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ORIGINAL ARTICLE

Vascular anatomy of the free fibula flap including the lateral head of the soleus muscle applied to maxillo-mandibular reconstruction

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Abstract

Purpose Initially described by Baudet in 1982, the fibula flap including the lateral head of the soleus muscle allows a one-stage reconstruction for large maxillo-mandibular defects. The aim of this study was to evaluate the number of muscular branches destined to the soleus muscle and their distance from the origin of the fibular artery, to assess the vascular anatomy of the free fibula flap including the lateral head of the soleus muscle applied to maxillo-mandibular reconstruction.

Methods We performed a cadaveric anatomic study on ten lower limbs, and a CT angiography anatomic study on 38 legs. The number of soleus branches originating from the fibular artery, and the distance between the origin of the fibular artery and each of the identified branches were measured.

Results The number of soleus branches destined to the lateral head of the soleus muscle is variable, with in our study 1–3 branches found. Soleus branches destined to the lateral head of the soleus muscle emerged at a distance ranging between 0 and 2.9 cm (mean value = 1.82 cm) from the origin of the fibular artery in 40% of cases, between 3 and 5.9 cm (mean value = 4.27 cm) from the origin of the fibular artery in 37% of cases, and was at a distance of 6 cm or more (mean value = 6.93 cm) from the origin of the fibular artery in 20% of cases.

Conclusions An origin of the soleus vessels in close proximity to the origin of the fibular artery represents the main limitation of this flap, the length of the remaining fibular pedicle making it difficult to achieve secure anastomosis in the cervical area. The vascular distribution of the proximal part of the lateral head of the soleus muscle being segmental, it is possible to lengthen the flap pedicle ligating the most proximal soleus branches originating from the fibular artery.

Keywords Fibula flap · Soleus muscle · Reconstruction · Pedicle length · CT angiography · Cadaveric study

Introduction

Initially described by Taylor in 1975, the free fibular flap is nowadays one of the workhorse flaps in head and neck reconstruction for maxillo-facial and plastic surgeons. It is a versatile flap that can be harvested with one or two skin paddle(s) and/or part of the soleus muscle, allowing a qualitative reconstruction for large maxillo-mandibular defects, while avoiding donor site multiplication and microsurgical anastomoses [4, 10, 14].

The fibula flap including the lateral head of the soleus muscle was first described in 1982 by Baudet [2], to reconstruct extensive osteocutaneous leg defects. In complex maxillo-mandibular defects, this flap avoids the need of a double free flap, and serves a double aim for better functional and aesthetic outcomes: functional, because it restores the maxillo-mandibular osseous continuity with the bony fragment

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of the fibula and obliterates the dead space with the soleus muscle, and aesthetic with the use of the lateral head of the soleus muscle to rebulk the submandibular or malar area. Descriptions focusing on the use of the composite fibula flap including the lateral head of the soleus muscle for head and neck reconstruction are, however, limited [5, 7, 15, 19, 35].

The soleus muscle is a pennate muscle with two heads, medial and lateral, divided by a sagittal septum forming a distinct watershed in the blood supply of the proximal half of the muscle [31]. However, some authors state that significant vascular communications do exist between the medial and lateral system [9, 30]. The soleus muscle presents a type II vascularization according to Mathes and Nahai classification [22], with large dominant vascular pedicles and minor pedicles. The vascularization of the lateral head of the soleus muscle is provided by the fibular artery, meanwhile the medial head is supplied by the posterior tibial artery. In the proximal part of the lateral head of the soleus muscle, the vascularization presents a segmental distribution by way of multiple branches (3–5) originating from the fibular artery. In the distal part of the lateral head of the soleus muscle, it presents an axial distribution directly by way of the fibular artery, accessory pedicles being scarce after the entrance of the fibular artery in the flexor hallucis longus in the middle third of the calf [6, 8, 12, 20, 26].

An origin of the soleus vessels in close proximity to the origin of the fibular artery represents the main limitation of the fibula flap including the lateral head of the soleus muscle, the length of the remaining fibular pedicle making it difficult to achieve secure anastomosis in the cervical area. Therefore, a pre-operative CT angiography of the lower limbs could help to determine patients that could benefit from this flap. Indeed, prior studies have demonstrated that it is possible to locate on a CT angiography more than 90% of the musculocutaneous and septocutaneous perforator vessels found preoperatively [11, 27].

The aim of this study was to evaluate the number of muscular branches destined to the soleus muscle and their distance from the origin of the fibular artery, to assess the vascular anatomy of the free fibula flap including the lateral head of the soleus muscle applied to maxillo-mandibular reconstruction.

Methods

Cadaveric anatomic study

The study design was approved, and the cadavers were bequested to the laboratory of anatomy of Paris V René Descartes medical school and the Fer à Moulin surgical school of Paris. All donors had previously completed a hand-written, dated and signed statement executed by them confirming their wish to donate their body [18, 21, 28]. Ten dissections of free fibula flaps including the lateral head of the soleus muscle were performed on ten caucasian cadavers. Within the ten cadavers, eight were females and two were males. The harvesting of composite fibula flaps was carried out on five left lower limbs, and five right lower limbs. Each body was installed on a supine position, the hip flexed at a 45° angle and the knee flexed at a 135° angle. The external malleolus, the head and the posterior border of the fibula were localized and drawn. The skin was incised along the fibula, the fascia superficialis and muscular aponeurosis were opened, and the fibularis longus was reclined, exposing the posterior intermuscular septum. The fibularis longus muscle and fibularis brevis muscle were then disinserted from the whole length of the fibula, exposing the anterior intermuscular septum. The anterior leg compartment was opened, and the dissection of the fibula completed with the disinsertion of the extensor digitorum longus and extensor hallucis longus muscles, exposing the interosseous membrane. After incising the interosseous membrane, the flexor hallucis longus muscle was reclined with caution with a rugine opposite to the distal and proximal osteotomy areas, to protect the fibular pedicle. Once the osteotomies were performed, the soleus muscle was disinserted from the posterior border of the fibula, exposing the proximal part of the fibular pedicle and its branches to the soleus muscle. The fibular pedicle was then ligated and sectioned distally, before being dissected from distal to proximal, taking care of not damaging the major soleus branches. The soleus branches with a diameter inferior to 1 mm were ligated and sectioned. The number of branches of 1 mm or more going to the soleus muscle and the distance between the origin of the fibular artery and each of the soleus branch identified were measured (Figs. 1, 2, 3).

CT angiography anatomic study

A population of 10 men and 12 women with a mean age of 59 years old, realized a CT angiography of the lower limbs prior to fibular reconstruction of the mandible/maxilla using CAD/CAM cutting guides. All subjects were free of vascular pathology. The CT angiograms were performed independently from the study for CAD/CAM planning purpose only. The parameters measured were: the number of soleus branches originating from the fibular artery and the distance between the origin of the fibular artery and each of the identified branches. Each measure was taken bilaterally.

A 64-layer CT scan [Discovery 750 HD Tomograph (General Electric)] was used. Arterial phase images of the lower limbs were acquired in a cranial to caudal direction after vascular injection of a contrast medium. The iodinated contrast medium used was Xenetix 350 (Guerbet) and was administered through an 18-gauge canula catheter in an

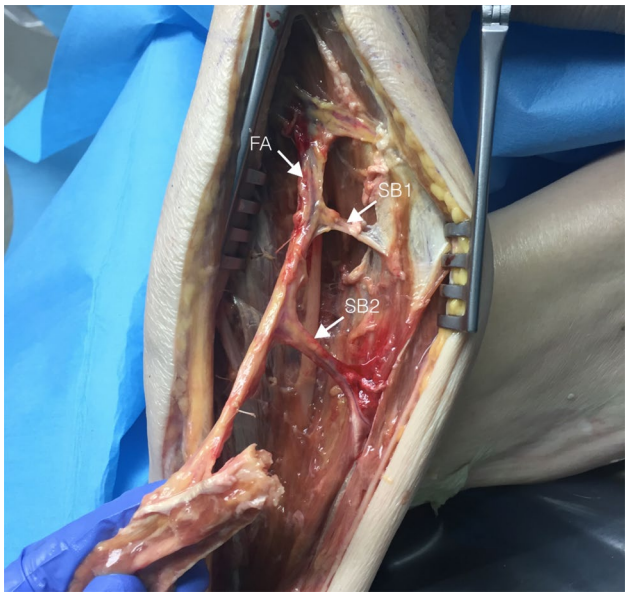

Fig. 1 Harvesting of a composite fibula free flap including part of the soleus muscle. Identification of the major pedicles for the lateral head of the soleus muscle. *FA* Fibular artery, *SB* soleus branch

Fig. 2 Free fibula flap including a septocutaneous skin paddle and part of the lateral head of the soleus muscle

antecubital right vein. A fixed volume of 1.5 mL/kg of contrast medium was injected at a rate of 3.5 mL/s. Acquisition parameters were as follows: 100 kV; 150 mA; 0.6 s rotation time, 0.625 mm slice thickness, pitch of 0.5. The acquired images were read on a standard work station (Advantage Window 4.6, General Electric). The origin of the bifurcation in fibular artery and posterior tibial artery, and the origin

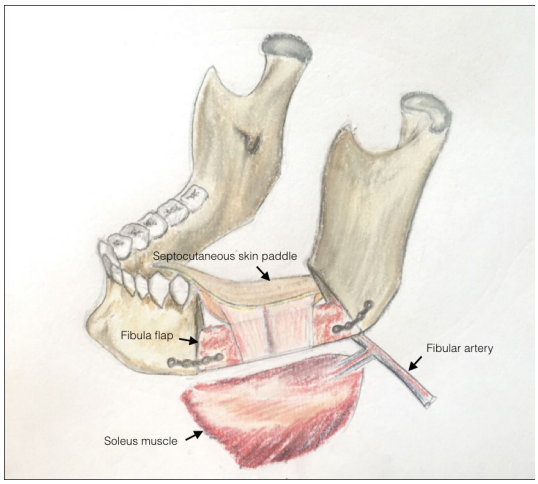

Fig. 3 Conformation of a free fibula flap including a septocutaneous skin paddle and the lateral head of the soleus muscle, for a large oromandibular defect

of the soleus branches issued from the fibular artery were pinpointed on transversal cuts. The distance between the origin of the fibular artery and the different soleus branches identified was measured on sagittal cuts. To ensure the reliability and reproducibility of our results, all measures were taken twice by the same operator (Fig. 4).

Results

Within the ten dissected limbs, a total of 17 branches originating from the fibular artery and destined to the lateral head of the soleus muscle were identified. Seven of the ten dissected limbs (70%) presented two major branches originating from the fibular artery, destined to the lateral head of the soleus muscle. For the other three limbs (30%), only one major branch was identified, however, another major branch originating from the bifurcation in fibular artery and posterior tibial artery or from the popliteal artery close to the bifurcation was systematically found. Soleus branches destined to the lateral head of the soleus muscle emerged at a distance ranging between 0 and 2.9 cm (mean value = 1.94 cm) in 41% of cases, between 3 and 5.9 cm (mean value = 4.28 cm) in 35% of cases, and at a distance of 6 cm or more (mean value = 7.05 cm) in 24% of cases. (Table 1).

22 CT angiography of the lower limbs were also examined. A comparative analysis of each leg was performed on 19 of the 22 subjects who realized a CT angiography. Two of the 22 subjects already had a fibula flap harvested. One of the 22 subjects presented an anatomical variation, with in one leg a high emergence of the posterior tibial artery directly from the popliteal fossa. Within the 38 limbs

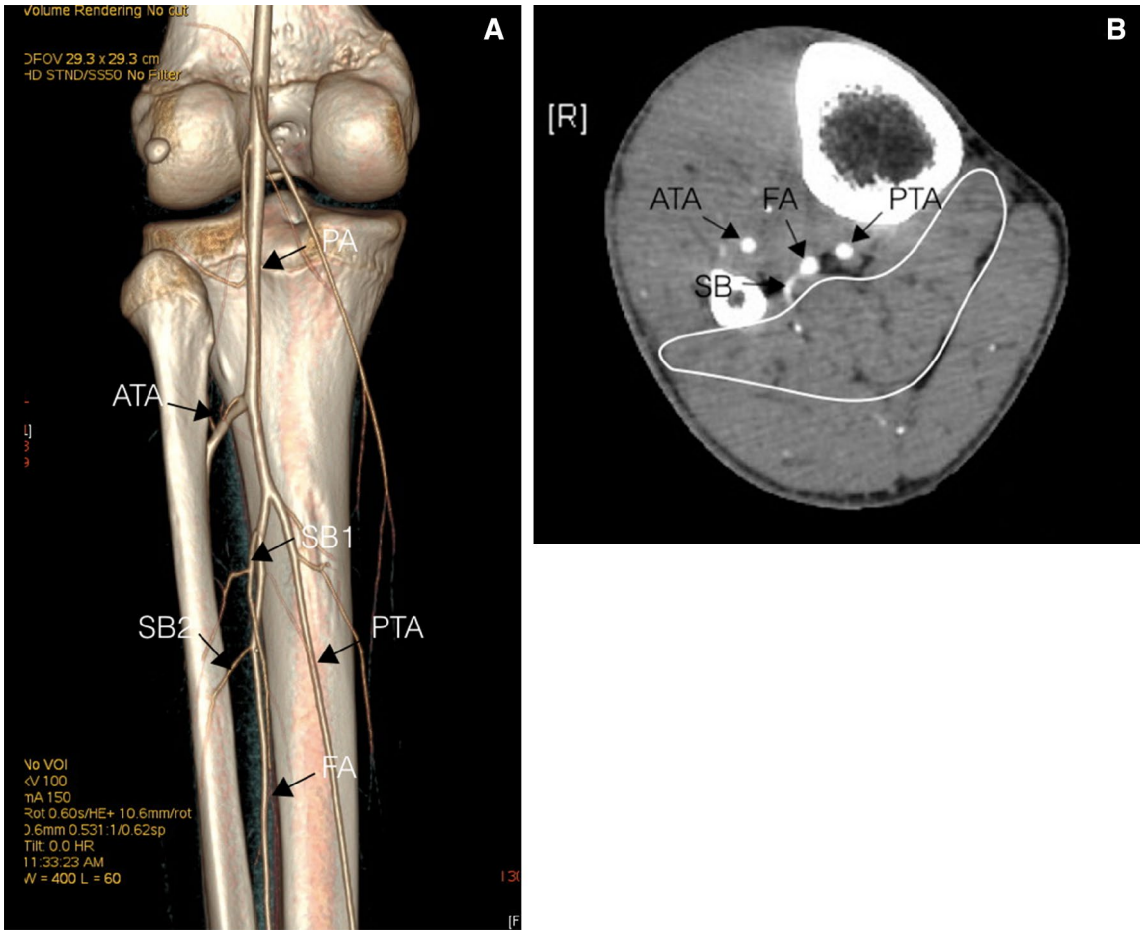

Fig. 4 **a** Volume rendering of the vascular tree of the left lower limb. **b** Identification of the soleus branches emerging from the fibular artery on a transverse CT angiography. A white line contours the soleus muscle on Fig. 2b. *PA* Popliteal artery, *ATA* anterior tibial artery, *FA* fibular artery, *PTA* posterior tibial artery, *SB* soleus branch

studied, a total of 88 branches originating from the fibular artery and destined to the lateral head of the soleus muscle were identified. The mean number of branches originating from the fibular artery destined to the soleus muscle was 1 in 4 legs (11%), 2 in 21 legs (55%), and 3 in 13 legs (34%). When only one branch was identified, there was systematically another branch destined to the lateral head of the soleus muscle emerging from the bifurcation in fibular artery and posterior tibial artery, or from the popliteal artery close to the bifurcation. Soleus branches destined to the lateral head of the soleus muscle emerged at a distance ranging between 0 and 2.9 cm (mean value = 1.70 cm) from the origin of the fibular artery in 39% of cases, between 3 and 5.9 cm (mean value = 4.26 cm) from the origin of the fibular artery in 44% of cases, and at a distance of 6 cm or more (mean value = 6.8 cm) from the origin of the fibular artery in 17% of cases (Table 2). Within the 19 subjects who could benefit from a comparative analysis of the two lower limbs, 9/19 (47%) presented a variable vascular pattern between the right and left leg, with a different number of soleus branches issued from the fibular artery in each leg.

Discussion

There are extensive merits to the use of a chimeric fibula flap including part of the soleus muscle when there is need for both bone, mucosa, and additional soft tissue. In case of extensive maxillary defects, the bony part of the fibula is used to restore the maxillary osseous continuity, while the skin paddle seals the palate, and the soleus muscle rebulks the malar area. It presents as a major advantage over the chimeric scapula flap in such indication, a better implant retention of the fibular bone when implant-retained dental rehabilitation is considered [14]. For large oromandibular defects, the soleus muscle can be used either to fill the dead space and rebulk the submandibular area or for external coverage in the setting of a through and through defect.

Table 1 Cadaveric study: pedicle length of the fibula flap including the lateral head of the soleus muscle according to the distance between the origin of the fibular artery and the emergence of the soleus branches issued from the fibular artery

	Sex	Side	Distance between the origin of the fibular artery and the emergence of the soleus branches (cm)		
			0–2.9	3–5.9	≥ 6
1	F	R	2	5	
2	F	L	2.8	4.3	
3	F	L	1.1		
4	F	R	2.2	5.5	
5	F	R		3.1	6.3
6	M	L	1.6		
7	F	R			6.1
					7.8
8	F	L	2		8
9	M	R		3.1	
10	F	L	1.9	4.7	
Mean	–	–	1.94	4.28	7.05
Standard deviation	–	–	0.52	0.99	0.99

F Female, *M* male, *R* right, *L* left

The pedicle length of the free fibular flap including the lateral head of the soleus muscle, although shortened, is similar to that of other osseous free flaps used for maxillo-mandibular reconstruction [iliac crest: 4 cm (1.5–7); lateral border of the scapula: 6 cm (5–7)] [3, 17, 29, 32, 33]. In our cadaveric and CT angiographic study, the pedicle length ranged between 0 and 2.9 cm (mean value = 1.82 cm) in 40% of cases, between 3 and 5.9 cm (mean value = 4.27 cm) in 37% of cases, and was superior or equal to 6 cm (mean value = 6.93 cm) in 20% of cases. There are very few articles in the literature evaluating the distance between the origin of the fibular artery and the emergence of branches destined to the lateral head of the soleus muscle [20, 35]. There are also some discrepancies between the results of these studies (Table 3). Indeed, Le Nen in his study on 15 lower limbs injected with latex finds a greater proportion of branches destined to the proximal part of the lateral head of the soleus muscle, and a greater proportion of branches issued at a distance of 6 cm or more from the origin of the fibular artery [20]. This difference can be explained by the absence of injection of the lower limbs dissected in our study and in Wong's study [35], making it more difficult to identify accessory pedicles. There are, moreover, no information about the size of the soleus branches identified in Le Nen study, meanwhile all the soleus branches in our study and Wong' were over 1 mm in diameter.

The vascular distribution of the proximal part of the lateral head of the soleus muscle being segmental, it is also possible to lengthen the flap pedicle ligating the most proximal soleus branches originating from the fibular artery. Indeed in the literature, the proximal part of the lateral head of the soleus muscle is supplied by at least two branches issued from the fibular artery in 76.3–100% of cases [8, 20, 25, 35]. In our study, the number of branches destined to the lateral head of the soleus muscle was variable (1–3 branches), with at least two branches found in 79.5% of cases in our cadaveric and CT angiographic study.

Soleus branches issued from the fibular artery are seen on good quality CT angiography of the lower limbs. In a study performed by Garvey in 2012 [11], it has been shown that it was possible to visualize 94.9% of fibular artery perforators, with a precision error of 8.7 mm between pre-operative and per-operative measurements. It was also possible to determine musculocutaneous branches from septocutaneous branches in 93% of cases. However, the size of the different perforators was more complicated to predict. The number of soleus branches being, furthermore, variable in 47% of cases between the left and right leg, a pre-operative CT angiography could help in selecting the limb to harvest, and to anticipate anatomical variations of the vascular tree that could compromise the realization of a composite fibula and soleus muscle free flap [34].

The failure rate of the composite fibula and soleus muscle flap is of 4% [16, 18, 24], and is no higher than that of the fibula flap including a septocutaneous skin-paddle. The donor site morbidity is moderate and similar to that of the osteocutaneous fibula flap, complications described in the literature consisting of paresthesia on the foot dorsum, extensor hallucis longus deficit, and moderate ankle stiffness [24]. Reconstruction of large maxillo-mandibular defects with a fibula flap including the lateral head of the soleus muscle can, moreover, avoid the need of a double free flap. Indeed, although the failure rate of double free flaps does not tend to increase in the literature [1, 13, 23], sequelae are more important due to donor site multiplication and postoperative care is more difficult. Finally, the use of a composite fibula flap including a skin paddle and a muscular fragment presents as major advantage a single arterio-venous microanastomosis to be performed, shortening the procedure duration and the number of cervical vessels to be sacrificed.

The main limitations of this flap consist in the shortening of the flap pedicle, and the more meticulous dissection, requiring a good knowledge of the fibular artery and its different branches. Flap spatialization is also more complicated due to the muscular fragment, any traction on the muscular branches risking to damage the vessels definitively.

Table 2 CT angiographic study: pedicle length of the fibula flap including the lateral head of the soleus muscle according to the distance between the origin of the fibular artery and the emergence of the soleus branches issued from the fibular artery

	Sex	Age (years)	Distance between the origin of the fibular artery and the emergence of the soleus branches (cm)					
			LEFT lower limb			RIGHT lower limb		
			0–2.9	3–5.9	≥6	0–2.9	3–5.9	≥6
1	M	49	1.6	3		1.3	4.5	
						2.8		
2	F	61		4.4	6.4		3.2	7.5
							5.4	
3	F	57	1	4.6	6.9	1.1	4.4	6.8
4	M	55		3		1.6	5.6	
				4.8				
5	M	59	1.3	3	5.1	1.3	3.6	
							5.3	
6	F	58	1	5.2		2.3		6.5
7	M	52				1.7		
8	F	68		3.6	6.7		4.9	7.6
9	F	59	1.8	3	6.8	1.8	4.4	
						2.9		
10	M	63	1.9	3.1		2.5	4.2	
							5.6	
11	F	79		3.7			4.3	
12	M	65	1.3		6.2	1.3		7.4
13	M	64	2.9	4.4		2.2	3.7	
14	F	60				1.1		
						2		
15	F	60	1.9	4.3		1.9	5	6.7
16	F	58		4.5	6			6.3
17	F	66	1.4	2.8	5.7	1.4	3.6	7
18	F	75	1.4	4.2				
19	M	57		3.2	7.4	1.7	5.3	
				4.2				
20	M	17	1.6	4.8			4	
21	M	68		5.3		1.9	3.1	
22	F	58	1			1.2	3	
Mean	–	59.45	1.64	4.15	6.63	1.79	4.37	6.98
Standard-deviation	–		0.60	0.86	0.47	0.55	0.85	0.48

F Female, *M* male

Table 3 Number of soleus branches destined to the proximal part of the lateral head of the soleus muscle in the literature

Article	Number of legs dissected	Total number of soleus branches	Mean number of soleus branches	Number of soleus branches according to their origin from the fibular artery (cm)		
				0–2.9	3–5.9	≥6
Wong 2009 [35]	10	59	2	7 (37%)	6 (31.5%)	6 (31.5%)
Le Nen 2009 [20]	15	19	4	8 (14%)	12 (20%)	15 (17%)

Conclusion

To conclude, the fibula flap including a skin paddle and the lateral head of the soleus muscle, although poorly described in the literature, allows an interesting one-stage reconstruction for large maxillo-mandibular defects. An origin of the soleus vessels in close proximity to the origin of the fibular artery represents the main limitation of this flap, the length of the remaining fibular pedicle making it difficult to achieve secure anastomosis in the cervical area. The vascular distribution of the proximal part of the lateral head of the soleus muscle being segmental, it is also possible to lengthen the flap pedicle ligating the most proximal soleus branches originating from the fibular artery.

Author contributions LN: protocol development, data collection, data analysis, manuscript writing. JD: data analysis, manuscript writing. FB: data collection. BD: other. SD: other. CV: protocol development, data analysis, manuscript writing and editing.

Compliance with ethical standards

Conflict of interest We have no conflict of interest to declare.

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