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Techniques in Vascular and Interventional Radiology

Surgical Considerations in Vascular Malformations

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Vascular malformations are generally congenital benign lesions that have multiple variations in treatment algorithms. Surgery can be used as a single modality or as an adjunct in multimodal therapy to treat these lesions. Here we discuss surgical treatment of the major vascular malformations, including lymphatic, venous, and arteriovenous malformations. We explain some of the basic principles to resection of simple and complex lesions and adjunctive therapies. These adjunct therapies include chemotherapeutic injections, embolization, and laser therapy. Surgical resection of complex lesions should only be performed by an experienced vascular anomalies surgeon. A team approach is generally necessary to provide safe and effective treatment. While surgery for these complex lesions is an option, the most important principle to adhere to when treating any of these lesions is that the treatment should be no worse than the disease.
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KEYWORDS vascular malformation, ateriorvenous malformation, lymphatic malformation, venous malformation, vascular anomalies

Introduction

Vascular malformations are rare lesions that are present at birth and which integrate into native and local soft tissue. Unlike infantile hemangiomas, venous malformations (VMs) do not resolve on their own. They are divided based on their flow characteristics and vessel type according to the 2014 ISSVA classification scheme.[1] Slow flow malformations include lymphatic malformations (LMs) and VMs while the most common fast flow malformations are arteriovenous malformations (AVMs). Characteristic of their vessel type, each vascular malformation behaves differently. Many are slow growing, gradually expanding, and infiltrative. Triggers such as hormones and trauma can influence acute expansion.

Unfortunately, because of the nature of their progressive and destructive growth, vascular malformations ultimately require intervention to arrest or eliminate the disease. This should entail selective treatment of malformed vessels while preserving normal architecture. This can be accomplished with laser therapy, intralesional or intravascular injury, surgical excision, or a combination of the above. Surgical management is generally a good option as long as the treatment does not lead to functional or esthetic outcomes worse than the disease. Tenants of surgical management should include staged treatments of affected vessels using a multimodal approach whereby the excision avoids injury to local surrounding vital structures. For example, preservation of normal mucosal and skin envelopes along with aerodigestive, visual, and neurologic function is paramount.

Lymphatic Malformations

LMs are a common slow flow vascular malformation, comprised of local cystic expansion of lymphatic vessels with poorly dilated draining outflow tracts. These are categorized by the size of their cysts, which can be visualized on diagnostic imaging, including magnetic resonance imaging (MRI) or ultrasound. If the majority of the cysts are less than 2 cm^3, they are considered microcystic lesions. LM can be deeply infiltrative into normal soft tissue with borders that can be difficult to delineate from normal adjacent structures. When the cysts are greater than 2 cm^3, LMs are considered macrocystic. Often, LMs are mixed macrocystic and microcystic. Cervicofacial macrocystic lesions are further defined by the De Serres classification scheme (Table) with a worse

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Table De Serres Classification

Type 1	Unilateral infrahyoid
Type 2	Unilateral suprahyoid
Type 3	Unilateral infra- and suprahyoid
Type 4	Bilateral infrahyoid
Type 5	Bilateral infra- and suprahyoid

prognosis occurring with higher type lesions.[2] Fortunately, macrocystic LM have discrete borders and cystic walls that compress adjacent soft tissues rather than infiltrating them.

For this reason, macrocystic LM are amendable to surgical resection. Uninvolved skin and mucosa may be elevated off underlying macrocysts that easy dissect off local tissue. Preservation of local neurovascular structures can be done with low risk for complications.[1,3] Macrocystic LM can be excised with limited or no cosmetic or functional disability as long as incisions are made in natural skin creases (Fig. 1). Of note, it has been reported that posterior neck triangle macrocystic LMs may resolve without intervention. Vigilant observation may be appropriate for this select group.[4] Sclerotherapy has been demonstrated to be equally effective vs surgical resection for selected macrocystic LM. This will be discussed by other authors.

The optimal age of the patient at the time of operation for macrocystic LM is controversial. Asymptomatic newborns with macrocystic disease may be observed and managed with steroids and antibiotics during periods of acute expansion. When compromise of vital structures is present or imminent, surgical resection of accessible macrocystic LM may be an acceptable option for therapy. However, if possible, a period of at least 6 months for environmental acclimation, immune maturation, and maternal bonding is recommended in otherwise healthy children. Prognosis and recurrence rates do not appear to be impacted by the patient's age at time of surgical resection. Anecdotally, skin elasticity, and accelerated healing in young children reduce the risk of long-term scarring. In the event of postoperative recurrence or residual disease, "touch up" sclerotherapy can be offered.

Mixed LMs are common, and microcystic components may be discovered to accompany macrocystic disease at the time of surgery. In these situations, the microcystic disease may difficult to resect without disrupting normal tissue. However, intraoperative sclerotherapy may be performed. This can help to reduce the volume and duration of postoperative drainage while limiting the need of future therapy. Bleomycin and doxycycline can be used as sclerotic agents, with direct administration to LM in the surgical field.

Microcystic LMs are clinically and genetically different then their macrocystic counterparts. They are not ideal for surgical intervention due to their infiltrative nature. Because they are enmeshed within normal soft tissue, surgical resection can lead to cosmetic and/or physical deformity and high rates of recurrence. However, bulky disease (eg, within muscle or bone), or that involving nonfunctional structures (ie, skin and subcutaneous fat) can be resected or debulked with good outcomes.

Postoperative Care

Perioperative management is important for the success of surgical therapy for LM. Due to their delicate and thin walled nature, lymphatic vessels are not ligated during the procedure. Therefore, after resection, a drain must be secured, allowing for gravity drainage. A week of drainage, or until it wanes significantly, will reduce the risk of postoperative seroma. This allows for a period of auto-sclerotherapy of remaining channels. A short course of systemic steroids and antibiotics will also reduce the volume of drainage after surgery. Sirolimus, a mamalian target of rapamyacin (MTOR) inhibitor and immune modulator, has been shown to improve symptoms in those with complex veno-LMs and reduce perioperative drainage.[5] Thus, a short course of Sirolimus following surgical intervention is also reasonable, and can be used in the event of lesion recurrence or persistent microcystic LMs.

Special Considerations

Cervicofacial LMs, especially in the setting of bilateral De Serres 4-5 disease, should be evaluated for upper airway involvement or compression. This can be performed with preoperative MRI and by otolaryngology with microlaryngoscopy and bronchoscopy. A supraglottic collapsible airway

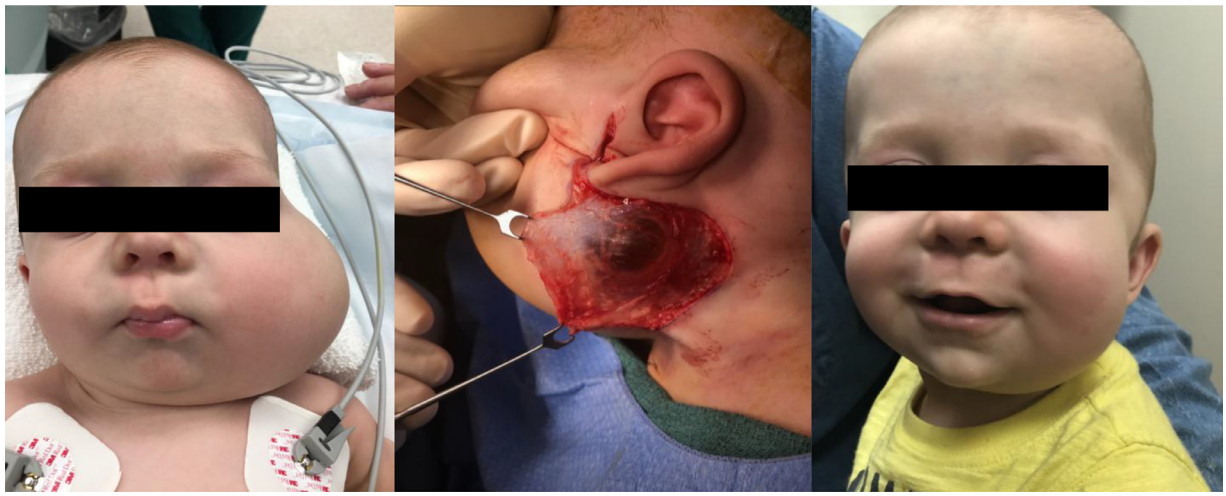

Figure 1 Surgical resection before, during, and after of cervical lymphatic malformation using a modified Blair incision.

abnormality may be present even when LM is not present in larynx (Fig. 2). This may be due to the elongation of the supraglottis and base of tongue due to advanced infiltrative microcystic disease of the neck and tongue.

LMs involving the extremities or thorax are frequently mixed lesions and may be accompanied by VMs. Disease involving the skin and subcutaneous tissue can often be resected successfully without sequelae. Subdermal dissection with broad-based skin flaps can prevent the need for large reconstructive efforts (Fig. 3). Excision of superficial vesicles, however, is important. Diffuse intramuscular disease is best managed with medical therapies or percutaneous sclerotherapy.

In essence, microcystic LM can be treated with surgical resection, without significant bleeding, if they do not infiltrate into vital structures. Midline tongue lesions can be addressed with a central wedge resection involving the mucosa and some central musculature without disruption of normal function or articulation. Cure is common with minimal morbidity if the lesion does not significantly involve the muscle.[6] Other focal small lesions can simply be resected with the local tissues primarily repaired. When the lesions involve major neurovascular structures, sclerotherapy is often attempted with marginal success.[7] A combined approach of sclerotherapy and surgical resection for these lesions can render them potentially curable, but, at the very least, manageable from a clinical standpoint. In the periorbital region, there has been great success with this bimodal technique using bleomycin and resection.[8]

Venous Malformation

VMs are slow flow lesions that are present at birth and comprised of a network of serpiginous interconnected veins with ectatic venous channels deficient in vascular smooth muscle. VMs are slow growing, low flow, and increase in size due to vascular expansion from perturbations in vascular pressure that occur during Valsalva, dependency, exercise, or agitation. Pain, dysfunction, and deformity occur with VM. Ultrasound and contrast-enhanced MRI are the imaging

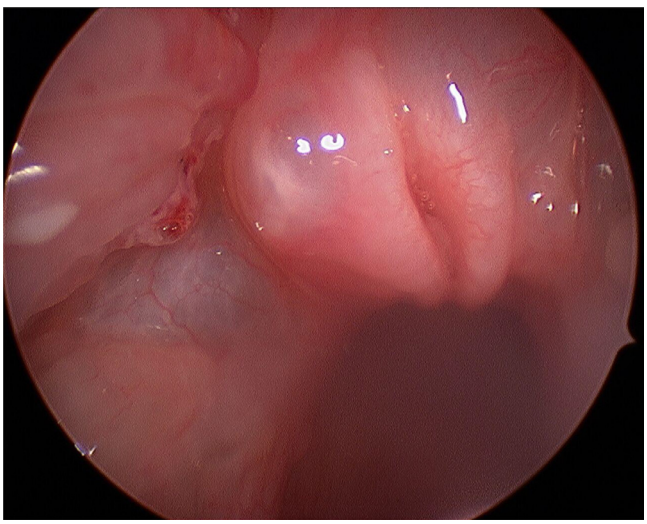

Figure 2 Typical laryngeal morphology of patient with a cervicofacial lymphatic malformation.

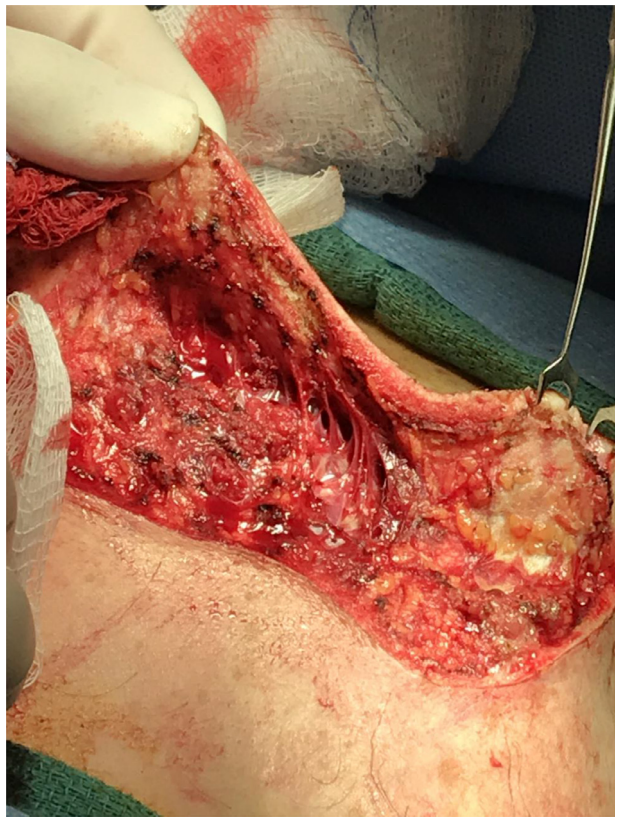

Figure 3 Broad-based skin flaps for resection of a lymphatic malformation.

modalities of choice when considering surgical intervention.[9] Surgical resection, laser therapy, and sclerotherapy are all applied during the planning of surgical control of VM.

Goals for surgical intervention of VM include preservation of the skin and mucosal envelopes along with staged interventions to remove painful or obstructive lesions. Heroic efforts with large resections often lead to long and risky procedures with poor outcomes. Targeted interventions at periodic intervals (ie, 3 months), along with strategic employment of preoperative sclerotherapy, will reduce perioperative complications and lead to progressive improvements in function and aesthetics.

Although imaging suggests otherwise, VMs are often diffusely invested into normal skin, mucosa, and muscle at time of surgery, with poorly delineated borders. The vascular walls of VMs are thin and leaky with dysfunctional clotting abilities. This makes them particularly delicate and friable during dissection, requiring skilled, and expedient surgical technique. Standard operative approaches may therefore not work well during the removal of VM, including blunt dissection and suture ligature. Attempts at suture repair of injured vessels may lead to greater exposure and worse bleeding due to quickly tearing fragile vessels.

A well-planned approach should be developed before each case, with the anatomy and targeted areas clearly defined, so a steady and rapid pace can be applied and blood loss minimized. Preoperative planning with anesthesia is also recommended so blood products can be made available and coagulation issues controlled. Of note, VMs are associated with local intravascular coagulation as the result of static blood in large diameter intravascular low-flow channels. In extensive lesions, local intravascular coagulation can lead to

elevation of D-Dimer levels and reduction in fibrinogen. During invasive procedures, a consumptive coagulation cascade may ensue, potentially causing disseminated intravascular coagulation if not controlled. Management with low doses of low molecular weight heparin up to 2 weeks before the procedure is recommended in patients with elevated D-dimers and low fibrinogen.

Although there is a propensity for bleeding during the removal of VM, several principals during resection can be applied to reduce blood loss. These include the generous use of *nonstick* bipolar cautery for dissection, wide exposure of the surgical field, staying beyond the VM margins, and removing as much of the lesion as possible before tying off major draining veins. Distal and proximal identification of nerves and vessels will improve visualizing these structures as they pass through the obscuring VM. Diffuse bleeding can be partially controlled with gelfoam-soaked thrombin covered by surgical pledgets. Appropriate use of tourniquets may also be beneficial.

Multimodal Management

Superficial disease involving the skin or mucosa should first be ablated with selective photothermolysis using ND:YAG lasers (1064 nm) at periodic intervals before surgical excision of deeper lesions (Fig. 4). The integrity of this skin and mucosa can thereby be retained at the time of resection to improve the cosmetic[10] outcome using local soft tissue.

Advanced VMs are amendable to surgical resection. In these cases, embolization using liquid embolics (most often with *N*-butyl cyanoacrylate, but also Onyx), via ultrasound or venogram-guided direct percutaneous puncture, of planned sites of resection is performed by interventional radiology prior to surgical resection. Although the optimal timing of preoperative embolization is controversial, this allows for the solidification and contraction of serpiginous venous channels into a localized ball (Fig. 5). During dissection, in this scenario, the targeted vessels are able to be removed while leaving behind normal and surrounding soft tissue (typically muscle). This strategy is ideal for extremity and cervicofacial lesions invading large muscle groups and can be repeated at well-spaced intervals. In essence, VM embolization with liquid embolics makes the VM easier to define during surgery and has been shown to reduce blood loss.[11] Of note, after *N*-butyl cyanoacrylate is administered, the surgeon must do everything possible to remove it. Otherwise, there is the potential for a foreign body reaction, with resultant inflammation, which can lead to wound infection and breakdown.

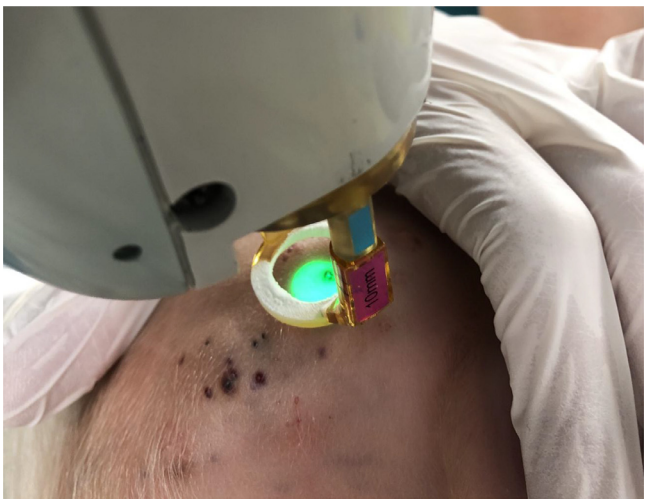

Figure 4 Superficial portion of a venous malformation undergoing Gentle YAG therapy.

Complex cervicofacial lesions often involve the aero digestive tract. These lesions can cause sleep apnea and make it difficult to intubate and extubate patients safely. Long-term stabilization of pharyngolaryngotracheal lesions should be accomplished before managing the remaining disease. Control of mucosal disease is paramount before embarking on large resections of these areas. ND:YAG laser is an excellent adjunct to selectively treat mucosal VMs using photothermolysis. Targeted ND:YAG laser will shrink VM of the mucosa, strengthen the mucosal walls, and help stabilize the airway. The ND:YAG laser technique involves polka-dotting the area of interest approximately 1 cm apart using 18-25 W and a 1 second pulse duration. (Fig. 6) This procedure helps preserve overlying functional mucosa. However, deeper aerodigestive disease often requires sclerotherapy. Intralesional and interstitial Bleomycin, the least inflammatory of the sclerosing agents, can be used in this setting so that airway edema is minimized. Bleomycin sclerotherapy and ND:YAG laser can be performed during the same treatment session. However, ND:YAG laser should be employed first as bleomycin can cause hyperpigmentation at sites of laser trauma. Simultaneous use also increases the risk of ulceration at treated areas. In addition, due to the mechanism of action of Bleomycin, delaying surgery for 6-8 weeks may be appropriate in some settings in order to achieve the desired sclerotherapy result.

Arteriovenous Malformations

AVMs are arguably one of the most challenging vascular malformations to manage. Like other malformations, AVMs are integrated within and among normal tissue and bone. They

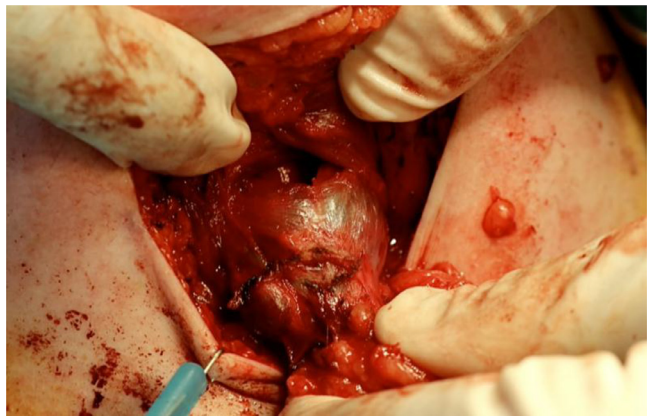

Figure 5 Example of N-BCA Glue embolization during resection.

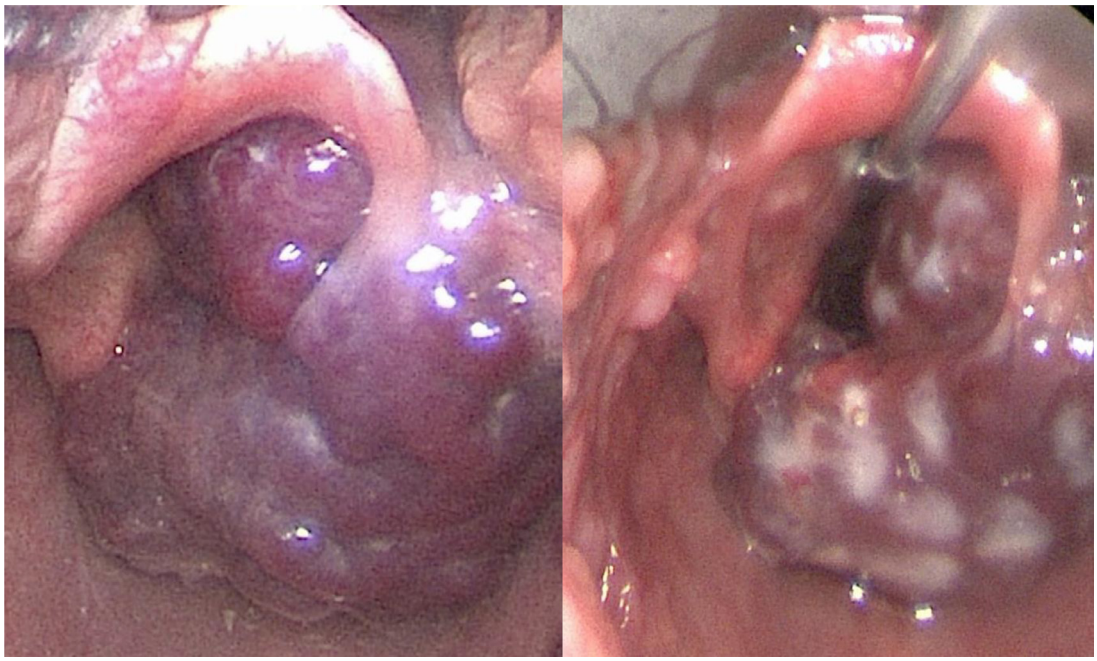

Figure 6 Laryngeal venous malformation before and after ND:YAG therapy.

are composed of one or more arteriovenous fistulae and presumed to be devoid of a normal capillary bed. With time, AVMs grow by vascular expansion, collateralization, and recruitment of additional abnormal vessels. Periods of hormone fluctuations and trauma have been associated with acute expansion.[12] Recent evidence points to both germline (RASA-1 and PTEN) and somatic mutations (MAP2K1) as to their origin.[13-15] Histologically, they demonstrate unstable, leaky, and poorly organized vascular walls with arterialization of outflow veins. Without an intervening capillary bed, the local tissue of AVM is plagued by persistent high flow, hypoxia, and poor nutritional diffusion. This leads to associated elevations in hypoxia-triggered vascular biomarkers involved in repair and vessel stabilization along the matrix metalloproteinase, vascular endothelial growth factor, and transforming growth factor pathways.[16] The result is an anomalous feedback loop to produce new, albeit abnormal, vessels in the affected area. This process can be exacerbated by partial or incomplete treatment.

AVM management is therefore plagued by high rates of local complications and recurrence. Effective treatments are staged, repeated, and multimodal, to gradually reduce the burden of disease and address newly arising or hidden channels. Like other vascular malformations, heroic efforts with large resections can lead to complications and deformity due to local nutritional deficits, bleeding, poor wound healing, and the removal of normal but involved architecture. The goal behind any AVM management should be to selectively treat the abnormal vessels while preserving associated normal tissue. This can be performed with superselective endovascular embolization, venous outflow sclerotherapy, laser therapy, and surgical resection. Performed in combination, and at periodic intervals, these treatment modalities are effective in removing AVM and controlling their growth. This requires a well-choreographed multidisciplinary approach.

Staging and Timing

When to intervene for extracranial AVM is controversial and often based upon clinical symptoms and its stage of development. The most widely used staging system is the Schobinger classification whereby the stage of an AVM is determined by clinical evidence of quiescence (1), expansion (2), destruction (3), or decompensation (4). Many vascular anomalies specialists reserve treatment for later stages. Other staging systems include those by Richter-Suen, Yakes, and Cho.[17-19] AVM staging in these is based on depth and extent of disease of the vascular pattern seen on angiography. Figure 7 is an example of an angiogram performed on an upper extremity AVM.

The authors use a functional staging approach to AVM by characterizing them as either focal or diffuse. Focal lesions have up to 2 arterial feeders and venous outflow tracts at a single site with a well-defined radiographic nidus. Diffuse lesions infiltrate larger areas, cross anatomic subsites, and demonstrate multiple arterial feeders and outflow tracts. The nidus is frequently multifocal or indiscriminate in diffuse lesions. Within many AVM, there is a central nidus, which is thought to be the origin and crux of the AVM.[20]

Focal lesions have the best clinical outcome to treatment irrespective of the modality used (surgery or embolization), while diffuse lesions demonstrate high recurrence rates and complications.[18]

Unfortunately, despite the stage or description, all AVMs eventually progress by adolescence or adulthood.[12] This is marked by expansion and destruction of local soft tissues. An early intervention is thereby often advocated. More importantly, once intervention begins, vigilant follow-up with recurrent staged treatment is required to achieve the best outcome. Longer treatment intervals may be employed after the lesion is under control. Along with local issues, systemic complications of AVM should also be considered, such

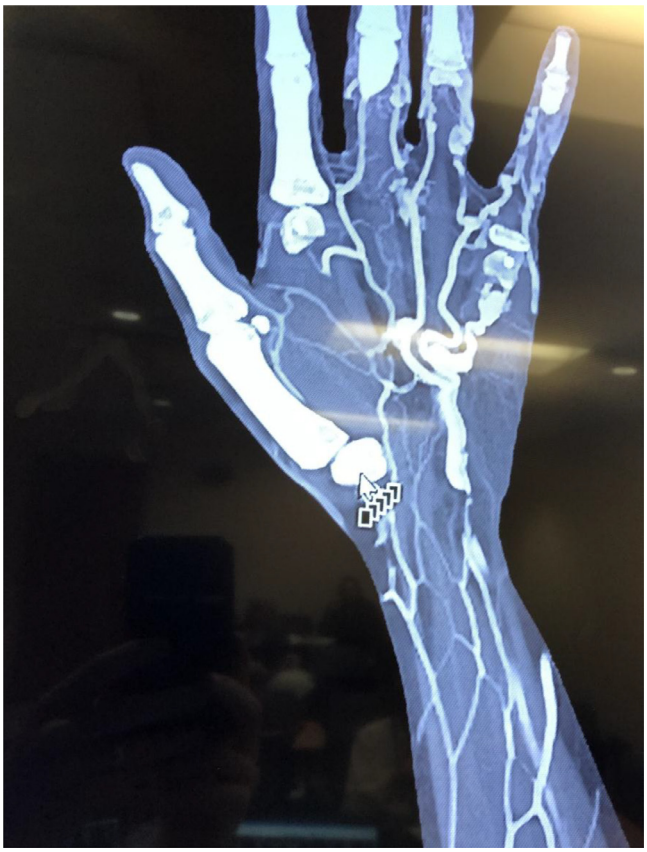

Figure 7 Angiogram of an upper extremity arteriovenous malformation.

as the impact of high output, and potential risk of high flow congestive heart failure. This may also serve as an indication for earlier treatment.

Surgical Approach

Super-selective embolization followed by surgical resection has proven to offer the best chance for control and cure of AVM. Adherence to the principle of local soft tissue preservation will allow the treatment outcome to be better than the disease. This includes elevation of skin flaps to be used for repair even if the skin is involved. Typically performed at 3-month intervals, Pulse Dye (595 nm and Gentle ND:YAG) laser can ablate skin disease. This is performed multiple times and can be accompanied with subcutaneous and intramuscular interstitial doxycycline or bleomycin sclerotherapy prior to resection of the deeper components of the AVM.

Surgical planning for large or diffuse AVM should include a mental and radiographic preoperative compartmentalization of the disease into anatomic subsites. MRI, including vascular imaging, is the modality of choice for evaluation and for embolization and surgical planning. However, in some situations, diagnostic catheter angiography may still be appropriate for appropriate counselling and planning. Multiple staged resections of AVM subsites will allow for appropriate wound healing and preservation of function and cosmesis, which is often at risk during massive surgical interventions. To reduce the load of vascular collateralization and recruitment after AVM resection, intervals between resections

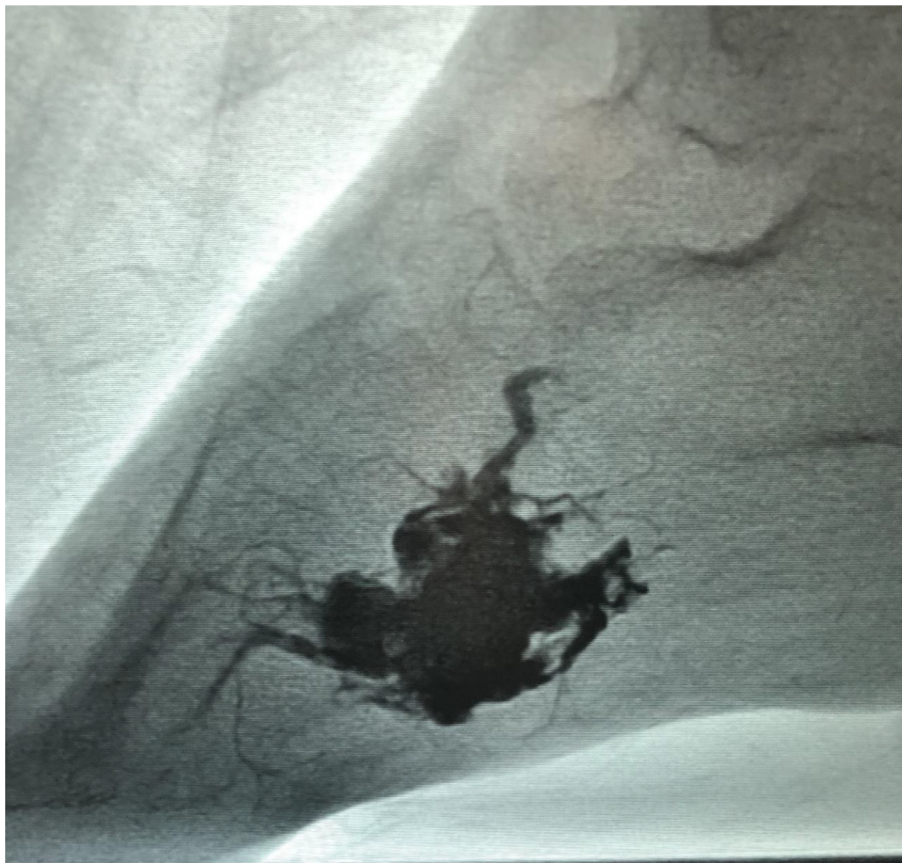

Figure 8 Intraoperative fluoroscopy of a foot arteriovenous malformation.

should range between 3 and 4 months. Preoperative embolization with liquid embolics can be performed up to 72 hours before planned surgery, if necessary. However, this is best done the day of or 24 hours prior to surgical excision to limit associated inflammation and local tissue swelling which may negatively impact the planned surgery (Fig. 8). Close communication between the interventional radiologist and the surgeon is critical to identify the planned area of resection. Liquid embolics, such as n-butyl cyanoacruylate (NCBA), assist with reducing blood loss and defining the AVM borders which can otherwise be elusive. Onyx is an excellent alternative, especially as it is more readily visualized at the time of surgery as a black agent within the treated vasculature. However, use of bipolar cautery is essential as the tantalum in the Onyx embolic will cause sparking with monopolar therapy. AVM resection can be challenging secondary to its infiltrative nature. AVM can grow and invade fat planes, muscle and even bone. Nonsclerosing embolic agents thereby help delineate the involved vessels without a significant inflammatory cascade that can disrupt surgical planes. When possible, the nidus should be identified and targeted for resection.

AVM surgery follows a similar algorithm for surgical resection as that for VMs. Focal lesions can be removed with or without preoperative embolization with a high rate of cure. Complex AVMs often require multimodal therapy. Laser therapy for the superficial cutaneous components near the resected site should be employed at the same time. Portions of AVM that infiltrate into tissue that should not be resected can be treated with bleomycin or doxycycline. Perioperative administration of oral doxycycline has been shown to be efficacious in prevention of growth before and after resection via mechanisms involving matrix metalloproteinase 9.

Sirolimus, an MTOR inhibitor and immune modulator, may also act as an adjunct to surgery and embolization following these procedures to prevent angiogenesis and recruitment of new vessels.[21]

The success of surgical resection of extracranial AVM is dependent upon the vigilance of the vascular anomalies multidisciplinary team and long-term follow-up. Reports vary in their success rate but cure is not common except in focal disease. Goldberg et al demonstrated that, after multiple embolizations, total resection was achieved in 22 cases (71.0%). Subtotal or partial resections were accomplished in 9 cases (29.0%).

The authors' experience indicates that surgical resection is part of the armamentarium of a multimodal approach to treat AVM whereby laser treatment and interstitial sclerotherapy is effective once the bulky disease is resected.

Complications From Surgical Resection of Vascular Malformations

Complications from surgical intervention are rare, but can be serious. Surgical risks and complications are dependent on the technique used for surgical intervention as well as the location of the lesion. Any surrounding nerves, arteries, or vital structures are potentially at risk. This underscores the importance of the surgeon having experience in the area of interest. An obvious yet serious complication can be hemorrhage and hematoma. LMs can easily form seromas postoperatively; therefore, the authors prefer to use a gravity-based drain in order to prevent this accumulation. As VMs tend to bleed until the lesion is removed, using preoperative liquid embolization has helped decrease intraoperative blood loss during these cases (data not published). AVMs have a higher tendency to bleed and need transfusion afterwards. This is intuitive as they are fast flow and high-pressure lesions. Blood loss can be rapid and the surgeon should pay close attention to how much is being suctioned during surgical intervention for AVM.

Summary

Vascular anomalies are difficult entities to treat. When surgery is applicable, the procedures can be daunting in inexperienced hands. Good surgical planning and following some basic principles can help with adequate and safe resection. All vascular anomalies should be managed using a multidisciplinary approach. Surgical resection should be performed by a surgeon who is familiar with the anomaly itself as well as familiar with surgical interventions in the area of the body affected by the lesion. As such, the treating team may involve surgical specialties spanning the entire body, but most often include otolaryngology, general surgery, orthopedics, and plastic surgery. Regardless of treatment selected, these are considered benign lesions and the treatment should not be worse than the disease.

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