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ISSN: 0015-5659

e-ISSN: 1644-3284

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DOI: 10.5603/FM.a2021.0111

Article type: Review article

Submitted: 2021-09-06

Accepted: 2021-10-13

Published online: 2021-10-26

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Anatomical variations of the vascular supply of the cutaneous component of the serratus anterior myocutaneous flap: a systematic review

Christos Gakis et al., Anatomy of serratus anterior myocutaneous flap vascular supply

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ABSTRACT

Although appealing from a reconstructive standpoint, the incorporation of the overlying skin in a serratus anterior muscle flap has not yet seen widespread use, due to considerations with its blood supply. In the present study, a systematic review of the literature has been performed, evaluating studies that investigated the vascular anatomy and variations of serratus anterior myocutaneous flap. The anatomy of the cutaneous blood supply, the size of the cutaneous territory, the design of the skin paddle and the reconstructive goals were analyzed. The results showed that the main blood supply originates from the intramuscular anastomoses between intercostal artery perforators and the serratus artery branch in the form of choke vessels. Complementary perfusion from true intramuscular vessel anastomoses or from direct serratus artery cutaneous perforators could contribute to the skin blood supply but only in 25% of the cases. The design of the flap is elliptical with its long axis over the harvested muscle slips and maximum width is approximately 6-8 cm. A

myocutaneous serratus anterior flap could be applied in a variety of reconstructive fields, most commonly for head and neck defects. A delay procedure would considerably enhance the perfusion of the cutaneous component and improve the overall viability of the flap.

Key words: serratus anterior, flap skin, cutaneous component, blood supply

INTRODUCTION

Myocutaneous flaps, flaps consisting of muscle and their overlying skin, are frequently used in reconstructive surgery, especially when large tissue bulk is required. When a skin island is transposed, attached to the underlying muscle, the subdermal vascular plexus is discontinued. Cutaneous blood supply then stems from perforator vessels, arteries and accompanying veins, that arise from the muscle surface [1]. This kind of cutaneous blood supply is very reliable in body areas where muscles and overlying skin are firmly connected, such as Latissimus Dorsi muscle, but becomes questionable when skin and muscle are loosely attached together, such as Serratus anterior [2].

EMBRYOLOGY

Serratus anterior muscle belongs to the superficial thoracic muscles. Its origin and development is different from those of limb muscles. It is believed that it is formed from myotomes but its exact origin is not certain, and it is not clarified how myotome cells attach to the scapula to create these muscle. At first in the 9 mm embryo it resembles a premuscle mass with no attachments neither to the scapula nor to the ribs. It becomes more defined and attaches with digitations to the ribs in the 11mm embryo. Finally it develops to its adult form with insertion into the scapula in the 14mm embryo [3],[4],[5].

SURGICAL ANATOMY

Serratus anterior muscle is a fan shaped muscle, originating from the upper 8 to 9 ribs at the lateral chest wall, which inserts into the superior angle, the medial border and the inferior angle of the scapula. Its blood supply stems from the superior

thoracic artery, the lateral thoracic artery and the serratus artery branch of the thoracodorsal artery. The latter perfuses the inferior part of the muscle which is commonly used as a free or pedicled flap [3].

A serratus anterior myocutaneous flap, although first reported in 1982 [6], has not yet seen widespread use due to considerations with the viability of the cutaneous component. It was even considered unacceptable to include the overlying skin, because until then a direct communication of the cutaneous perforators with the serratus arterial network had yet not been identified [7].

An anatomic investigation of the cutaneous blood supply over the muscle and its relation with the arterial axis of the serratus anterior flap, the definition of the shape and size of the flap and the possible technical pitfalls, would delineate the likelihood of harvesting a myocutaneous flap, which would be a useful option in the armamentarium of a Reconstructive Surgeon.

MATERIALS AND METHODS

Search strategy

This systematic review was performed in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The protocol of this systematic review has been submitted to the Institutional Review Board of Department of Anatomy, National and Kapodistrian, University of Athens, Greece, and is available upon request. Eligible articles were identified by a search of the Medline, the Cochrane Library and the Google Scholar bibliographical databases for the period from April 1982 up to May 2019. The study protocol was agreed by all co-authors. The search strategy included the following keywords: (“serratus anterior flap” OR “skin” OR “cutaneous” OR “myocutaneous” OR “musculocutaneous” AND (“anatomical variants” OR “anomalies”). Language restrictions were applied (only articles in English, French, and German were considered eligible). Two investigators (CG and DC), working independently, searched the literature and extracted data from each eligible study. Reviews were not eligible, while all prospective and retrospective studies, as well as case reports, were eligible for this systematic review. Manuscripts that did not state the names of the authors were excluded. Case reports of a serratus anterior flap with a cutaneous component without an anatomic investigation of the

skin blood supply were also excluded. In addition, we checked all the references of relevant reviews and eligible articles that our search retrieved, so as to identify potentially eligible conference abstracts. Titles of interest were further reviewed by abstract. Finally, reference lists of eligible studies were manually assessed in order to detect any potential relevant article (“snowball” procedure).

The literature review resulted in 10 relevant anatomical studies. Data was collected and analyzed based on the anatomic basis of the cutaneous blood supply, the cutaneous island dimensions (theoretical in cadavers and applied in patients), the suggested design of a myocutaneous flap and the defect area where each one of them was applied on.

RESULTS

The flow chart of the study depicts that the investigated subject is not an intensively reviewed field (Figure 1).

Four studies proved the reliance of the blood supply of the cutaneous surface on the serratus branch by a cause and effect experiment (intra-arterial dye injection caused skin staining). Additionally, these studies calculated the mean cutaneous island surface stained. Typically the procedure included the catheterization of the thoracodorsal artery and the injection of variable volumes of a dye (methylene blue or black ink). Perrot in his study used a mixture of a dye and a radiopaque substance for radiologic co-evaluation [8]. All but one studies [9] stated that the arterial branch to LD muscle was ligated prior to the injection of the dye.

The calculation of the stained surface was accomplished following a computer assisted planimetric method [10], using a photo-processing software [9] or with a simple estimation based on length and width [6]. Estimated width ranged between 5.5 and 21cm, length between 6 and 20.5 cm and surface between 38.4 and 223.6 cm². The boundaries of the stained skin in relation to anatomic landmarks were also taken into consideration (Table I).

Apart from the cutaneous staining experiment, Perrot performed a cadaver dissection and recognized multiple cutaneous perforators arising from the muscle

fascia, but did not proceed with a further investigation of their intramuscular course [8].

Inoue noticed intraoperatively multiple short muscular branches arising from the muscle fascia, during the harvest of pedicled myocutaneous Serratus Anterior flaps. He speculated that the surface fascia of Serratus Anterior muscle receives its blood supply from the thoracodorsal artery and perfuses the overlying skin through these short perforators [11].

Pittet in her cadaver study injected a mixture of a dye, gelatin and barium for radiologic co-evaluation. She recognized intercostal artery perforators reaching the skin, as well as giving branches to Serratus Anterior during their intramuscular course. However, she did not observe any anastomosis between these muscular branches and the Serratus Artery branch [12].

Infact, it was Godat's study that uncovered an intramuscular arterial anastomosis. Following a large number of cadaver dissections, a detailed description of the vascular anatomy of the Serratus Anterior muscle was achieved. Contributions to the blood supply from the intercostal artery perforators were found through an intramuscular anastomosis, however these were inconstant [13].

Hamdi as part of his cadaver dissection study, made a detailed mapping of the intercostal perforators in the lateral thoracic wall (number of intercostal perforators and their mean distance from the anterior border of Latissimus Dorsi muscle) trying to delineate the anatomy of a lateral intercostal perforator fasciocutaneous flap (LICAP). In 21% of the cases, a vascular anastomosis between Serratus Anterior muscle arteries and intercostal artery perforators was found. The most frequent positions were in the 6th(30%) and 7th(38%) intercostal spaces. Based on this finding he suggested that in the presence of that anastomosis, a Serratus Anterior perforator (fasciocutaneous) flap could be raised [14].

Park found in his study (cadaver dissection and angiography) a similar frequency of intramuscular anastomosis of the Serratus Anterior artery branch and intercostal perforators (25%), although the sample in question was small. The perforators arose from the 6th and 7th intercostal spaces in one case and from the 4th intercostal space in another [15].

Tamburino in her cadaver dissection study discovered a direct cutaneous perforator branching from the serratus artery branch in 25% of the cases. She emphasized that these perforators had no intramuscular course and lay superficial to

the muscle. This perforator was found arising more frequently from the 6th (33%) and 7th (41.6%) intercostal spaces. In her radiologic study, occurrence was reported less frequently (18%). The author attributed this to the radiological protocol used, since the samples had been derived from CT chest angiographies of patients suspected for pneumonic embolism. She believes that a special radiological protocol would have probably revealed more perforators [16], (Table II).

The suggested design of the flap typically centers the axis of the flap over the selected muscle slips. Lateral border varies from 2 to 3 cm over the Latissimus Dorsi muscle to the anterior axillary line. Medial border most commonly reaches the midclavicular line but a medial extension of 2cm is also described. The superior border extends to the 5th or the 6th rib and the inferior border to the 8th or the 9th rib. Maximum width is kept approximately to 6-8 cm to facilitate direct closure. A different description was given by Janik who defined the vertical anatomic borders of the flap in relation to the height of the hemithorax [9]. In Park's study the suggested orientation of the flap is parallel to the anterior border of Latissimus Dorsi muscle and not to the Serratus Anterior [15], (Table III).(Figure 2)

The studies included in our review, reported 54 successful flaps with a cutaneous component. The flaps were either pedicled or free and were aimed to reconstruct defects in various anatomic areas, most commonly head and neck defects [6],[9],[11],[12],[25],[26] (Table IV).

DISCUSSION

Serratus anterior muscle flap is a useful alternative option for the reconstruction of various anatomical areas. The muscle is quite thin which makes it superior compared to other workhorse muscle flaps such as Latissimus Dorsi and Rectus Abdominis, in cases where a large muscle bulk is not desired. In cases where only the lower slips are harvested, the resulting functional deficit is negligible [17]. It is worth mentioning that the overlying skin is generally delicate and pliable. Additionally the intervening subcutaneous fat in individuals with normal Body Mass Index is thin. The incorporation of the skin in a myocutaneous Serratus Anterior flap adds cosmetic superiority and durability while it allows for a shorter healing period in comparison with a skin graft coverage. Flap monitoring is another convenience that a

skin paddle offers. Clinical examination of a muscle flap, is not as simple as of a myocutaneous flap, and is even harder if the muscle is covered with a skin graft. Capillary refill test and flap colour estimation are easily done on a cutaneous paddle and reflect the viability of the whole flap. Monitoring of the skin island permits an early recognition of a microvascular compromise and a timely surgical reexploration. This has been shown to lead to higher salvage rates [27].

These advantages have, for the most part, encouraged the research on the cutaneous blood supply anatomy.

The skin staining observed after the injection of a dye in the thoracodorsal artery has proven that a myocutaneous flap could be perfused by this vascular axis. On the other hand, the estimation of skin surface size using this method is considered inefficient. Several small cutaneous perforators arise along the course of the thoracodorsal artery, around the anterior border of the Latissimus Dorsi muscle[18]. In addition a direct dominant perforator branches off the thoracodorsal artery in 55-60% with three branching patterns being reported, arising from the thoracodorsal artery(50%), the Latissimus Dorsi branch(30%) and the Serratus branch(20%) [19], [20]. When placing the catheter proximal to the origin of the thoracodorsal artery, these perforators are also perfused. Moreover, in the study with the biggest stained skin territory, it was not clarified whether the branch to the Latissimus Dorsi was ligated [7]. Through this branch the perforators arising from the Latissimus Dorsi muscle surface would also perfuse their overlying surface as well as adjacent territories. Considering the close relationship of Latissimus Dorsi and Serratus muscles, this could lead to an overestimation of the possible cutaneous territory. Incising the perimetry of the flap to the level of the muscle fascia first, and then injecting the dye, would preclude the perfusion of the skin from perforators that do not arise from the Serratus Anterior muscle.

The lateral thoracic wall has been recognized as a well perfused area receiving blood from the intercostal artery perforators [21]. Multiple reviewed anatomic studies confirmed that several intercostal artery perforators pierce the Serratus Anterior muscle reaching the overlying skin. Further dissection has led to recognition of intramuscular anastomoses between intercostal artery perforators and the serratus artery branch in approximately 20-25% [14], [13], [15]. These anastomoses were most frequently found in the sixth and seventh intercostal spaces (typically the 6,7,8 serratus muscle slips overlying the 6th and 7th intercostal spaces are raised when

harvesting a serratus anterior muscle flap). Interestingly in one study, a cutaneous perforator arising directly from the serratus artery branch and not from the intercostal artery, was found in 25% [16]. The low consistency of these anastomoses does not however correspond to the high success rates of Pittet and Inoue (almost 90% of complete flap survival) [11], [12].

A reasonable theory was reported by Pittet. In a cadaveric study it was recognized that intercostal artery perforators give cutaneous and muscular branches. Although an intramuscular connection between intercostal artery perforators and the Serratus Anterior muscle arterial network was not directly visualized in her cadaveric study, she hypothesized the existence of this connection through choke vessels. As the angiosome theory suggests, three dimensional blocks of tissue (angiosomes) are perfused by a source artery. Neighboring angiosomes are linked with true vascular anastomosis (same vessel calibre) or with choke vessels (vessels of smaller size) [22]. Choke vessels distend to the calibre of true anastomosis in cases of blood supply insufficiency, such as when a flap is delayed, with a peak effect after 2 to 3 days [23]. A clinical indication of the existence of these choke vessels in the case series of Pittet was that immediately postoperatively, no cutaneous perforators of the myocutaneous flaps were traceable with a doppler examination. They became progressively audible, suggesting the opening of the choke vessels. It is likely that the reviewed anatomic studies have not recognized these choke vessels because of their minor diameter.

In cases where a preoperative recognition of a direct cutaneous perforator is not feasible, as suggested by Tamburino [16], a reasonable approach would be to delay the flap in order to enhance its vascularity. Flap delay is a preliminary procedure of incompletely raising a flap, thus partially obscuring its blood supply. During the delay period, choke vessels are allowed to dilate and as a result the flap becomes more tolerant to relevant ischemia. That process is extremely beneficial to the surgical outcome [24].

Serratus anterior is a thin muscle. For that reason, the point of bifurcation of the intercostal artery perforator to a muscular and a cutaneous branch would not be far from its undersurface. This bifurcation would be susceptible to thermal injury from heat dissipation, if a cautery was uncontrollably used. In that case, blood would not be allowed to run in a retrograde fashion, (serratus artery branch-choke vessels-muscular branch of intercostal perforator-cutaneous branch of intercostal perforator) resulting in flap failure. From a clinical standpoint, it should be noted that Pittet in her surgical

technique description highlighted that she paid attention not to damage the intercostal artery perforators with the cautery [12]. Most likely her meticulous harvesting technique preserves greater number of intercostal artery perforators, therefore achieving high success rates. Consequently it would be advisable to avoid using a monopolar cautery in the undersurface of the serratus anterior muscle. Instead bipolar cautery or ligaclips should be used to isolate the perforators.

When the proposed flap designs were compared, homogeneity was observed. The flaps are commonly oriented over the muscle slips to be used with slight differences in their medial and lateral extent. On the contrary, Park positions the long axis of the flap almost vertically against the serratus anterior muscle. Five to six muscle slips are incorporated compared to authors who only harvest two or three [15]. Although not mentioned in this study, harvesting more muscle slips could have possibly impaired function in a greater degree. That would be a concern when dealing with reconstruction in young, active individuals.

CONCLUSIONS

Serratus anterior myocutaneous flap is a useful option for reconstruction in various anatomical sites.

The intramuscular anastomoses of intercostal artery perforators with the Serratus artery branch, in the form of choke vessels, is the basis of cutaneous blood supply, while direct serratus artery cutaneous perforators and true anastomoses of same size vessels contribute in a less predictable manner, in almost 25% of the cases.

Flap delay and meticulous dissection with avoidance of cautery induced damage to the intercostal artery perforators, are considered important for a successful outcome.

Conflicts of interest: None declared

REFERENCES

1 Carvey M, Yang G, Hage R. Skin flaps: A novel approach to medical student instruction on integumentary arterial blood supply. *Transl. Res. Anat.*, 23 (2021), Article 100104, 10.1016/j.tria.2020.100104

2 Gurtner G, Neligan P. Plastic Surgery: Volume 1: Principles, 3rd Edition, Elsevier, 2013

3 Lung K, St Lucia K, Lui F. Anatomy, Thorax, Serratus Anterior Muscles. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2021

4 Pu Q, Huang R, Brand-Saberi B. Development of the shoulder girdle musculature. *Dev Dyn*. 2016 ;245(3):342-50. doi: 10.1002/dvdy.24378.

5 Valasek P, Theis S, Krejci E, et al. Somitic origin of the medial border of the mammalian scapula and its homology to the avian scapula blade. *J Anat*. 2010;216(4):482-8. doi: 10.1111/j.1469-7580.2009.01200.

6 Takayanagi S, Tsukie T. Free serratus anterior muscle and myocutaneous flaps. *Ann Plast Surg*. 1982 ; 8(4):277-83. doi: 10.1097/00000637-198204000-00003.

7 Merle, M. Grandes pertes de substance de la main. In P. Banzet and J. M. Servant (Eds.), *Chirurgie Plastique, Reconstructive et Esthetique*. Paris: Flammarion, 1994. P. 580

8 Perrot P, Duteille F, Leaute F et al. Etude anatomique et applications cliniques des caractéristiques de la palette cutanée du lambeau libre de grand dentelé , *Ann Chir Plast Esthet*. 2006 ;51(6):494-8.. doi: 10.1016/j.anplas.2006.02.003.

9 Janik SJ, Paraszti I, Hirtler L et al. Design of skin islands for a myocutaneous serratus anterior free flap-An anatomical study and clinical implication for pharyngeal reconstruction after laryngopharyngectomy. *Clin Otolaryngol*. 2019;44(3):227-234. doi: 10.1111/coa.13257.

10 Mijatović D, Bulić K, Dzepina I et al. The supply of blood in the skin territory above the lower part of the serratus anterior muscle. *Coll Antropol*. 2006;30(3):543-7. PMID: 17058521.

11 Inoue T, Ueda K, Hatoko M, et al. The pedicled extended serratus anterior myocutaneous flap for head and neck reconstruction. *Br J Plast Surg*. 1991;44(4):259-65. doi: 10.1016/0007-1226(91)90067-t.

- 12 Pittet B, Mahajan AL, Alizadeh N, et al. The free serratus anterior flap and its cutaneous component for reconstruction of the face: a series of 27 cases. *Plast Reconstr Surg*. 2006;117(4):1277-88. doi: 10.1097/01.prs.0000208297.02556.a5.
- 13 Godat DM, Sanger JR, Lifchez SD et al. Detailed neurovascular anatomy of the serratus anterior muscle: implications for a functional muscle flap with multiple independent force vectors. *Plast Reconstr Surg*. 2004;114(1):21-9; discussion 30-1. doi: 10.1097/01.prs.0000129072.11466.c3.
- 14 Hamdi M, Spano A, Landuyt KV et al. The lateral intercostal artery perforators: anatomical study and clinical application in breast surgery. *Plast Reconstr Surg*. 2008;121(2):389-396. doi: 10.1097/01.prs.0000298317.65296.cf.
- 15 Park SO, Chang H, Imanishi N. The free serratus anterior artery perforator flap-A case report and anatomic study. *Microsurgery*. 2016;36(4):339-344. doi: 10.1002/micr.30038.
- 16 Tamburino S, Menez T, Laloze J et al. Free serratus anterior artery perforator flap: a case report with an anatomic and radiological study. *Surg Radiol Anat*. 2017;39(8):837-842. doi: 10.1007/s00276-017-1824-0.
- 17 Whitney TM, Buncke HJ, Alpert BS et al. The serratus anterior free-muscle flap: experience with 100 consecutive cases. *Plast Reconstr Surg*. 1990;86(3):481-90; discussion 491.
- 18 Miyamoto S, Arikawa M, Kagaya Y et al. Septocutaneous thoracodorsal artery perforator flaps: a retrospective cohort study. *J Plast Reconstr Aesthet Surg*. 2019;72(1):78-84. doi: 10.1016/j.bjps.2018.08.026.
- 19 Thomas BP, Geddes CR, Tang M et al. The vascular basis of the thoracodorsal artery perforator flap. *Plast Reconstr Surg*. 2005;116(3):818-22. doi: 10.1097/01.prs.0000176253.42394.7c
- 20 Heitmann C, Guerra A, Metzinger SW et al. The thoracodorsal artery perforator flap: anatomic basis and clinical application. *Ann Plast Surg*. 2003;51(1):23-9. doi: 10.1097/01.SAP.0000054189.14799.F3.

- 21 Palmer JH, Taylor GI. The vascular territories of the anterior chest wall. *Br J Plast Surg.* 1986;39(3):287-99. doi: 10.1016/0007-1226(86)90037-8.
- 22 Taylor GI, Palmer JH. The vascular territories (angiosomes) of the body: experimental study and clinical applications. *Br J Plast Surg.* 1987;40(2):113-41. doi: 10.1016/0007-1226(87)90185-8.
- 23 Taylor GI, Corlett RJ, Dhar SC et al. The anatomical (angiosome) and clinical territories of cutaneous perforating arteries: development of the concept and designing safe flaps. *Plast Reconstr Surg.* 2011;127(4):1447-1459. doi: 10.1097/PRS.0b013e318208d21b.
- 24 Kevin C. Chung . *Grabb and Smith's Plastic Surgery.* Wolters Kluwer 2019
- 25 Bruck JC, Bier J, Kistler D. The serratus anterior osteocutaneous free flap. *J Reconstr Microsurg.* 1990;6(3):209-13. doi: 10.1055/s-2007-1006820
- 26 Janik S, Pyka J, Stanisz I, et al. Use of the myocutaneous serratus anterior free flap for reconstruction after salvage glossectomy. *Eur Arch Otorhinolaryngol.* 2019;276(2):559-566. doi: 10.1007/s00405-018-5245-4.
- 27 Stranix JT, Jacoby A, Lee ZH, et al. Skin Paddles Improve Muscle Flap Salvage Rates After Microvascular Compromise in Lower Extremity Reconstruction. *Ann Plast Surg.* 2018 ;81(1):68-70. doi: 10.1097/SAP.0000000000001425.

Table I. Surface of cutaneous staining after dye injection in cadavers

Author	Dye and injected volume	Width (mean) [cm]	Length (mean) [cm]	Territory (mean) [sqcm]	Relation to anatomic landmarks
Bruck (12 hemithoraces)	10 ml of methylene blue	range 5.5-7	12-15	No data	Laterally: anterior axillary line Medially: not specified Superiorly: 5 th rib Inferiorly: 7 th rib
Perrot (26 hemithoraces)	2 ml of methylene blue mixed with 30ml iodinated contrast	10.75 range 9-12	11.75 (range 10-14)	125 range:110-140	Laterally: anterior axillary line Medially: nipple Superiorly: 5 th rib Inferiorly: 7 th rib
Mijatovic (50 hemithoraces)	40 ml of black ink	No data	No data	143.79 range:131,8-211.4	Not specified
*Janik (20 hemithoraces)	40 to 60 ml of methylene blue	15.5 range 10-21	10.9 (range 6-20.5)	85.6 range 38.4-223.6	Laterally: posterior axillary line Medially: nipple Superiorly: 29.3% of hemithorax Inferiorly: 51.7% of hemithorax (<i>in craniocaudal direction calculated from axilla</i>),
	<i>*Janik injects TDA without ligating LD branch</i>				

Table II. Summary of anatomic studies

Author	Type of anatomic study	Number of hemithoraces	Observations	Conclusions
Bruck (1990)	Fresh cadaver: dye injection in TDA, (LD branch ligated)	12	Overlying skin of SAM as well as periosteum of 5,6,7 ribs were stained	There is a connection between serratus anterior branch and intercostals perforators (though not visualized) since both skin and periosteum were stained
Inoue (1991)	Intraoperative observations during myocutaneous serratus anterior flap harvest	11	Multiple short muscular branches arising from muscle fascia were observed	The carrier of the blood supply is considered to be the surface fascia of SAM in continuity to the serratus branch of the thoracodorsal artery
Godat (2004)	Cadaver, latex+dye injection, anatomic dissection of the muscle and its arterial network	50	There were <i>variable</i> intramuscular connections between serratus branch, intercostals perforators and lateral thoracic artery	
Mijatovic (2006)	Fresh cadaver: dye injection in TDA, (LD branch ligated)	50	Overlying skin of SAM was stained.	
Perrot (2006)	Fresh cadaver: dye+ iodized product injection in TDA, (LD branch ligated), macroscopic and radiographic evaluation	25	Overlying skin of SAM was stained. Multiple cutaneous perforators arising from the surface fascia of the SAM were observed	The cutaneous perforators rely on the blood supply of the serratus branch of the thoracodorsal artery
Pittet (2006)	Fresh cadaver: blue dye+ barium+gelatin injection in TDA, anatomic dissection + radiographic evaluation	Not mentioned	The study confirmed the presence of i) perforator vessels from intercostals reaching the skin; ii) intercostals perforators giving muscular branches	Skin blood supply is derived from perforator branches from intercostals, which also give muscular branches. This intramuscular connection with the

				thoracodorsal system could not be visualized
Hamdi (2008)	Fresh formalin preserved cadavers, anatomic dissection	47	A vascular connection between intercostal perforators and serratus Branch was found in 21% overall, 38% in 7 th intercostal space, 30% in 6 th intercostal space. Dominant intercostal perforators were found approximately 3.5 cm medial to LD	There is only a 21% overall incidence of vascular connection between serratus branch and intercostal perforators permitting the harvesting of overlying skin based on TDA
Park (2016)	Fresh cadaver, angiography+dissection	8 (4 angiography, 4 dissection)	A connection between intercostal perforators and serratus Branch via an intramuscular branch was observed in 25%	A Serratus Anterior Perforator Flap feasible in 25% of patients
Tamburino (2017)	Fresh cadaver, latex injection in TDA + dissection CT chest angiographies (for suspected PE)	8 33	In 25% of cadaver dissections a cutaneous perforator was found arising directly from the serratus branch(no intramuscular course) The 'direct' cutaneous perforator was found in 18%(always bilaterally) of the cases	A Serratus Anterior Perforator Flap is possible with suitable preoperative perforator mapping
Janik (2018)	Fresh cadaver,dye injection (LD branch not ligated)	20	Cutaneous staining measurement, definition of anatomical landmarks	Suggested design: superior border = 29.3% of hemithorax, inferior border = 51.7% of hemithorax (in craniocaudal direction calculated from axilla), posterior border not passing LD, anterior border = anterior axillary line

Table III. Suggested design

Author	Suggested design
Bruck(1990)	Superiorly above the fifth rib Inferiorly below the seventh rib Laterally anterior axillary line Medially: not specified flap is centered over the sixth rib 5 th ,6 th slips and ribs are harvested skin island is approximately 6 by 12 cm
Inoue(1991)	Laterally midaxillary line Medially hypochondrium (medial extent is the end of the 7,8 slips) centered over 7th,8th ribs
Pittet(2006)	Superiorly inframammary crease Inferiorly 9 th rib Laterally anterior border of LD Medially 2cm medially to midclavicular line Skin paddle can be extended 2-3cm over LD and harvested with underlying fascia. Usually 2 slips of serratus harvested but no more than 3

Park(2015)	<p><u>Long Axis of flap near the anterior axillary line</u> , anterior to ant border of LD. Flap centered over 5-7 rib. width 6-8 cm to permit direct closure. Length extended in fusiform fashion to facilitate closure. Distal part not adequately perfused, discarded before flap inset . Caudal 5-6 muscle slips incorporated</p>
Janik(2018)	<p>Superiorly within 1/3-2/3 of hemithorax Inferiorly on superior half of hemithorax Laterally post. axillary line Medially midclavicular line</p>

No	Author	Free/Pedicled	Composition	Slips	Lenght	Width	Reconstruction site/purpose
1	Takayanagi	f	Myocutaneous	5,6,7,8	11	7	Foot
2	Bruck	f	Osteomyocutaneous	5,6	12	7	Foot
3	Inoue	p	Myocutaneous	6,7,8	14	7	Oral cavity
4	Inoue	p	Myocutaneous	7,8	20	10	Cervical oesophagus
5	Inoue	p	Myocutaneous	6,7,8	14	7	Tempo-auricular skin
6	Inoue	p	Myocutaneous	8	14	7	Cheek soft tissue
7	Inoue	p	Myocutaneous	6,7,8	14	7	Oral cavity
8	Inoue	p	Myocutaneous	6,7,8	15	7	Cervical oesophagus
9	Inoue	p	Myocutaneous	6,7,8	15	7	Cervical oesophagus
10	Inoue	p	Myocutaneous	6,7,8	12	6	Oral cavity
11	Inoue	p	Myocutaneous	6,7,8	15	7	Oral cavity
12	Inoue	p	Myocutaneous	6,7,8	22	10	Cervical oesophagus
13	Pittet	f	Myocutaneous	6,7,8	12	5	Noma, cheek, oral lining
14	Pittet	f	Myocutaneous	7,8,9	12	6.5	Noma, cheek, upper lip, inferior eyelid
15	Pittet	f	Myocutaneous	6,7,8,9	5	8	Noma, cheek, oral lining
16	Pittet	f	Myocutaneous	7,8,9	9	4,5	Noma, cheek, oral lining
17	Pittet	f	Osteomyocutaneous	7,8	8	6	Noma, cheek, mandible, oral lining
18	Pittet	f	Myocutaneous	7,8,9	15	6	Noma, cheek, upper lip, oral lining
No	Author	Free/Pedicled	Composition	Slips	Lenght	Width	Reconstruction site/purpose
19	Pittet	f	Osseomyocutaneous	7,8	12	6	Noma, maxilla, upper lip, cheek, oral lining

20	Pittet	f	Myocutaneous	7,8,9	12	5	Noma, cheek, oral lining, upper lip, nose
21	Pittet	f	Myocutaneous	7,8,9	11	5	Trauma, cheek, inferior lid
22	Pittet	f	Osteomyocutaneous	6,7,8	10	5.5	Noma, maxilla, upper lip
23	Pittet	f	Myocutaneous	6,7,8	9	5	Noma, cheek, nose, inferior eyelid
24	Pittet	f	Myocutaneous	7,8	12	6	Noma, cheek, oral lining
25	Pittet	f	Osteomyocutaneous	7,8,9	9	7	Neoplasm, lower cheek, pharynx, mandible
26	Pittet	f	Myocutaneous	7,8	12	8	Noma, lower lip, chin
27	Pittet	f	Myocutaneous	7,8,9	8	4.5	Noma, cheek, oral lining
28	Pittet	f	Myocutaneous	7,8	12	5.5	Noma, cheek, oral lining
29	Pittet	f	Myocutaneous	7,8,9	9	7	Noma, cheek
30	Pittet	f	Myocutaneous	7,8	11	6.5	Noma, cheek, oral lining
31	Pittet	f	Myocutaneous	7,8,9,10	14	7	Noma, cheek, upper lip, oral lining
32	Pittet	f	Myocutaneous	7,8	11	6.5	Noma, cheek, oral lining
33	Pittet	f	Myocutaneous	7,8	7	5	Noma, cheek, upper lip, commissure, oral lining
34	Pittet	f	Myocutaneous	7,8	7.5	6.5	Noma, chin, lower lip, oral lining
35	Pittet	f	Myocutaneous	7,8,9	8	5	Noma, cheek, nasal lining
No	Author	Free/Pediced	Composition	Slips	Lenght	Width	Reconstruction site/purpose
36	Pittet	f	Myocutaneous	7,8	6.5	6	Noma, upper lip, commissure, maxilla
37	Perrot	f	Osteomyocutaneous	10x8 (muscle)	4	4	Inferior 1/3 tibia

38	Perrot	f	Osteomyocutaneous	14x10 (muscle)	6	4	Inferior 1/3 tibia
39	Perrot	F	Osteomyocutaneous	13x10 (muscle)	5	3	Inferior 1/3 tibia
40	Perrot	f	Osteomyocutaneous	18x11 (muscle)	5	4	Inferior 1/3 tibia
41	Perrot	f	Osteomyocutaneous	18x6 (muscle)	6	3	Inferior 1/3 tibia
42	Perrot	F	Myocutaneous	13x9 (muscle)	5	3	Inner surface of foot
43	Perrot	F	Myocutaneous	14x10 (muscle)	5	3	Inner surface of knee
44	Perrot	f	Myocutaneous	13x9 (muscle)	5	4	Anterior carpal surface
45	Janik	f	Myocutaneous	No data	10	9	Laryngopharygectomy
46	Janik	f	Myocutaneous	No data	7	7	Laryngopharygectomy
47	Janik	f	Myocutaneous	No data	9	9	Laryngopharygectomy
48 - 54	Janik (series of 7 flaps)	f	Myocutaneous	No data	8.7 (mean)	6.7 (mean)	Reconstruction after salvage glossectomy

Table IV. Summary of successful flaps

1. Only flaps with complete survival were included
2. Perrot (muscle dimensions are mentioned but not which slips are taken. Cutaneous island was harvested intentionally small just for flap monitoring)

Figure 1. Flow chart

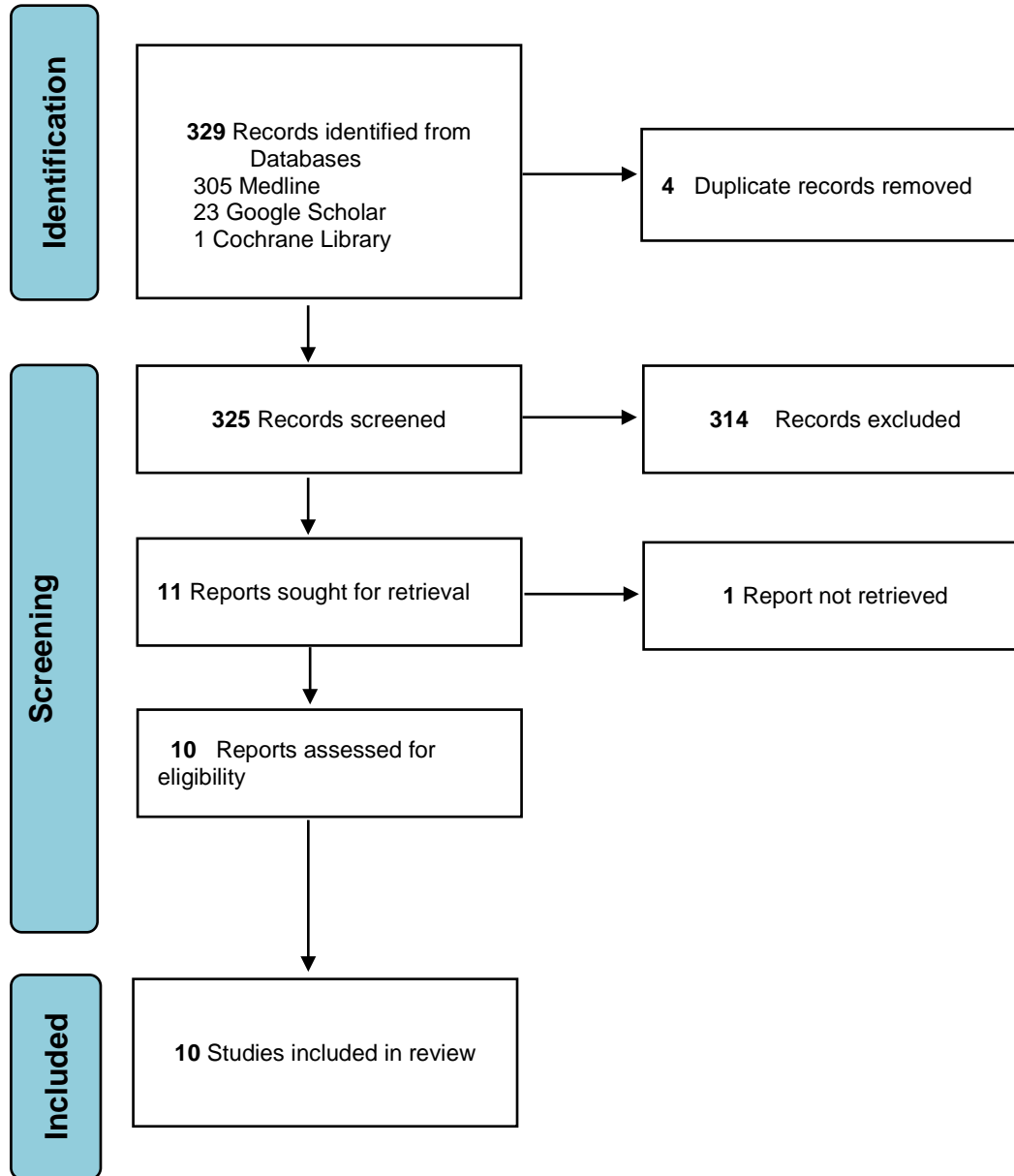


Figure 2. Suggested design

Bruck
Inoue
Pittet
Park
Janik

