Open, percutaneous, and hybrid deep venous arterialization technique for no-option foot salvage

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ABSTRACT

Objective: Deep venous arterialization (DVA) is a technique aimed at providing an option for chronic limb-threatening ischemia patients with no options except amputation. In patients with no outflow distal targets permitting bypass, DVA involves creating a connection between a proximal arterial inflow and a distal venous outflow in conjunction with disruption of the vein valves in the foot. This permits blood flow to reach the foot and potentially to resolve rest pain or to assist in healing of a chronic wound. We aimed to provide an up-to-date review of DVA indications; to describe the open, percutaneous, and hybrid technique; to detail outcomes of each of the available techniques; and to relay the post-operative considerations for the DVA approach.

Methods: A literature review of relevant articles containing all permutations of the terms "deep venous arterialization" and "distal venous arterialization" was undertaken with the MEDLINE, Cochrane, and PubMed databases to find cases of open, percutaneous, and hybrid DVA in the peer-reviewed literature. The free text and Medical Subject Headings search terms included were "ischemia," "lower extremity," "venous arterialization," "arteriovenous reversal," and "lower limb salvage." Studies were primarily retrospective case series but did include two studies with matched controls. Recorded primary outcomes were patency, limb salvage, wound healing, amputation, and resolution of rest pain, with secondary outcomes of complication and overall mortality. Studies were excluded if there was insufficient discussion of technical details (graft type, target vein) or lack of reported outcome measure.

Results: Studies that met inclusion criteria (12 open, 3 percutaneous, 2 hybrid) were identified, reviewed, and summarized to compare technique, patient selection, and outcomes between open, percutaneous, and hybrid DVA. For open procedures, 1-year primary patency ranged from 44.4% to 87.5%; secondary patency was less reported but ranged from 55.6% at 1 year to 72% at 25-month follow-up. Limb salvage rates ranged from 25% to 100%, wound healing occurred in 28.6% to 100% of cases, and rest pain resolved in 11.9% to 100% across cohorts. For the endovascular approach, primary patency ranged from 28.6% to 40% at 6-month and 10-month follow-up. Limb salvage rates ranged from 60% to 71%, with rates of major amputation ranging from 20% to 28.5%.

Conclusions: This review provides an up-to-date review of DVA indications, description of various DVA techniques, patient selection associated with each approach, and outcomes for each technique. (J Vasc Surg 2019;■:1-10.)

Keywords: Deep venous arterialization; Percutaneous DVA; Hybrid DVA; Limb salvage; No-option critical limb ischemia

Chronic limb-threatening ischemia (CLTI) is characterized by ischemic rest pain or tissue loss, and the goal of limb salvage is to re-establish blood flow to a point at which healing is promoted and amputation avoided. However, there are challenging situations in which conventional revascularization techniques still fail to have a tangible positive result because of lack of outflow in the foot.[1] Although arterial revascularization is the primary approach, a subset of patients have disease recalcitrant to endovascular recanalization or open bypass. At-risk populations include patients with diabetes, end-stage renal disease, and thromboangiitis obliterans who develop disease in the tibial arteries and small arteries of the foot. In these patients without an adequate distal arterial outflow target, amputation was essentially the only option to manage their rest pain or tissue loss. Deep venous arterialization (DVA) involves creating a connection between an arterial proximal inflow and a distal deep venous target at the ankle with the intent of "arterializing" the veins of the foot, thereby providing adequate blood flow to resolve rest pain or to heal a chronic wound. It involves creating a connection between an arterial inflow and distal venous segment outflow, allowing adequate timing for arterialization of the veins to occur, breaking the valves in the foot, and then ligating or coiling any venous branches to allow the maximal amount of arterialized blood to reach the distal aspects of the foot.

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Author conflict of interest: none.

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The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a conflict of interest.

0741-5214

https://doi.org/10.1016/j.jvs.2019.10.085

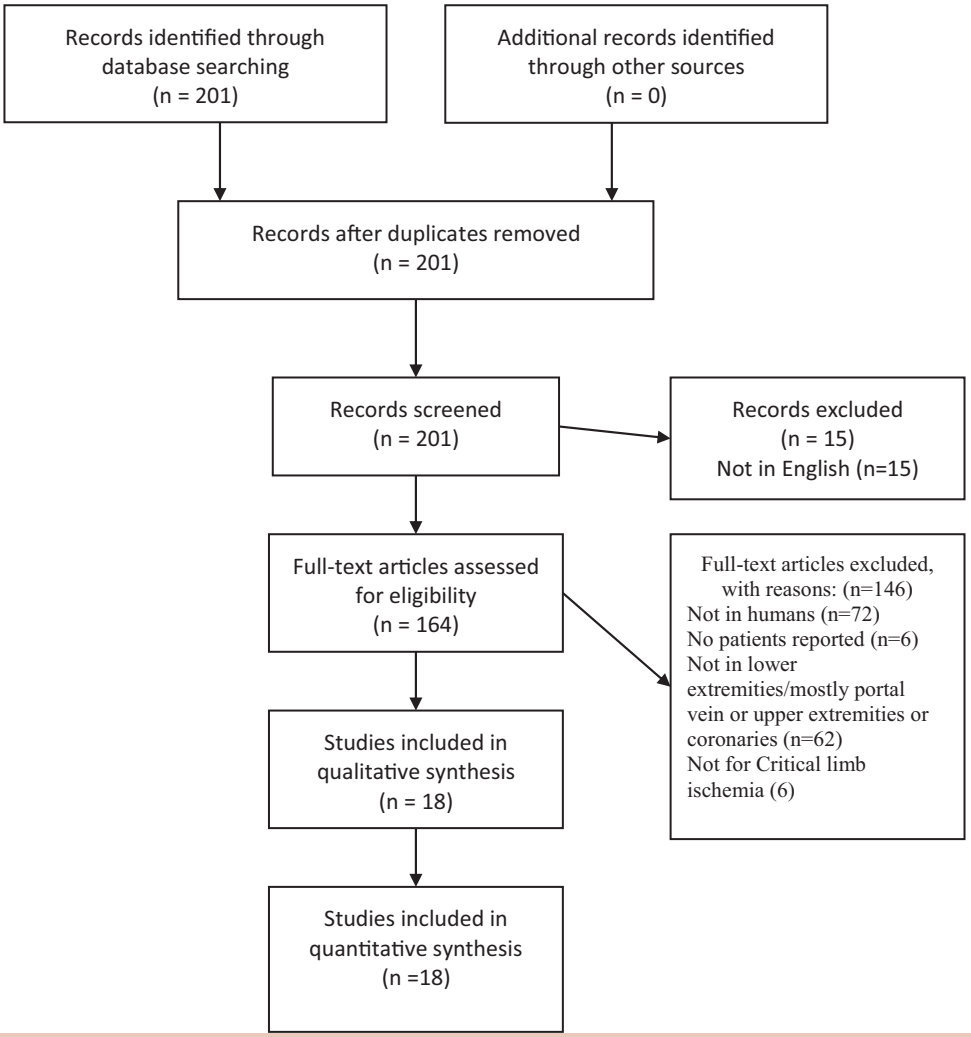

Fig 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram of included articles.

DVA was first described by Francois-Frank; he performed femoral arteriovenous anastomosis in dogs in 1881[2] and in humans in 1894,[3] but poor rates of wound healing and limb salvage were reported as well as complications including congestive heart failure and severe extremity edema.[2,4] In 1977, Sheil[5] described the modern version of the procedure. The great saphenous vein was anastomosed to the dorsal venous arch of the foot in six patients with critical limb ischemia, with resolution of rest pain and healing of wounds in five of six patients.[5] Since that initial series, numerous case series have been published. Percutaneous and hybrid approaches to creation of the arteriovenous anastomosis have been developed, and a multicenter trial for the percutaneous device is currently under way.[6] Given that DVA is an option for the "no-option" CLTI patient, we aimed to provide an up-to-date review of DVA indications, to describe the techniques (open, percutaneous, and hybrid), to detail outcomes of each of the available techniques, and to relay the postoperative considerations for the DVA approach.

PHYSIOLOGIC DATA TO SUPPORT DVA

The principle of DVA involves anastomosis of a lower extremity artery to a venous conduit, through which flow is reversed into a distal venous target. In animal models, postoperative target vein samples have shown evidence of arterialization with reduced ischemic markers in the target tissue. Ozek et al[7] performed DVA in a rat model, after which the femoral artery was ligated to induce limb ischemia. In vitro samples of the conduit vein demonstrated arterialized characteristics, whereas target skeletal muscle had increased neovascularization and reduced ischemic injury compared with controls. Subsequent

studies have shown increased skin blood flow after DVA in rats,[8] with similar findings of limb salvage in dogs.[9]

Analogous findings have been reported in humans, with improved microvascularization seen in target skeletal muscles as early as 11 weeks after DVA.[10] DVA was also shown to reduce ischemic markers in human tissue, with reduction in venous lactate after reperfusion.[11] Overall, investigations into the physiologic mechanism of DVA suggest success in arterializing the deep venous system with subsequent improvement in distal perfusion.[12]

LITERATURE REVIEW

A literature review of relevant articles containing all permutations of the terms "deep venous arterialization" and "distal venous arterialization" was undertaken with the MEDLINE, Cochrane, and PubMed databases to find cases of DVA in the peer-reviewed literature (Fig 1). The free text and Medical Subject Headings search terms included were "ischemia," "lower extremity," "venous arterialization," "arteriovenous reversal," and "lower limb salvage." A.D., V.H., and R.G. reviewed and graded the included references.

Studies were primarily retrospective case series but did include two studies with matched controls.[12] Recorded primary outcomes were patency, limb salvage, wound healing, amputation, and resolution of rest pain, with secondary outcomes of complication and overall mortality. Studies were excluded if there was insufficient discussion of technical details (graft type, target vein) or lack of reported outcome measure.[13-16] One study uniquely included use of a free flap for patients with significant lower extremity tissue loss.[17] Table I summarizes these studies, reviewing indication, graft type, follow-up period, patency, limb salvage, wound healing rate, amputation rate, resolution of rest pain, and mortality rates.[11,12,17-26]

Subsequent review yielded a total of 184 revascularized limbs that met criteria for relevancy and completeness for open DVA procedures. All specified indications included the presence of rest pain or wounds, with Fontaine stage III or stage IV or Rutherford class 5 or class 6. Notable technical features include the predominance of great saphenous vein as the preferred conduit, with spliced cephalic vein and polytetrafluoroethylene (PTFE) with vein patch as secondary conduit options. All reported cases underwent valvulotomy of the pedal veins (not venous conduit if reversed), although methods varied from direct valvulotomy to use of cutting angioplasty balloon and valvulotomes. For endovascular DVA, three studies were identified, with a total of 22 revascularized limbs (Table II).[6,27,28]

DVA OPEN SURGICAL APPROACH

Patient selection. The typical candidate for DVA is a patient with Rutherford class 5 or class 6 disease who is not a candidate for open or endovascular arterial revascularization because of lack of a distal target *and* a "desert" foot—angiographically described as the lack of both plantar arteries, the plantar arch, and the dorsalis pedis and lateral tarsal arteries. DVA is an option particularly if symptoms are not improved with measures including excellent wound care, medications, and attempts at revascularization. It is also an option if revascularization is not feasible, given the lack of distal outflow. The deep venous arch does need to be both patent and complete; furthermore, extensive tissue loss that would threaten viability or healing potential is also a relative contraindication. The deep venous arch can be studied using either ultrasound or venography before the procedure. There are numerous communications between the lateral plantar vein and the lateral marginal veins, between the medial plantar vein and the medial marginal veins, and between the deep plantar venous arch and the superficial plantar and dorsal venous arches in the foot that should be identified as they may require ligation or future embolization to prevent steal. Tissue loss is not an absolute contraindication to DVA as some patients with wounds may heal if DVA is successful. Once DVA is performed, wound débridement should be suspended for 3 months to allow the wound to heal unless infection is an issue. All relevant structures for conduit and arterial and venous target must be patent.

Open DVA technique. In open DVA, preoperative lower extremity arterial and venous imaging is performed with both angiography and venography to delineate anatomy and to select the ideal bypass target. It is key to determine a strong source of inflow but equivalently important to ensure that the distal anatomy of the venous complex in the foot (namely, the deep venous arch) is identified so that the valves can be broken to allow ease of flow. Previously described conduits include the great saphenous vein, cephalic vein, and PTFE with vein patch in rarer cases; proximal arterial targets include the common femoral artery, superficial femoral artery, popliteal artery, and proximal tibial arteries. Target distal veins include the vena comitans of the posterior tibial vein and dorsal venous arch. Choice of conduit, inflow, and outflow vessels is dependent on the pre-existing patency and the operator's judgment, although the most distal satisfactory inflow artery is preferred. The conduit vein can be harvested, reversed, and directly tunneled before anastomosis. Alternatively, the valves are disrupted and the vein is kept in situ to perform the bypass. Ideally, the vein diameter is 3 mm or more; however, this is based wholly on data regarding arteriovenous fistula for dialysis access as there are no data to support this size in DVA specifically. Valvulotomy of the distal venous target vessels must be undertaken; techniques include the use of a retrograde balloon catheter,

Table I. Summary of literature describing outcomes in open deep venous arterialization (DVA)

Study	No.	Indication	Graft	Target vein	Follow-up, months
Engelke,[18] 2001	18	Fontaine stage IV	GSV (11) Cephalic (1) SSV (2) PTFE with vein (4)	Dorsal venous arch (14) Vena comitans of PTA (4)	25
Lengua,[19] 1984	8	Fontaine stages III and IV	—	Distal GSV	12
Schreve,[12] 2014	21	Fontaine stage IV	GSV	Dorsal venous arch	12
Özbek,[20] 2005	7	Fontaine stages III (3) and IV (4)	GSV	Distal GSV	12
Sasajima,[17] 2010	9	Rutherford class 6	GSV	Plantar vein (6) Dorsal pedal vein (3)	12
Jacob,[21] 1999	15	Fontaine stages III and IV	Right GSV (5) Composite graft (3) PTFE with vein patch (7)	Dorsal venous arch (13) Vena comitans of PTA (2)	2-22
Gasparis,[22] 2002	1	Rutherford class 6	GSV	Unspecified pedal vein	48
Taylor,[23] 1999	18	Fontaine stages III (4) and IV (14)	SVG (8) Cephalic (3) PTFE with vein patch (7)	Dorsal venous arch (16) Vena comitans of PTV (2)	17
Mutirangura,[24] 2011	26	Fontaine stages III (10) and IV (16)	GSV	PTV (24) ATV (2)	12
Djoric,[11] 2012	30	Fontaine stages III (3) and IV (9)	GSV	MMV	6.1
Houlind,[25] 2013	10	Fontaine stages III (2) and IV (8)	GSV (8) GSV-PTFE spliced (2)	Dorsal venous arch (5) Vena comitans of PTA (3) Vena comitans of CPA (2)	1-12
Arsenault,[26] 2017	14	Rutherford classes 4 (2), 5 (10), and 6 (2)	GSV or cephalic	Distal GSV	1

ATV, Anterior tibial vein; *CPA,* common plantar artery; *GSV,* great saphenous vein; *INR,* international normalized ratio; *MMV,* median marginal vein; *PTA,* posterior tibial artery; *PTFE,* polytetrafluoroethylene; *PTV,* posterior tibial vein; *SSV,* small saphenous vein; *SVG,* saphenous vein graft.

Table II. Summary of literature describing outcomes in percutaneous deep venous arterialization (DVA)

Study	No.	Indication	Target vein	Follow-up, months	Patency, %	Limb salvage, %
Del Guidice,[27] 2018	5	Rutherford classes 4 to 6	PTV (4) ATV (1)	6	Primary: 40	60
Kum,[28] 2018	7	CLI without candidacy for angioplasty or open bypass	PTV	10	Primary: 28.6	71
Mustapha,[6] 2019	10	Rutherford classes 5 and 6	PTV (6)	6	Primary: 90 at 1 month; 40 at 6 months	86

ATV, Anterior tibial vein; *CLI,* critical limb ischemia; *PTV,* posterior tibial vein.

valvulotome, dilators, direct valvulectomy, and cutting balloons to break the valves. Most commonly, an end-to-side anastomosis is performed at the level of the target deep vein, commonly the posterior tibial vein at the ankle. Caution is taken to ensure a tension-free anastomosis as the distal tissue is considered ischemic and at high risk of local necrosis. Fig 2 depicts a connection between the posterior tibial vein at the ankle and the

Table I. Continued.

Patency, %	Limb salvage, %	Wound healing, %	Major amputation, %	Rest pain resolved, %	Complications	Mortality, %	Postoperative medications
Primary: 66 Secondary: 72	83	–	16.7	–	–	5.6	Postoperative duplex
Primary: 87.5	25	–	–	–	–	0	–
Primary: 71	53	–	43	–	Infection (1)	24.1	Statin, warfarin (INR, 2.5-3.5)
Primary: 100 at 6 months	100	100	0	100	–	–	Aspirin, clopidogrel
Primary: 44.4 Secondary: 55.6	77.8	77.7	22.2	22.2	–	33.3	Statin, low-dose aspirin
Primary: 66.6 Secondary: 80	80	–	20	–	–	0	–
Primary: 100	100	100	0	100	–	0	Oral anticoagulation not specified
–	75 at 1 year	83.3	16.7	83.3	–	11.1	–
Primary: 59	76.0	76.0	23.1	–	Cardiac decompensation (3.8%) Retained valve (11.5%)	14.6	–
Primary: 80	91.6	87.5	16.7	91.7	Cardiac decompensation (6.6%)	3.3	–
Primary: 80	30.0	30.0	70.0	–	–	10.0	–
Primary: 82	42.8	42.8	28.6	42.8	–	7.7	–

Table II. Continued.

Wound healing, %	Major amputation, %	Rest pain resolved, %	Complications	Mortality, %	Postoperative medications
40	20	100	60	20	
71.4	28.5	14.2	–	0	Clopidogrel and warfarin for 3 months, then lifelong aspirin or clopidogrel
100	0	–	–	0	

popliteal artery at the knee to delineate what an arterial-venous connection in an open DVA procedure may entail. Typical wound care adjuncts including negative pressure therapy, offloading, and topical products may be used while waiting for the arterialization of the venous system to occur. Approximately 5 to 7 days after the DVA procedure, an operative procedure is performed to ligate the proximal aspect of the posterior tibial vein, thereby preventing steal from the foot and cardiac overload.

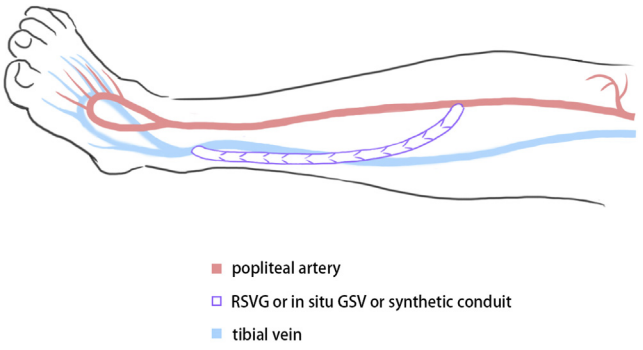

Fig 2. Depiction of open surgical deep venous arterialization (DVA) procedure with bypass from proximal arterial inflow to distal venous target with reversed saphenous vein graft (*RSVG*), in situ great saphenous vein (*GSV*), or synthetic conduit.

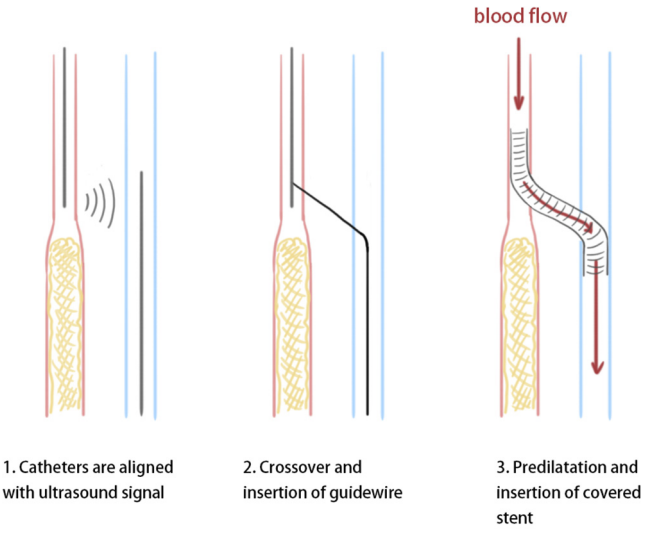

Fig 3. Depiction of percutaneous deep venous arterialization (DVA) procedure with retrograde venous access and antegrade arterial access to place bridging stent.

Published outcomes of open DVA. In regard to primary outcomes, 1-year primary patency for open DVA ranged from 44.4% to 87.5%; secondary patency was less reported but ranged from 55.6% at 1 year to 72% at 25-month follow-up.[17-19] Limb salvage rates ranged from 25% to 100%, wound healing occurred in 28.6% to 100% of cases, and rest pain resolved in 11.9% to 100% across cohorts. Major amputation rates ranged from 0% to 70%. These findings suggest a wide variation in the outcomes related to DVA in the open approach. In 2014, Schreve et al[12] performed a systematic meta-analysis of outcomes of open DVA, finding moderate to poor methodologic quality in 15 studies, several of which were excluded by our review because of insufficient discussion of technique or outcomes. Despite the addition of more recent studies, our findings mirror the conclusions of Schreve et al that there is a broad range of patency, limb salvage, and survival outcomes in open DVA. This may be due to the variation in patient anatomy, operator comfort with the procedure, and extent of patient disease at presentation.

In regard to secondary outcomes, complications reported included wound infection[12] and cardiac decompensation. Overall mortality ranged from 0% to 33.3%.[17] It is notable that the worst outcomes in regard to mortality and patency were from the one study in which DVA was also performed with free flaps, which may be explained by patient selection in a group with significant tissue loss requiring flap coverage.[17]

ENDOVASCULAR APPROACH TO DVA

Patient selection. Patient selection for percutaneous DVA is similar to that for open DVA, with additional approach considerations. A patent proximal tibial vessel is needed to allow antegrade arterial cannulation and to serve as inflow for the percutaneously created arteriovenous fistula. In early studies, the posterior tibial vein is the preferred conduit as it is difficult to access the malleolar vessels with this strategy. The venous access site is typically at the level of the medial malleolus; as such, the overlying tissues should not be infected, or if only superficial infection is present, the area should be treated before the procedure.

Endovascular DVA technique. The LimFlow (LimFlow SA, Paris, France) is an endovascular DVA system not yet approved in the United States. The system is composed of an antegrade 7F arterial and retrograde 5F venous access catheter. The catheters are inserted, and initial arteriography and venography are performed to identify the shortest distance between the vessels. Mustapha et al[6] noted in their early experience with the device that most patients required arterial and venous angioplasty before creation of the arteriovenous fistula (80% required arterial intervention, 30% required venous intervention). The catheters are advanced to the area closest to the target artery and vein, and a needle is deployed from the arterial catheter into the vein. A catheter is advanced over the needle, then a proprietary valvulotome is advanced to perform distal valvulotomy of the foot vein. Angioplasty of the vein assists with creating persistent venous incompetence by displacing the valves. Stenting is then performed with a proprietary LimFlow 7F PTFE tapered crossing covered stent after predilations with a 3-mm angioplasty balloon, with multiple stents placed proximally into the venous side below the level of the knee to cover collaterals. Essentially, the process involves approaching the posterior tibial vein at the ankle retrograde and the inflow artery antegrade, identifying the shortest distance between the two vessels and creating a channel between them that is bridged with a stent (Fig 3). The valves in veins of the foot are then broken percutaneously specifically in the deep arch. The stent is covered and serves to

obstruct posterior tibial flow proximally, thereby decreasing steal from the foot and preventing cardiac overload. If there are collateral branches that continue to allow flow to the heart, these branches are typically coiled.

Published outcomes of endovascular DVA. The target vein in most cases was the posterior tibial vein, with primary patency ranging from 28.6% to 40% at 6-month and 10-month follow-up, respectively. Limb salvage rates ranged from 60% to 71%, with rates of major amputation ranging from 20% to 28.5%. Of concern, a 60% serious adverse event rate (thus afflicting three patients) was reported in one series but not elaborated further.[27] Overall mortality ranged from 0% to 20%.

In the limited amount of published experience, percutaneous DVA demonstrates <50% primary patency rate at 6 months across cohorts but 60% or higher rates of limb salvage in patients who present with critical limb ischemia without options for traditional arterial revascularization. Two studies were case series, whereas Mustapha et al[6] published early results from the PROMISE I trial, a single-arm multicenter pilot study to evaluate safety and efficacy of the LimFlow system in the United States. Technical success was 100% in this cohort, with 100% of patients experiencing >50% wound healing and 40% patency at 6 months and >50% wound bed granulation in all patients. The paucity of reported cases prohibits true statistical comparison, but salvage rates were within range for those found in the open DVA literature.

HYBRID APPROACH TO DVA

In the hybrid approach, an open surgical bypass (in situ or reversed saphenous vein graft) is created with the typical proximal arterial and distal venous anastomoses, but the valvulotomy or embolization of distal collateral venous branches is performed through an endovascular approach immediately (during the initial procedure) or through angiographic procedures in the weeks following. This differs from the conventional open DVA approach in that during the open approach, the valves are disrupted on the operating room table with a valvulotome directly being passed through the vein mechanically; whereas in the hybrid approach, only the anastomosis takes place open, but the disruption of the valves is done with an endovascular approach (ie, balloon disruption of valves).

Two case series have been published to date detailing different techniques (Table III).[29,30] Ferraresi et al[29] reported a series of 36 limbs with Wound, Ischemia, and foot Infection (WIfI) grade 3 disease and no arterial revascularization options. Open bypass with great saphenous vein was performed, during which a valvulotome was used to destroy all above-ankle venous valves; all above-ankle venous side branches were ligated during open bypass, but endovascular valvulotomy with angioplasty to all valves below the ankle was performed on the same day of open bypass. Two to 4 weeks later, proximal foot vein collaterals were embolized through an antegrade femoral approach to encourage caudal venous flow, with adjunctive valvulotomy as needed. Postoperatively, the foot was elevated to avoid edema. This approach demonstrated an 86.1% primary patency rate and 91.7% secondary patency rate at 1 month, which was reduced to a 6.9% primary patency rate and 8.1% secondary patency rate at 12 months. Despite abrupt loss in patency after 1 month, limb salvage was 69% at 10.8-month mean follow-up, with a 44% rate of wound healing and 31% rate of major amputation.

In contrast, Alexandrescu et al[30] treated 26 limbs of Rutherford class 5 or class 6 severity using PTFE with an angiosome-guided model to perform PTFE bypasses from the common femoral, superficial femoral, or popliteal artery to a tibial calf vein. After the bypass was unclamped, antegrade access was obtained through the common femoral artery, and venography was performed to evaluate for distal valves and collaterals. Valvulotomy was performed by advancing and retracting a 6F sheath over the cannulating wire, and venous collaterals below the ankle were occluded with metal coils, with an average of six or seven coils deployed. Aspirin or clopidogrel were administered in the first 3 months after the procedure, with transition to lifelong aspirin afterward. Patency outcomes were improved compared with those of Ferraresi et al,[29] with 46% primary patency at 1-year follow-up for Alexandrescu et al compared with 6.9% at 10.8-month follow-up for Ferraresi et al, but wound healing rates (46% vs 44%) and major amputation rates (23% vs 31%) were similar. Mortality was 43% in the Alexandrescu group compared with 5.5% in the Ferraresi cohort.

Thus, in a limited series, hybrid DVA demonstrates <50% patency at 6-month follow-up across cohorts, with wound healing rates ranging from 44% to 46% and limb salvage rates ranging from 46% to 69%. Further recruitment with more stringent matching of comorbidities and disease patterns is necessary to compare hybrid DVA outcomes with percutaneous and open approaches, and further standardization of the hybrid DVA approach will improve reliable ascertainment of outcomes.

OPTIMIZATION AND EVALUATION OF DVA

The success of DVA, like that of any bypass, revolves around inflow, outflow, and the conduit. Selecting an appropriate inflow and outflow target can be done by arteriography and venography before the procedure.

Table III. Summary of literature describing outcomes in hybrid deep venous arterialization (DVA)

Study	No.	Indication	Graft	Target vein	Follow-up, months	Patency, %
Ferraresi,[29] 2018	36	WIfI grade 3, $TcPo_2$ <30 mm Hg Severe pedal disease not amenable to arterial revascularization	GSV	MMV (17) PTV (18)	10.8	Primary: 86.1 at 1 month, 20.7 at 6 months, 6.9 at 12 months Secondary: 91.7 at 1 month, 30.3 at 6 months, 8.1 at 12 months
Alexandrescu,[30] 2011	26	Rutherford classes 5 and 6	PTFE	ATV (12) PTV (11) Peroneal vein (2)	12	Primary: 46

ATV, Anterior tibial vein; *GSV,* great saphenous vein; *MMV,* median marginal vein; *PTFE,* polytetrafluoroethylene; *PTV,* posterior tibial vein; *$TcPo_2$,* transcutaneous oxygen pressure; *WIfI,* Wound, Ischemia, and foot Infection.

The optimal bypass conduit is great saphenous vein of >3 mm with disrupted valves (based on the literature for arteriovenous fistula in dialysis access). We hypothesize that venous incompetence resulting in a large dilated vein with incompetent valves may be an ideal conduit that may result in maximal flow.

In reviewing outcomes from the open[11,12,17-26] vs the endovascular techniques[6,27-30] for DVA included in this review, there appears to be a trend toward better results with the open technique. Although there is no literature directly comparing open and endovascular DVA approaches, we surmise, on the basis of the open vs endovascular bypass literature, that there are similar reasons for this better outcome with open surgical technical vs endovascular DVA. The endovascular option requires stent placement to achieve a durable correction between the arterial and venous systems. This is likely to have the same complications (eg, thrombosis, in-stent stenosis) that general peripheral stenting is prone to and likely is a contributor to the poorer results compared with open techniques. Open techniques also allow direct visualization of collaterals and perforators, which in turn allows direct ligation (vs coiling) to direct blood flow to the foot. Finally, one of the most important elements for success in DVA operations is ensuring optimal disruption of the valves in the vein. Open surgery allows either reversal of the GSV if it is used as a conduit or direct access to the vein conduit with an open valvulotome to disrupt the valves. Endovascular approaches to disruption of the valves may not be as successful (prolonged balloon inflation), which may detract from the amount of blood that is directed to the foot.

After patients have undergone the DVA procedure, evaluation of the graft or stent can be performed in the usual fashion with ultrasound evaluation. Patients should undergo angiography to evaluate flow to the foot in conjunction with toe-brachial index pressure measurement. With angiography, possible intervention (namely, coiling) may be performed of large venous branches to direct flow to the foot. Patients should continue with optimal wound care and frequent evaluation.

LIMITATIONS

This study was limited by the paucity of data regarding outcomes of both open and endovascular options for DVA. There is considerable heterogenicity in the patient populations within these groups and the selection criteria for the patients included in the studies. The studies also span a number of years in which wound care, revascularization techniques, and vascular approaches have varied. Importantly, given the same sample sizes within the studies included, it is difficult to ascertain significance of outcomes, especially considering that patient selection would be highly variable from location to location, and these sample sizes do not make it possible to sort out independent risk factors including comorbidities, smoking status, age, sex, and surgical history. Another limitation is that there are very few studies that detail endovascular DVA therapy compared with open DVA, and the outcomes are hence difficult to compare.

CONCLUSIONS

Although first reported >100 years ago, DVA is in an early phase of use as a revascularization strategy for patients with CLTI and no options for distal revascularization. Review of the literature suggests that DVA is universally undertaken for patients with rest pain or nonhealing wounds who lack distal arterial targets for conventional open or endovascular arterial revascularization because of advanced small-artery disease. As such, it is considered a final option for limb salvage in contexts in which amputation is the only other appropriate approach. Review of the literature proffers rates of limb salvage from 25% to 100% for open DVA, 60% to 71% for percutaneous DVA, and 46% to 69% in hybrid DVA approaches. Percutaneous DVA offers a minimally invasive option for patients with adequate endoluminal access. The introduction of hybrid methods for valvulotomy and collateral embolization suggests the importance of ensuring adequate forward flow in the distal venous target. Ultimately, further recruitment of patients and

Table III. Continued.

Limb salvage, %	Wound healing, %	Major amputation, %	Rest pain resolved, %	Complications	Mortality, %	Postoperative medications
69	44	31	—	—	5.5	—
46	54	23	—		43	Aspirin or clopidogrel within 3 months, lifetime aspirin

standardization of technique are necessary to better ascertain and to distinguish the outcomes of DVA across approaches.

AUTHOR CONTRIBUTIONS

Conception and design: VH, RG, AD
Analysis and interpretation: VH, RG, VC, AP, JL, AD
Data collection: VH, RG, AD
Writing the article: VH, RG, AD
Critical revision of the article: VH, RG, VC, AP, JL, AD
Final approval of the article: VH, RG, VC, AP, JL, AD
Statistical analysis: Not applicable
Obtained funding: Not applicable
Overall responsibility: AD

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Submitted May 16, 2019; accepted Oct 19, 2019.