

Research Article

The anatomical investigation for harvesting various chimeric flaps based on the peroneal artery

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ABSTRACT

Background: The conventional fibular composite flap with its various components tethered together is not maneuverable enough to cover the complex three dimensional defects. An in-depth anatomical study into the peroneal vascular system was performed to explore the possibility of harvesting various the fibular chimeric composite.

Methods: 30 cadaveric lower extremities with perfusion of red latex in their arteries were used for this study. The fibular head and the lateral malleolus were used as the landmarks and the calf was divided into the upper, middle and lower segments, respectively. Dissection of the calves was carried out to investigate mainly the musculo (septo) cutaneous perforators and periosteal branches given off from the peroneal artery.

Results: An average of 4.8 ± 0.9 cutaneous perforators was given off from the peroneal artery to nourish the lateral aspect of the lower leg. An average number of 4.7 ± 1.3 periosteal branches were given off from the peroneal artery to the surface of the fibula. In 40% of the cases, a periosteal branch to the tibia with an external diameter of about 0.8 mm was found to originate from the peroneal artery. In 60% of cases, 2 to 3 periosteal branches with an external diameter of about 0.6 mm were found to originate from the peroneal artery. Several patterns of the chimeric fibular composite flap can be harvested based on the peroneal artery.

Conclusions: It is anatomically practical to harvest various patterns of chimeric fibular composite flaps based on the peroneal artery to reconstruct three-dimensional complex defects.

Keywords: Peroneal artery, Fibula, Chimeric flap, Perforator, Periosteum

INTRODUCTION

Since the report of free fibular flap by Taylor et al¹ in 1975, the fibular flap has undergone evolution and modification from being avascularized to being vascularized, being straight to being osteotomized and folded, being bone only to being composite in composition.¹⁻³ The vascularized fibular flap or fibular

osteocutaneous flap has indisputably become the workhorse for reconstruction of bony defects, particularly in the construction of mandibular defect after tumor ablation and long bone defects in the extremities of considerable length.⁴⁻⁷ However, when defects are extensive, complex and three-dimensional in nature, the conventional fibular composite flap whose various components, being interdependent on each other for

vascularization and survival, are unable to be separated, is not maneuverable enough to inset to cover the defects as described above.⁸ Meanwhile, when the ends of a bone defect are not well vascularized, modification should be made to the conventional composite fibular flap to include excessive vascularized periosteum which can be wrapped around the graft-and host contact so that bone union can be enhanced by the osteogenic and angiogenic property of the periosteum. Consequently, in this paper, we presented an in-depth anatomical study into the peroneal vascular system, providing the anatomical basis for harvest various peroneal artery-based chimeric composite flaps for repair of compound tissue defects with complex geometric distribution.

METHODS

31 embalmed cadaveric extremities were used for this anatomical study. All extremities were perfused with gelatin mixed with red painting dye through the internal iliac artery until dissection at the toes stained red. The tip of the fibular head and the tip of the lateral malleola were adopted as the landmarks to divide the lower leg into the superior, middle and inferior segments. Then meticulous dissection was carried out to observe the following contents: the origin and course of the peroneal artery as well as the number and distribution of the musculo (septo) cutaneous perforators and the periosteal branches given off from the peroneal artery. An additional fresh cadaveric extremity was used for simulated surgery of harvesting various chimeric fibular composite flaps. All data were processed in Microsoft Excel 2010 and expressed in the form of $\bar{x} \pm s$.

RESULTS

The course, branches and distribution of the peroneal artery

After being given off from the posterior tibial artery, the peroneal artery travelled laterally and downward

underneath the soleus. It travelled between the flexor hallucis longus and the fibula at the middle segment of the lower leg, and continued as the lateral calcaneal artery around the lateral malleola. The peroneal artery gave off nutritional arteries to the fibula, arcuate (periosteal) branches, musculo (septo) cutaneous perforators, anterior septocutaneous perforators, communicating branches to the nourish the fibula, the muscles surrounding the fibula and the skin at the lateral aspect of the leg (Figure 1).

The perforators of the peroneal artery

A total of 4 to 8 cutaneous perforators, averaging 4.8 ± 0.9 branches, were given off from the peroneal artery to nourish the lateral aspect of the lower leg. The perforators could be divided into two broad types: the musculocutaneous perforators and the septocutaneous perforators. The musculocutaneous perforators, 3.0 ± 0.6 in number, accounting for 64.2%, penetrated the soleus or the flexor hallucis longus to reach the skin. The musculocutaneous perforators could be further divided into two subtypes: perforators of one subtype were sparsely-distributed and large in diameter, which were the majority of the musculocutaneous perforators located in the proximal 2/3 of the lower leg, accounting for 76.4%; perforators of the other subtype, accounting for 23.6%, were densely-distributed and minute in diameter, embodying the inverse relationship of interval between the perforators to the diameter of the perforators (Figure 2). The septocutaneous perforators, accounting for 35.8%, were mainly located in the lower 1/3 of the leg. The perforators of the septocutaneous had a constant presence at 4 to 7 cm superior to the external malleola, and divided into an anterior branch, a posterior branch, an ascending branch and a descending branch upon reaching the deep fascia; the branches anastomose with each other as well as the perforators from the anterior and posterior tibial arteries. The relevant data of the perforators of the peroneal artery were listed in Table 1.

Table 1: Measurement data for the perforators from the peroneal artery.

| Location | Musculocutaneous perforator | | | | Septocutaneous perforator | | | |
|--------------|-----------------------------|---------------|-------------|-----------------------------|---------------------------|---------------|-------------|-----------------------------|
| | Number (n) | diameter (mm) | Length (cm) | Incidence of occurrence (%) | Number (n) | Diameter (mm) | Length (cm) | Incidence of occurrence (%) |
| Superior 1/3 | 0.8±0.2 | 1.5±0.4 | 7.1±0.7 | 86% | - | - | - | - |
| Middle 1/3 | 1.9±0.3 | 1.6±0.3 | 6.1±1.7 | 100% | 0.3±0.5 | 1.0±0.2 | 5.0±1.1 | 26.7% |
| Inferior 1/3 | 0.6±0.4 | 1.6±0.2 | 5.2±1.2 | 73.3% | 1.2±0.1 | 1.3±0.2 | 4.5±1.3 | 100% |

The periosteal branches to the fibula

The peroneal artery gave off the arcuate artery, nutritional artery and epiphyseal artery to nourish the fibula. The nutritional and epiphyseal arteries were not the focus of this study because the segment of the fibula nourished by them was not commonly harvested for graft. An average number of 4.7 ± 1.3 periosteal arteries, ranging from 2 to 8 branches, were given off from the peroneal artery, assuming a segmental distribution to the surface of the fibula. 36.5% of the periosteal arteries were in direct contact with the periosteum immediately after being given off from the peroneal artery, whereas 63.5% of the periosteal arteries traversed in the muscular substance for about 1.5 ± 0.3 cm before reaching the periosteum. After reaching the periosteum, the periosteal arteries coursed encircled the fibula in a lateral and forward direction, giving off ascending and descending branches to anastomose with each other, forming periosteal plexus. The relevant data of the periosteal branches to the fibula were shown in Table 2.

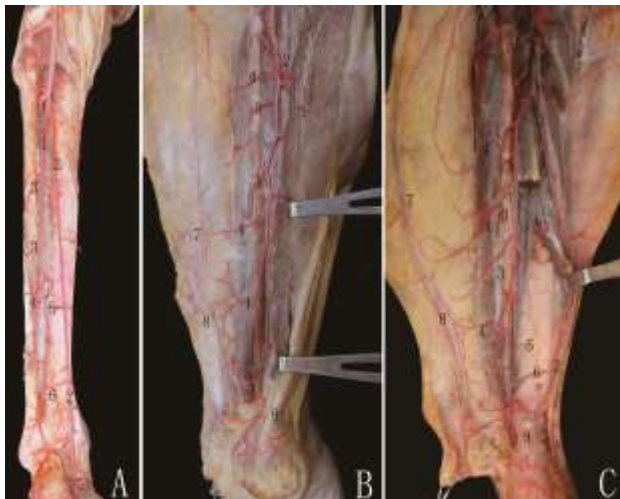


Figure 1: The peroneal artery and its branches. (A) Posterior view of the lower leg with all muscles stripped off to demonstrate the course and branches of the peroneal artery; **(B)** : Expose the posterior crural septum and retract the soleus and the gastrocnemius laterally to show the peroneal artery and its periosteal branches 1, the peroneal artery; 2, the posterior tibial artery; 3, the arcuate artery (the periosteal branches to the fibula); 4, the cutaneous perforators; 5, periosteal branches to the tibia; 6, communicating branches between the fibular and posterior tibial arteries; 7, sural nerve; 8, lesser saphenous vein; 9, the Achilles tendon; **(C)** : The remarkable longitudinal vascular plexus along the sural neurovascular bundle formed by superficial sural artery and the segmentally-distributed perforators from the peroneal artery.

The periosteal branches to the tibia

In 12 cadaveric legs, accounting for 40%, a periosteal branch to the tibia with an external diameter of about 0.8 mm was found to originate from the peroneal artery. In the remaining 18 cadaveric legs, accounting for 60 %, 2

to 3 periosteal branches with an external diameter of about 0.6 mm were found to originate from the peroneal artery. The tibial periosteal branches traveled deep to tibialis posterior and posterior to the interosseous membrane to the periosteum of the tibia. The relevant data of the periosteal branches to the tibia were listed in Table 3.



Figure 2: The pattern of the cutaneous perforators of the peroneal artery. (A): Scarcely-distributed by large in diameter; **(B):** Densely-distributed by minute in diameter; 1, cutaneous perforators; 2, the sural nerve; 3, the small saphenous vein; 4, soleus; 5, peroneus longus.

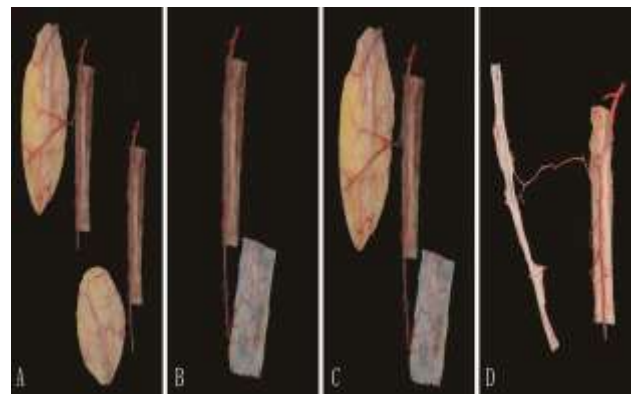


Figure 3: The chimeric fibular composite flap based on the peroneal artery. (A): A chimeric composite flap composed of a bone block and a skin paddle either nourished by a perforator of the middle 1/3 segment and a perforator of the lower 1/3 segment; **(B)** : A chimeric composite flap composed of a bone block and a tibial periosteal graft; **(C):** the chimeric composite flap composed of a bone block, a tibial periosteal graft and a skin paddle; **(D):** a chimeric composite flap composed of a bone block, a segment of the sural nerve / lesser saphenous vein.

Surgical simulation of harvesting various chimeric fibular composite flaps

Several patterns of the chimeric fibular composite flap can be harvested based on the peroneal artery: the bone component could be harvested based on arcuate artery, the cutaneous component on the dominant musculo (septo)cutaneous perforator at the middle 1/3 segment or septocutaneous perforator at the lower 1/3 segment, the periosteum of the tibia and fibula on the periosteal branches at the lower segment. A surgeon can choose a specific form of the flap depending on the need of clinical practice, for example: 1. a chimeric flap containing a

segment of the fibula and a skin paddle could be harvested for reconstruction of compound defect of the extremities and the mandible; 2. a flap containing only a bone block could be harvested for simple bone defect of the extremities and the mandible; 3. a chimeric flap containing the a bone block, a skin paddle and a tibial or fibular periosteal component could be harvested for reconstruction of the compound defect at the extremities with very poor condition for bone union; 4. a chimeric flap containing a bone block and a part of the sural nerve and the lesser saphenous vein could be harvested for reconstruction of extremities with bone defect accompanied by neurovascular injury.

Table 2: Measurement data for periosteal branches to the fibula.

| Segment | Number (n) | diameter (mm) | Length (cm) | Incidence of occurrence (%) |
|--------------|------------|---------------|-------------|-----------------------------|
| Superior 1/3 | 1.9±1.1 | 1.1±0.3 | 1.1±0.3 | 93 |
| Middle 1/3 | 3.2±2.0 | 0.8±0.4 | 1.0±0.2 | 93 |
| Inferior 1/3 | 1.9±2.0 | 0.5±0.2 | 0.9±0.3 | 10 |

Table 3: Measurement data for periosteal branches to the tibia.

| Segment | Number (n) | Diameter (mm) | Length (cm) | Incidence of occurrence (%) |
|--------------|------------|---------------|-------------|-----------------------------|
| Middle 1/3 | 1.1±0.2 | 0.5±0.3 | 1.1±0.3 | 60% |
| Inferior 1/3 | 1.9±0.3 | 0.6±0.2 | 0.9±0.2 | 80% |

DISCUSSION

A chimeric flap, by Hallock's definition,⁹ has separate components with separate vascular supplies that are attached to a common mother vessel. In this sense, the chimeric flap is a combination of different flaps; each is capable of independence with a separate blood supply but all originate from the same source artery. The individual parts may consist of a single type of tissue or may also be a composite of multiple tissue types. Unlike from the conventional composite flap which is composed of many tissue types with interdependence on one another for vascularity and survival and whose various tissue components are of very limited mobility from each other, the chimeric composite flap has various tissue components with their disparate vascular pedicles, thus enjoying a comparatively much larger mobility among its various tissue components. The greatest advantage of the chimeric composite flap over the conventional one is its theoretically much larger maneuverability, which facilitates its inset into three-dimensional defects. The chimeric fibular composite flap which contains skin paddles and a bone block has already been reported in the literature for coverage of tissues defects. However, detailed anatomical investigation for harvest of a chimeric fibular composite flap with a periosteal component, the sural nerve and the lesser saphenous vein,

which has significant clinical implication, has still not been documented, driving us to carry out this study.

The surgical technique for harvesting the fibular segment and the skin paddle has already been elaborately illustrated in the literature. Wang et al¹⁰ used a novel chimeric flap composed of a sural neurocutaneous flap and a vascularized fibular graft for coverage of the compound osteocutaneous defects in the forearm. Preoperatively, the fibula bone is marked and handheld Doppler probe is used to locate the perforators the posterior border of the fibula. The course of the sural nerve was drawn from the mid-popliteal point to the midpoint of the Achilles tendon and the lateral malleolus, serving as the axis of the skin paddle to be harvested. Incision was first made the anterior border of the pre-outlined skin paddle, and the flap was raised toward the posterior crural septum where the septocutaneous perforators are identified, of which the most sizable one was chosen, often located at the junction of the middle and inferior 1/3 segments of the lower leg. The size of the skin paddles in the two cases reported by Wang was exceptionally large, reaching 288 and 250 cm², respectively, and both survived completely. They contended that the longitudinal vascular plexus around the sural neurocutaneous bundle as shown in figure 1C with low resistance to blood flow and additional route of

venous drainage by anastomosing the lesser saphenous vein to a vein in the recipient site are the reasons why such large a size can the skin flap be harvested. The fibular chimeric composite flap proposed by Wang is particularly useful for reconstruction of bone defects accompanied a large size of skin defect. Massarelli et al¹¹ and Cossio P et al¹² reported using the chimeric osteoseptocutaneous-lateral superamalleolar flap for reconstruction of complex mandibular defects. This chimeric flap is combination of the conventional fibular osteomusculocutaneous flap with an additional skin paddle. The additional skin paddle was nourished by the supramalleolar perforator was first defined by Masquelet et al¹³ with a course emerging superficially between the extensor digitorum longus and the peroneus brevis and perforating the deep fascia 5 cm above the lateral malleolus. This supramalleolar perforator is the anterior septocutaneous perforator of the peroneal artery, which pierces the interosseous membrane about 5 cm above the lateral malleolus. During the isolation of the perforator, the incision of the interosseous membrane must be made carefully from the perforator to the level of planned osteotomy in the fibula and should expose the deep peroneal vessels, which are tied. The fasciocutaneous skin paddle tethered with the fibula by the muscles is nourished by the perforators emerging superficially from the posterior aspect of the fibula at the middle segment of the lower leg. As demonstrated in our simulated surgery, the muscles can be dissected off the further liberate the skin paddle, making the chimeric osteoseptocutaneous-lateral superamalleolar flap even more maneuverable.

Severely traumatized extremities with compound bone and soft-tissue defects have always been a challenging problems for surgeons. Since the report of Taylor and coworkers for using the vascularized fibular flap for successful treatment of tibial bone defects,¹ the vascularized fibular flap has one of the most important options in fixing the defects of long bones in the extremities. However, the osteocutaneous defects in severely traumatized extremities are often accompanied by compromised local blood supply due to vascular damage and infection et al, the bone graft can sometimes have difficulty in achieving bony union with the host.¹⁴ The vascularized periosteal graft has been established with the ability to enhance bone union with its osteogenic and angiogenic property both in animal experiments and clinical practice.¹⁵⁻¹⁸ Consequently, we demonstrated in this study the feasibility of harvesting the fibular segment along with the periosteum nourished by the periosteal branches of the peroneal artery in the distal part of the tibia and fibula, developing the novel chimeric fibular osteo-cutaneo-periosteal flap, which would have the following advantages: 1. the periosteal component can be wrapped around the contact between the bone graft and the recipient bone, achieving a better soft tissue coverage, which can prevent the ingrowth of the cicatricial tissue as well as considerably enhance local vascularization; 2. the cambium layer of the periosteal component in direct contact around the graft-host contact

can strongly augment the bone union with its osteogenic ability.

As for the harvest of the periosteum, the lower boundary is the intermalleolar line of the ankle, the medial and lateral boundaries correspond to the medial aspect the tibia and the lateral aspect of the fibula, respectively, and the superior boundary is 5 to 7 cm above the inferior boundary. To expose posterior aspect of the tibia and fibula, the peroneus longus and brevis muscles should be retracted laterally, and the Achilles tendon, the flexor digitorum longus and flexor hallucis longus should be retracted medially. If necessary, an incision can be made at the posterior aspect of the fibula to facilitate the exposure. Minute periosteal branches from the peroneal artery to the tibia can be observed about 4.5 cm above the posterior malleolus of the tibia. If a traverse incision is made at the level of the tip of the tibial posterior malleolus on the tibial periosteum which is then elevated upward, a periosteal graft about 3 cm in width can be harvested. Similarly, an incision made at the same level at the posteromedial aspect of the fibula at the fibular periosteum which is then elevated upward along the lateral aspect of the fibula can lead to harvest of a fibular periosteal graft about 2 cm in width. If the tibial periosteum and the fibular periosteum are harvested together with the part of the interosseous membrane, a periosteal graft as large as 7 cm×5 cm can be harvested.

Defect of bone that occurs as a result from injury related to trauma or surgical treatments for tumors are usually accompanied by neurovascular defects. The surgeon must repair the neurovascular defects to provide the best functional outcome for the patient. As for the vascular defects, venous graft has been the most commonly used method for reconstruction.¹⁹ When it comes to nerve defect, the nerve is repaired by direct coaptation, nerve rerouting and transposition under the most ideal circumstances.²⁰ When these maneuvers are inadequate to provide a tension-less repair, the vascularized nerve graft from the peripheral sensory nerves is the most effective way available, particularly for nerve defects larger than 3 cm in length.²¹ The vascularized nerve graft has been used successfully in brachial plexus, upper and lower extremity nerve reconstruction.^{22,23} There are many sources of cutaneous nerve graft, but the most popular is the sural nerve, which can be harvested to a length of 30 to 40 cm with minimal functional deficit to the patient.²⁴ Hence, planning of chimeric fibular sural nerve/ lesser saphenous vein as demonstrated in this anatomical study is of significant clinical importance in repair of bone defect accompanied by defects of the nerve/ vessel.

CONCLUSION

In conclusion, the anatomical information provided in this paper demonstrates the possibility of harvesting various chimeric fibular composite flaps. The surgeon can have a free combination of such various components

as bone, muscle, neurocutaneous structures, periosteum, and skin depending on actual clinical needs.

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