) procedures. This approach to carotid revascularization combines direct carotid access, flow reversal as a means of emboli protection, and carotid stent insertion. Again, it is useful in populations with difficult transfemoral access, but head-to-head comparisons with transfemoral stenting and CEA are lacking [6].

Endovascular Treatment of Central Retinal Artery Occlusion

Central retinal artery occlusion (CRAO) is an ophthalmologic emergency with an incidence of 1/10,000 but as high as 57/100,000 person-years in the age range of 80–84. Acute retinal infarction and vision loss is the result of CRAO. This carotid circulation ischemic syndrome should be considered as a nervous system condition but has not benefited from the therapeutic growth that has come with systemic and catheter-based therapies for stroke. Proof of efficacy for reperfusion therapies is still lacking. Recognition of CRAO as a neurological emergency makes delayed diagnosis frequent, but the American Academy of Ophthalmology (AAO)-endorsed preferred practices highlight that acute symptomatic CRAO should prompt an immediate referral to the nearest stroke referral center. Several case series and some small controlled trials have investigated the use of endovascular infusion of pharmacologic agents to improve outcomes, but a large randomized clinical trial is still needed making treatments of CRAO one of the future challenges for the neurointerventional field [7]. Multidisciplinary collaborations and standardization of protocols will be needed for this promising therapy to gain more widespread use and offer the potential to spare patients from blindness [8].

Middle Meningeal Artery Embolization for Chronic Subdural Hematomas

Chronic subdural hematomas (cSDH) are common with an increasing prevalence as the population ages. The population that should be considered for embolization can be defined as patients with an "extra-axial, crescentic, fluid collection, the majority of which (>50% volume) is either hypo- or isodense to the underlying brain on CT" and is associated with neurological decompensation [9]. There are an estimated 60,000 new cases per year expected by 2030 which represents double the number of ruptured aneurysms in the United States annually. Embolization of the middle meningeal artery (MMA) has quickly become part of management armamentarium for cSDH. It involves microcatheterization of the external carotid artery, the internal maxillary artery, and finally the middle meningeal artery itself. Embolization with a liquid embolic agent is the most widely used technique. Large case series have reported dramatic results when MMA embolization is used as a primary treatment or as an adjunct to surgical interventions [10]. However, controlled clinical trials are still needed. Standardization of treatment protocols and investigations into the advantages of liquid embolics or other forms of vessel embolization will further clarify the efficacy of this procedure [11].

Endovascular Treatment of Headache

Headache is a leading cause of pain and disability in adults. One in five adults in the United States suffers from severe headaches or chronic migraines. This tremendous disease burden is also associated with a large annual economic cost. Pharmacologic interventions are available for headache, but it continues to lead to almost 4% of all Emergency Room visits where a significant number of patients are treated with opiates. The MMA is the main arterial feeder of the dura and is dilated during migraines. A recent study reported successful administration of intra-arterial lidocaine and steroids into the MMA for refractory migraine [12]. Much remains to be learned from controlled trials regarding the safety and efficacy of this intervention, but there is a great need to alleviate pain and diminish disability due to headache, and endovascular treatment offers hope for the future [13].

Endovascular Neuro-Oncology

Central nervous system tumors have an incidence of 24,000 new cases per year in the United States. The most common primary brain tumor is glioblastoma (GBM), which is also the deadliest. Many advances in the chemotherapeutic and immunotherapy fields have shown promise, but nervous system malignancies continue to be a therapeutic challenge. Their complex molecular biology and the relative protection offered by the blood-brain barrier are partly responsible for the lack of response of these tumors to current therapies. Endovascular selective intra-arterial (ESIA) approaches offer a way to disrupt the blood-brain barrier and to deliver targeted biologic therapies to brain tumors. There is an increased urgency and need to develop ESIA approaches in brain tumor therapy [14]. In contrast to the difficulty of finding a successful IA therapy for brain tumors, IA chemotherapy (IAC) has become increasingly used to treat retinoblastoma, the most common childhood intraocular malignancy [15].

Endovascular Treatment of Intracranial Hypertension

Idiopathic intracranial hypertension (IIH) is a disease process of abnormally increased intracranial pressure in the absence of a mass lesion. Medical management, optic nerve fenestration, and surgical shunting procedures are sometimes successful, but a significant population of treatment refractory patients remains. In an unknown percentage of cases, intracranial hypertension is not idiopathic but instead is caused by dural venous sinus obstruction which can be treated with dural venous sinus stenting. The goal of these surgeries is to prevent progressive vision loss and worsening papilledema caused by underlying increased intracranial pressure from venous outflow obstruction. Documenting a pressure gradient of at least 8 mmHg or greater across the stenosis is diagnostic. When patients are selected with care, it is reasonable to expect normalization of the intracranial pressure, and there is an increasing body of literature showing stabilization and improvement in vision [16]. Randomized controlled trials of this approach are still needed to validate its widespread use.

Endovascular Neuromodulation

Endovascular neuromodulation is an emerging technology that is still largely confined to animal models, but it holds great future promise. An example interface is the StentrodeTM, a stent-electrode array which can be implanted into the superior sagittal sinus. The Stentrode transmits signals through a transvenous lead to a receiver located subcutaneously in the chest. Transvenous leads have been successfully employed for decades in the setting of implantable cardiac pacemakers and defibrillators. Through this brain-computer interface, patients with severe paralysis can control digital devices and overcome severe disability. It has the potential to restore a patient's ability to perform activities of daily living [17].

Direct Intravascular Visualization

Intravascular ultrasound (IVUS) and optical coherence tomography (OCT) are two techniques that allow direct intravascular visualization. IVUS uses ultrasound to provide cross-sectional images of the vessel and vessel wall. Its use has mainly been described in cervical atherosclerotic disease and stenting, but the availability of smaller profile devices promises to expand this into the intracranial circulation.

OCT uses a wire that emits near-infrared light. This technology has been used to image the cervical stents and flow diverters. Like IVUS, the use of OCT will expand as the devices become smaller and trackable into the intracranial circulation [18].

Robotic Neurointerventional Techniques

Robotic neurointervention is a promising emerging field. Endovascular robots enable proceduralists who are not physically present in the procedural suite to control wires, catheters, and other devices. This ability to perform procedures remotely holds the potential to dramatically expand access to care. Telestroke technology coupled with these robotic techniques could make highly subspecialized care available to underserved areas and overcome the devastating consequences of the delayed treatment of cerebrovascular emergencies. It also could reduce occupational hazards such as radiation exposure. Preliminary clinical research has been published describing the safety and feasibility of such robotic technology in diagnostic cerebral angiography as well as cervical and intracranial interventions. Larger prospective clinical trials are currently being planned [19].

Artificial Intelligence and Neurointervention

Artificial intelligence (AI) can improve disease detection, auxiliary diagnosis, and precision medicine. The accuracy of brain imaging diagnostics has been increased by the extraction of imaging features using artificial intelligence techniques such as machine learning. Rapid automated differentiation of ischemic and hemorrhagic cerebrovascular diseases, risk assessment of intracranial aneurysm rupture, and rapid assessment of large vessel occlusion and ischemic penumbra by computerized brain imaging analysis algorithms are now common [20].

Conclusion

The armamentarium of the neurointerventionist is growing at an accelerating pace. While these tools hold great promise, many new technologies remain in an early phase or are yet to be tested in randomized controlled studies. This burgeoning collection of investigational treatments will likely continue to expand the role of neurointervention in the medical specialties.

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