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Review Article

Angiosome~From the Standpoint of Bypass Surgery

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Although several studies showed that angiosome-guided endovascular treatment improved wound healing and major amputation rates in patients with chronic limb-threatening ischemia (CLTI), effectiveness of the angiosome concept to the treatment of ischemic foot remains to be elucidated, especially in bypass surgery. Arterial anatomy of the foot and ankle shows that there are multiple supplementary circulation including arterial–arterial connections and choke nexus, which indicates angiosome concept may carry limited importance in bypass surgery for CLTI. On the other hand, patients with diabetes or renal dysfunction have partial occlusion of arterial–arterial connections and, therefore, quite a few patients with CLTI in Japan may present with limited but impaired supplementary circulation around the ankle. This article reviews the arterial anatomy and circulation of the foot and ankle and discusses availability and limitations of angiosome-guided bypass surgery.

Keywords: angiosome, bypass surgery, arterial–arterial connection

Introduction

Peripheral arterial disease (PAD) is prevalent worldwide, especially in the elderly (65 years and older) and those with risk factors for atherosclerosis.[1] Chronic limb-threatening ischemia (CLTI) represents the most severe form of PAD, characterized by infection, ischemia, and tissue loss. As CLTI carries an excessive risk of major amputation, revascularization through surgical bypass or endovascular intervention is the first-line treatment for CLTI.[2] Complete revascularization, defined by direct in-line flow to the ankle, is associated with clinical success for treatment of limb ischemia. However, there are a subset of patients with CLTI who suffer from prolonged wound healing or non-healing wound even after complete revascularization.[3,4] These patients require another approach able to provide effective blood flow directly to ischemic tissues. Revascularization based on the angiosome concept may be one of these approaches.[5,6]

The angiosome concept was introduced by Taylor and Palmer in 1987 to provide a basis for the logical planning of flaps.[7,8] Using ink injection and radiographic studies of cadaveric specimen, they defined an angiosome as a three-dimensional unit of all tissues fed by a single source artery. Understanding this concept provides the basis for designing incisions and tissue exposure that preserves blood flow in the field of skin flap grafting.[9]

Therefore, the selection of a target distal artery based on the angiosome concept could potentially achieve a sustained supply of blood flow directly to severe ischemic tissues.[10,11] This could in turn speed up the process of time-consuming wound healing and increase the chance of limb salvage. These 'direct' arterial revascularizations have been proposed as a superior option to improve wound healing and limb salvage.[12–14]

However, there have been several debates about applying the angiosome concept to the treatment of ischemic foot disease.[2,15–19] Assignment of ischemic wounds is ambiguous in lesions separated by angiosome concept. Half of ischemic wounds involve toe lesion, that have dual supply from the anterior and posterior tibial arteries. Patients with CLTI, especially those with diabetic foot ulcers, often present with a multitude of wounds that are heterogenous in morphology and topography. When the wound spreads over several angiosomes, assignment of angiosome is subject to individual interpretation, thereby affecting the outcome of angiosome-directed revascularization.[20,21] Complete wound healing is sometimes obtained after metatarsal amputation, which typically straddles two or three angiosome assignments.[22] Furthermore, major amputation and patency rates are not always superior following angiosome-guided revascularization[6,23,24] and as such, this treatment strategy remains controversial, especially in bypass surgery.[16]

This article reviews the arterial anatomy and circulation of the foot and ankle and discusses limitations of

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angiosome-guided bypass surgery.

Angiosome for the Foot and Ankle and Its Source Artery

Six angiosomes were identified for the foot and ankle; the medial calcaneal artery angiosome, the medial plantar artery angiosome, the lateral plantar artery angiosome, the lateral calcaneal artery angiosome, the anterior perforator artery angiosome, and the anterior and dorsalis pedis angiosome[7] (**Fig. 1**). The first three angiosomes originate from the posterior tibial artery, the second two from the peroneal artery and the last one from the anterior tibial artery. The tibial or peroneal artery diverges horizontally and vertically to connect other branches to form various plexuses. In the ankle, there are also arterial–arterial connections arising from the tibial arteries (such as the plantar arch).

Small terminal arteries derived from the plexus through the arterial–arterial connection, that primarily supply the deeper tissues, provide blood to the skin. Adjacent angiosomes are bordered by 'choke' anastomotic arteries, which link neighboring angiosomes and demarcate the border of each angiosome[25,26] (**Fig. 2**). As such each angiosome is interconnected via a 'choke' collateral system.[27] As Tayler and Attinger advocated, those complex networks form one source artery to provide blood flow to multiple angiosomes beyond its immediate border. Therefore, they emphasized upon angiosome-oriented incision or angiosome-oriented flap making, but not a single angiosome as a circulation area.[25]

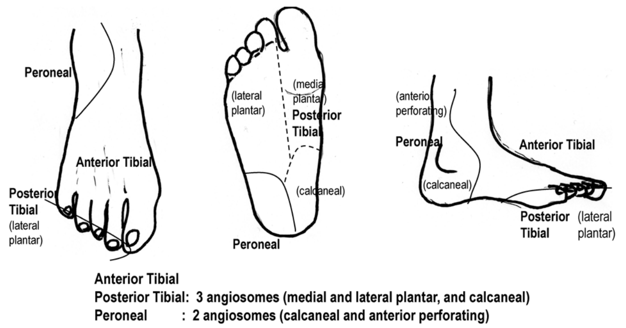

Fig. 1 Angiosome of the foot.

Impact of Angiosome Targeted Revascularization for Wound Healing and Limb Salvage

A literature search was performed to identify articles on angiosome-directed bypass surgery for CLTI. Eight articles

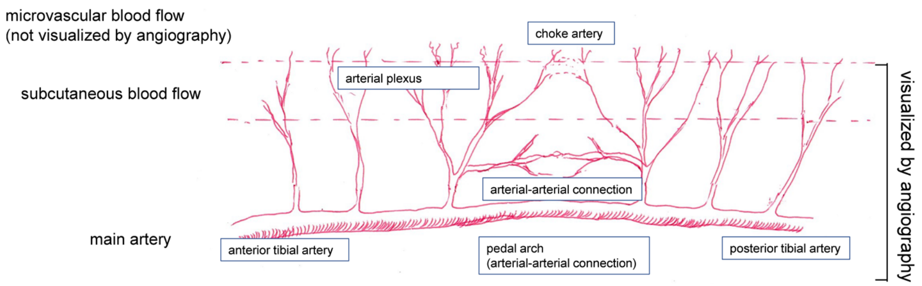

Fig. 2 Summary of the relationship among arterial–arterial connections, arterial plexus and choke artery.

Table 1 A list of manuscripts showing angiosome-guided surgical revascularization

Author	Year	Type of revascularization	Limb (Pts)	Wound healing	Limb salvage	Amputation free survival
Varela	2010	By+E	76 (70)	DR>ID DR=ID with collateral	DR>ID DR=ID with collateral	Survival rate: similar
Azuma	2012	By	249 (228)	DR=ID*	DR=ID*	
Kabra	2013	By+E	64 (64)	DR>ID	DR=ID	
Rashid	2013	By	141	DR=ID	DR=ID	
Kret	2014	By	106 (106)	DR>ID**	DR=ID**	DR=ID**
Lejay	2014	By	58 (54)	DR>ID	DR>ID	
Bosanquet	2014	By+E (meta-analysis)	508	DR>ID	DR>ID	Survival rate: similar
Ricco	2017	By (peroneal artery)	120 (120)	DR=ID	NA	DR=ID

By: bypass; E: endovascular treatment; DR: direct revascularization; ID: indirect revascularization. =: not significantly different result, DR>ID means that direct revascularization achieved better results than indirect revascularization. *: after matching according to propensity score, **: after controlling runoff score fulfilled the inclusion criteria of this review. **Table 1** summarizes the main characteristics of these studies.[16,23,28–33)]

Several studies showed that angiosome-guided endovascular treatment in patients with CLTI improved wound healing and major amputation rates.[6,24,34,35)] However, the differences in severity of local wounds and difficulties in identifying accurate arterial anatomy from inconsistent individual angiograms affect the results of angiosome-guided endovascular treatment. A prospective randomized study is warranted to guide further understanding of this treatment strategy.

The "directed" angiosome bypass surgery is not usually favored over the "indirect" angiosome bypass surgery.[36)] The angiosome strategy is less applicable in bypass revascularization for CLTI patients in the first place, because bypass generally targets the least affected artery. Rashid et al. showed that direct angiosome revascularization was feasible in only 47% of their patients.[29)] They also reported that the rates for wound healing and time to wound healing were directly influenced by the quality of the pedal arch rather than the angiosome, which may reflect collateral circulation. Furthermore, Azuma et al. described a similar wound healing rate between direct and indirect angiosome bypass surgeries, although healing was slower in indirect angiosome bypass surgeries.[16)] Conversely, those reports showed similar graft patency rates between direct and indirect angiosome bypass surgeries. Those results indicate that collateral circulation at the ankle after bypass surgery plays an important role in wound healing of CLTI patients, although direct blood flow to the anatomical location of the wound remains paramount. Similar bypass graft patency rates between direct and indirect angiosome suggests that the bypass target artery has its own vascular bed including collateral circulation.

Arterial–Arterial Connections at the Foot and Ankle

The angiosome concept was designed for a healthy subject with normal choke network and arterial–arterial connection system, which are additional mechanisms preventing each angiosome from becoming ischemic. All three main arteries (the anterior tibial, posterior tibial, and peroneal arteries) of the leg communicate with each other around the ankle.[10)] The anterior tibial artery connects the peroneal artery via the anterior perforating branch and the lateral malleolar branch. The posterior tibial artery forms anastomoses with three transverse communicating branches of the peroneal artery. The anterior tibial artery forms a direct connection with the plantar arch to the posterior tibial artery (**Fig. 3**).

There are multiple arterial–arterial connections in the plantar foot. The branches of the medial tarsal artery (originating from the anterior tibial artery) connect with the superficial medial plantar artery (originating from the posterior tibial artery) at the proximal-medial plane of the plantar foot. At the metatarsal and proximal phalanx, the dorsalis pedis artery (the anterior tibial artery) connects directly with the lateral plantar artery (the posterior tibial artery) to form the plantar arch and the arcuate artery (**Fig. 4**). The plantar arch gives off the plantar metatarsal arteries to the plantar side of toes and the arcuate artery branches off to the dorsal metatarsal arteries to the dorsal side of toes, but the plantar and dorsal metatarsal arteries connect through three perforating branches (**Fig. 4**).

Moreover, there is a subdermal arteriolar plexus formed by the dorsalis pedis artery (the anterior tibial artery) and the lateral plantar artery (the posterior tibial artery). Due to those arterial–arterial connections, the three arterial systems including the anterior, posterior tibial artery and the peroneal artery circulate redundantly over the foot and ankle.

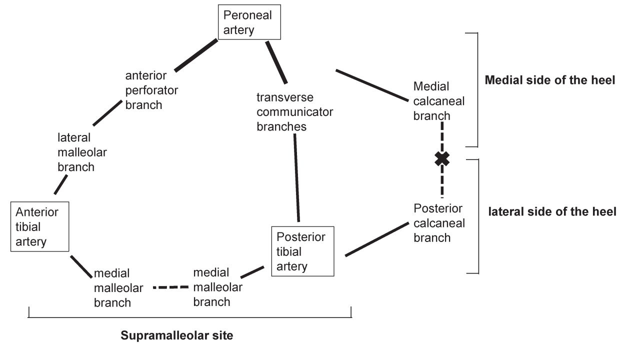

Fig. 3 Arterial–arterial connections among the anterior, posterior tibial arteries and the peroneal artery at the supramalleolar site. Solid lines represent direct arterial–arterial connection and dot lines represent fine arterial–arterial connections. Note that there is not clear arterial–arterial connection between the medial and posterior calcaneal branches.

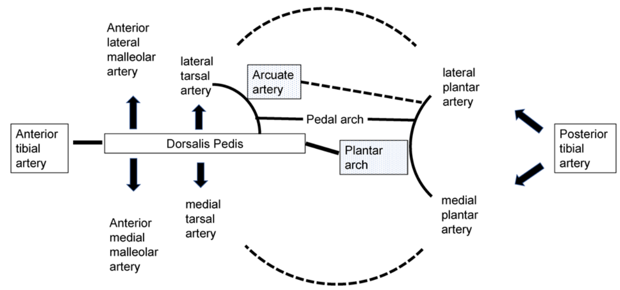

Fig. 4 Arterial–arterial connections between the anterior and posterior tibial arteries at the ankle. Solid lines represent direct arterial–arterial connection and dot lines represent fine arterial–arterial connection. Note that there are thick direct arterial–arterial connections between the dorsalis pedis and the plantar arteries with the pedal arch and the plantar arch.

However, the heel is somewhat unique because two angiosomes located at the heel receive a single inflow without apparent arterial–arterial connection.[10] The medial aspect of the heel is supplied by the posterior tibial calcaneal branch, and the lateral aspect is supplied by the peroneal calcaneal branch. The posterior and peroneal calcaneal branches do not have direct arterial–arterial connection with each other around the heel (**Fig. 3**).

Macrovascular and Microvascular Dysfunction at the Foot and Ankle in Patients with CLTI

CLTI represents an advanced stage of PAD and is often associated with altered anatomy of mid-sized arteries even at the infrapopliteal level. Most of the patients in Japan with CLTI have a background of diabetes mellitus and half of the patients have chronic renal failure requiring dialysis. Diabetes and chronic kidney disease (CKD) show limited patency of the arterial pedal-plantar arch and distal branches, which indicates that CLTI has impaired arterial–arterial connection at the foot and ankle. Haine et al. showed that CKD was associated with loss of patency of the pedal arch compared to diabetes mellitus.[37] Randhawa described that only 16% of patients with CLTI had a patent pedal arch.[38] Moreover, diabetic macroangiopathy is characterized by Monckeberg's sclerosis (mediasclerosis) that represents calcification of the media. These stiff arteries reduce the blood circulation significantly when blood pressure decreases. Therefore, poor circulation due to impairment of peripheral arterial connections are surmised to be typically located at the foot and ankle in CLTI.

In addition, patients with CLTI may have microcirculatory impairment including arterioles and 'choke' arteries, mainly because of endothelial dysfunction.[39] Patients with diabetes are consistently observed to have a thickened capillary basement membrane. This capillary basement thickening induces capillary thrombosis and closure, impairing capillary function.[39] Moreover, ischemia affects regulation of skin microcirculation due to the presence of thermoregulating arterio-venous shut vessels. Although the choke vessels function as a rescue system for the ischemic foot, diabetes mellitus promotes microvascular complications and impairs the microvascular system.

Influence of Collateral Circulation on the Angiosome Concept

There have been five studies thus far comparing angiosome-guided endovascular revascularization in diabetic patients[5,6,24,40,41] and these have showed that the direct angiosome strategy has a better outcome with regard to wound healing and amputation free survival.[42] However, Jongsma's review highlighted that collaterals strongly influence wound healing and major amputation rates, and that indirect angiosome revascularization with an intact pedal arch or distal peroneal branch to the angiosome artery may achieve the same outcome after direct angiosome revascularization.[43] Kagaya showed that the distribution of peripheral tissue perfusion in critical lima ischemia varied widely within the same angiosome area by using tissue oxygen saturation.[44] In addition, Azuma et al. indicated end-stage renal failure (ESRF), diabetes mellitus, hypoalbuminemia and wound categorized in the Rutherford classification 6 as clinical factors for unhealed wounds after bypass surgery.[16] Considering that CKD and diabetes mellitus significantly impair collateral circulation (including arterial–arterial connection) at the ankle, ESRF and diabetes may affect would healing via local collateral dysfunction aligned with the Rutherford classification 6 that represents wound severity.

As mentioned above, healthy individuals possess abundant collateral circulation including arterial–arterial connection and skin microcirculation. So far, the vascular anatomy of the distal foot in CLTI patients is only evaluated using the pedal arch. Although such collateral circulation assuredly varies between individuals with CLTI, it would have a substantial effect on the outcome of angiosome-guided revascularization.[45]

Role of the Angiosome Concept in Bypass Surgery

It is unclear as to why an angiosome-guided revascularization strategy could provide better wound healing in endovascular revascularization but not in bypass revascularization. A series of studies showed that in general, bypass surgery tends to achieve better and faster wound healing than endovascular treatment. Those data have pertinent limitations and thus cannot be directly compared, but Spillerova showed that wound healing is better after bypass surgery than after endovascular treatment, independent of the angiosome orientation.[35] It may be surmised that bypass surgery using good autologous vein elevates arterial pressure effectively at the ankle, restoring direct blood flow as well as collateral blood from indirect angiosome territories, which is not the case in indirect endovascular treatment.

Conclusion

Bypass surgery targets the best available crural artery independent of the angiosome concept. Both angiosomes and the quality of the pedal arch, which may reflect the efficacy of collateral circulation, affect wound healing and limb salvage. Precise evaluation of the collateral circulation will provide a more appropriate strategy in addition to that from angiosome concept, and improve outcomes of revascularization.

Disclosure Statements

There is no conflict of interest in this paper.

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