The Angiosome Concept

A look at how this concept is being used to treat patients with critical limb ischemia.

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Increasing life expectancy has resulted in a growing elderly population and an increase in the number of patients with critical limb ischemia (CLI).[1] Multidisciplinary treatment is needed for CLI patients to prevent limb loss, improve quality of life, and prolong survival.[1,2] Depending on the condition of their extremities, most CLI patients will ultimately require a revascularization procedure. Two strategies of revascularization are currently used for these patients: bypass surgery and endovascular therapy (EVT). Although bypass surgery has been the standard method of revascularization because it achieves good long-term patency, it is not feasible in every patient because of the associated comorbidities. According to the recommendations from the BASIL trial,[3] severe limb ischemia patients with a life expectancy of > 2 years and with a usable vein are recommended to undergo bypass surgery because of the long-term patency of the saphenous vein. However, patients with a life expectancy of < 2 years who are without an adequate vein should undergo EVT because they are not expected to reap the long-term benefits of surgery. In addition, the results of prosthetic bypass show poor durability in infrainguinal lesions.

Although the increase in blood flow after successful bypass surgery sufficiently heals the ulcer, operative mortality is relatively high compared to EVT. From a published meta-analysis of infrainguinal bypass in renal failure, early mortality rates were 1.3% to 18%, and operative complications occurred in 10% to 20% of patients (wound infection, 13%; cardiovascular events, 13%; early bypass occlusion, 21%).[4] Bypass surgery has also been reported to result in major amputations in approximately 15% of ischemic lower extremity wounds despite a patent bypass.[5-8] Currently, there is increasing evidence that the angiosome concept—that of three-dimensional tissue territories supplied by source arteries—has been clinically useful in bypass surgery for limb salvage.[9] As a result of bypass surgery, the limb salvage rate was 91% with direct revascularization and 62% with indirect revascularization.[9]

EVT has been widely applied in CLI patients due to the development of low-profile devices, hydrophilic guidewires, and other technologies, producing favorable initial results with low complication rates and high limb salvage rates.[10-14] This has become an increasingly attractive alternative to bypass surgery and is the first revascularization procedure for patients with CLI.[15]

WHAT IS THE ANGIOSOME CONCEPT?

In 1987, Taylor and Palmer introduced the angiosome concept, which divided the body into three-dimensional vascular territories supplied by specific source arteries and drained by specific veins.[16] They defined five distinct angiosomes of the lower legs as fed by the medial sural

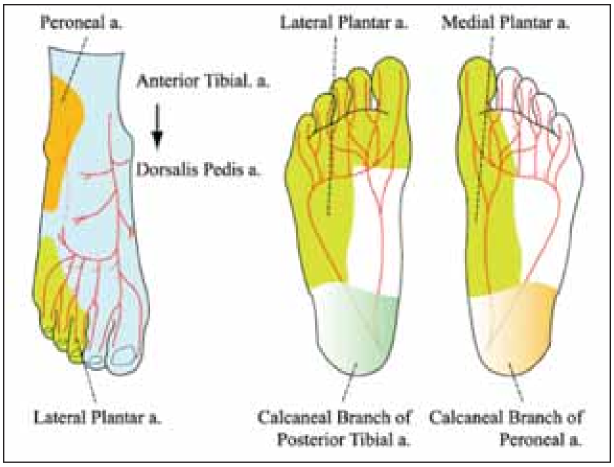

Figure 1. Angiosomes of the foot and ankle.

TABLE 1. PATIENT CHARACTERISTICS				
	All (n = 177)	Direct (n = 107)	Indirect (n = 70)	*P* Value
Age / >80 years	70 ± 11 / 18% (32)	69 ± 10 / 15% (16)	71 ± 11 / 23% (16)	.17 / .18
Gender (male)	72% (127)	73% (78)	70% (49)	0.68
Body mass index	21 ± 3	21 ± 3	21 ± 3	0.97
Hypertension	82% (145)	83% (89)	80% (56)	0.59
Hyperlipidemia/LDL (mg/dL)	30% (53)/100 ± 34	29% (31)/97 ± 34	31% (22)/105 ± 32	.76/.39
Diabetes mellitus/HbA1c	68% (120)/6.5 ± 1.7	64% (69)/6.4 ± 1.7	73% (51)/6.7 ± 1.7	.24/.35
Smoking	31% (54)	31% (33)	30% (21)	.87
Renal insufficiency/dialysis	54% (96)/51% (90)	57% (61)/55% (59)	50% (35)/44% (31)	.36/.16
Coronary artery disease	54% (95)	55% (59)	52% (36)	.63
Ejection fraction by echocardiography (%)	63 ± 14	63 ± 14	63 ± 14	.86
Ejection fraction < 35%	9% (12)	7% (6)	11% (6)	.41
Cerebrovascular disease	49% (86)	49% (48)	54% (38)	.22
Bedridden/wheelchair/ambulatory	11/69/97	4/40/63	7/29/34	.16

artery, lateral sural artery, posterior tibial artery (PTA), anterior tibial artery (ATA), and peroneal artery (PA). The foot and ankle area has six distinct angiosomes arising from the PTA, ATA, and peroneal artery.

In 2006, Attinger and colleagues investigated the angiosome of the foot and ankle and the clinical implications for limb salvage with an additional understanding of muscle and skin anatomy.[17] This concept was originally pioneered in plastic and reconstructive surgery. The angiosome model of reperfusion can be applied to planning incisions and tissue exposures that preserve blood flow for surgical wounds to heal and predicting which pedicled flap can be successfully harvested or whether a particular amputation will heal.[18] It can also help in choosing whether a bypass or an endovascular procedure has the best chance of healing an existent ischemic ulcer.

Six angiosomes of the foot and ankle originate from the three main arteries to the foot and ankle (Figure 1). The PTA supplies the medial ankle and the plantar foot. The three main branches of the PTA supply distinct portions of the plantar foot: the calcaneal branch supplies the medial heel, the medial plantar artery supplies the instep, and the lateral plantar artery supplies the lateral midfoot and forefoot. The ATA supplies the dorsum of the foot and then becomes the dorsalis pedis artery, which supplies the dorsum of the foot after communicating with the PTA and PA. The two branches of the PA supply the anterolateral portion of the ankle and rear foot. The anterior perforating branch supplies the lateral anterior upper ankle, and the calcaneal branch supplies the lateral heel. The dorsum side of the toe and foot are fed by the ATA and dorsalis pedis artery, the plantar side of the toe and foot without the lateral heel are fed by the PTA and plantar artery, and the lateral ankle and outside of the heel are fed by the peroneal artery.

POTENTIAL ROLE OF ANGIOSOMES IN LIMB SALVAGE

Clinical success of EVT for patients with CLI has previously been defined as dilation of all critical inflow lesions with a residual stenosis < 30% and straight line outflow in at least one tibial vessel without flow being limited to the pedal arch.[12,13] However, in our clinical practice, this does not always result in limb salvage. Consequently, we investigated whether the angiosome concept is useful when performing successful EVT for limb salvage in patients with CLI.[19]

We analyzed 203 limbs in 177 consecutive patients (men, 127; age, 70 ± 11 years) with ischemic ulceration that was Rutherford class 5 or 6 (5 in 145 limbs and 6 in

TABLE 2. LESION CHARACTERISTICS AND ENDOVASCULAR PROCEDURES PERFORMED				
	All (n = 203)	Direct (n = 118)	Indirect (n = 85)	*P* Value
Rutherford class 5/6	163/61	85/33	60/25	.82
Location of the ulcer or gangrene				.20
Toe (dorsal side/plantar side)	163 (102/61)	62/36	40/25	
Sole of foot	2	2	0	
Dorsum of foot	5	1	4	
Heel	30	14	16	
Ankle	1	1	0	
Leg	2	2	0	
Feeding artery to the ulcer/gangrene				.90
Anterior tibial artery	53% (108)	55% (64)	58% (44)	
Posterior tibial artery	45% (91)	44% (52)	46% (39)	
Peroneal artery	2% (4)	2% (2)	2% (2)	
ABI before EVT	0.74 ± 0.27	0.77 ± 0.28	0.70 ± 0.26	.15
SPP near the ulcer before EVT	27 ± 16	27 ± 18	27 ± 11	.91
Lesion location before EVT				
Aortoiliac lesion/calcification	16% (33)/76% (153)	13% (15)/75% (89)	21% (18)/76% (64)	.11/.99
Femoropopliteal lesion/calcification	60% (123)/76% (154)	59% (70)/75% (89)	62% (53)/76% (53)	.66/.86
Tibioperoneal lesion/calcification	99% (199)/77% (157)	97% (114)/74% (87)	100% (85)/82% (70)	.14/.15
Primary stenting for aortoiliac lesions	17% (35)	12% (14)	19% (16)	.19
Angioplasty alone for femoropopliteal lesions	6% (12)	5% (6)	7% (6)	.63
Stenting for femoropopliteal lesions (cobalt/nitinol)	4% (9)/49% (100)	5% (6)/49% (58)	4% (3)/49% (42)	.87
Angioplasty for tibioperoneal lesions	82% (167)	83% (99)	80% (68)	.47
Patency of peroneal artery after EVT	44% (89)	49% (56)	39% (33)	.2
Target lesion revascularization (TLR)	23% (46)	23% (27)	22% (19)	.92
SPP after EVT (mm Hg)	57 ± 26 mm Hg	67 ± 25 mm Hg	41 ± 20 mm Hg	.0002
ΔSPP	33 ± 22 mm Hg	40 ± 22 mm Hg	18 ± 14 mm Hg	.0018

SPP, skin perfusion pressure. ΔSPP was calculated as the difference between the SPP before and after EVT.

58 limbs; pretreatment ankle-brachial index, 0.74 ± 0.27), who underwent EVT alone without bypass surgery. It should be noted that approximately half of the patients in this study received dialysis therapy; these patients may show a high incidence of false-negative ankle-brachial index because the arteries may be noncompliant due to severe calcification. We have accordingly added evaluation for limb ischemia using skin perfusion pressure. We included patients with successful revascularization by EVT, which we defined as obtaining flow from more than one vessel to the pedal arch without surgical bypass, and excluded patients who were considered to be poor candidates for revascularization due to severe comorbidities, as well as those who refused revascularization. Patients who had rest pain but no ulceration/gangrene (Rutherford class 4) were also excluded, as were those who underwent bypass surgery (12 patients) and those with failure of EVT (runoff from 0 vessels = 19 patients). These latter patients were excluded due to the clinical discrepancy we have seen between the traditional defini-

tion of successful EVT and our own limb salvage results; our goal was to evaluate whether the angiosome concept is useful when successfully performing EVT in these patients.

We divided the enrolled patients into a direct group and an indirect group. The direct group consisted of 107 patients (118 limbs) in whom feeding artery flow to the site of ulceration/gangrene was successfully achieved by EVT according to the angiosome concept. The indirect group included 70 patients (85 limbs), in whom feeding artery flow to the site of ulceration/gangrene was not successfully achieved by the angiosome concept. Freedom from amputation was subsequently compared between the direct and the indirect groups by Kaplan-Meier analysis.

There were no significant differences in patients, lower limb lesion characteristics, or endovascular procedures between the direct and indirect groups (Tables 1 and 2). The overall limb salvage rate was 82% (167/203). The limb salvage rate was significantly higher in the direct group than in the indirect group (86% vs 69%, $P = .03$ at 1 y; 82% vs 64%, $P = .029$ at 2 y; 82% vs 64%, $P = .029$ at 3 y; and 82% vs 64%, $P = .029$ at 4 y). When limb salvage rates were compared in relation to the number of patent runoff vessels, having fewer patent vessels was not shown to be related to a lower salvage rate. In addition, the number of runoff vessels did not influence the limb salvage rates within either the direct group or the indirect group.

LIMITATIONS OF THE ANGIOSOME CONCEPT

In our experience, there are several limitations to the angiosome concept. First, the angiosomes vary among patients. We believe that, similar to the presence of anatomic anomaly, infrapopliteal arterial distribution does not completely identify the original angiosome. In our study, all patients underwent diagnostic angiography to determine the blood supply to each area. Although our strategy of EVT for patients with CLI was based on the angiosome concept, we could not treat all of the target lesions according to the angiosome concept due to technical barriers and lesion severity. In the vascularly compromised foot, collateral flow may keep the ischemic angiosome vascularized to some extent, with the original vasculature changed to an alternative ischemic angiosome through an arterial-arterial connection.[20]

An additional limitation of the study is that half of the patients were on dialysis. Significant pedal artery involvement with severe calcification is often found in dialysis patients, but pedal artery flow was not precisely evaluated in this study. Finally, our experience was a retrospective and nonrandomized analysis of a prospectively maintained database. Therefore, a prospective, multicenter trial is required to confirm our findings. ■

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1. Norgren L, Hiatt WR, Dormandy JA, et al. Inter-society consensus for the management of peripheral arterial disease (TASC II). Eur J Vasc Endovasc Surg. 2007;33(suppl 1):S1-75.
2. Dormandy JA, Rutherford RB. Management of peripheral arterial disease (PAD). TASC Working Group. Transatlantic inter-society consensus (TASC). J Vasc Surg. 2000;31(1 pt 2):S1-S296
3. Bradbury AW, Adam DJ, Bell J, et al. Bypass versus angioplasty in severe ischemia of the leg (BASIL) trial: analysis of amputation free and overall survival by treatment received. J Vasc Surg. 2010;51(5 suppl):18S-31S.
4. Townley WA, Carrell TW, Jenkins MP, et al. Critical limb ischemia in the dialysis-dependent patient: infrainguinal vein bypass is justified. Vasc Endovasc Surg. 2006;40:362-366.
5. Elliott BM, Robison JG, Brothers TE, et al. Limitations of peroneal artery bypass grafting for limb salvage. J Vasc Surg. 1993;18:881-888.
6. Johnson BL, Glickman MH, Bandyk DF, et al. Failure of foot salvage in patients with end-stage renal disease after surgical revascularization. J Vasc Surg. 1995;22:280-285; discussion 285-286.
7. Berceli SA, Chan AK, Pomposelli FB Jr, et al. Efficacy of dorsal pedal artery bypass in limb salvage for ischemic heel ulcers. J Vasc Surg. 1999;30:499-508.
8. Treiman GS, Oderich GS, Ashrafi A, et al. Management of ischemic heel ulceration and gangrene: an evaluation of factors associated with successful healing. J Vasc Surg. 2000;31:1110-1118.
9. Neville RF, Attinger CE, Bulan EJ, et al. Revascularization of a specific angiosome for limb salvage: does the target artery matter? Ann Vasc Surg. 2009;23:367-373.
10. Parsons RE, Suggs WD, Lee JJ, et al. Percutaneous transluminal angioplasty for the treatment of limb threatening ischemia: do the results justify an attempt before bypass grafting? J Vasc Surg. 1998;28:1066-1071.
11. Löfberg AM, Karacagil S, Ljungman C, et al. Percutaneous transluminal angioplasty of the femoropopliteal arteries in limbs with chronic critical lower limb ischemia. J Vasc Surg. 2001;34:114-121.
12. Dorros G, Jaff MR, Dorros AM, et al. Tibioperoneal (outflow lesion) angioplasty can be used as primary treatment in 235 patients with critical limb ischemia: five-year follow-up. Circulation. 2001;104:2057-2062.
13. Feiring AJ, Wesolowski AA, Lade S. Primary stent-supported angioplasty for treatment of below-knee critical limb ischemia and severe claudication: early and 1-year outcomes. J Am Coll Cardiol. 2004;44:2307-2314
14. Tefera G, Hoch J, Turnipseed WD. Limb-salvage angioplasty in vascular surgery practice. J Vasc Surg. 2005;41:988-993.
15. Kudo T, Chandra FA, Kwun WH, et al. Changing pattern of surgical revascularization for critical limb ischemia over 12 years: endovascular vs open bypass surgery. J Vasc Surg. 2006;44:304-313
16. Taylor GI, Palmer JH. The vascular territories (angiosomes) of the body: experimental study and clinical applications. Br J Plast Surg. 1987;40:113-141.
17. Attinger CE, Evans KK, Bulan E, et al. Angiosomes of the foot and ankle and clinical implications for limb salvage: reconstruction, incisions, and revascularization. Plast Reconstr Surg. 2006;117(7 suppl):261S-293S.
18. Terashi H, Kitano I, Tsuji Y, et al. A modified transmetatarsal amputation. J Foot Ankle Surg. In press.
19. Iida O, Nanto S, Uematsu M, et al. Importance of the angiosome concept for endovascular therapy in patients with critical limb ischemia. Cathet Cardiovasc Interv. 2010;75:830-836.
20. Terashi H, Iwayama T, Iida O, et al. Dynamic SPP: a new measure of assessment for wound healing capacity and alternative angiosome in critical limb ischemia (CLI). Plast Reconstr Surg. In press.