Clinical Radiology 74 (2019) 756–762

Contents lists available at ScienceDirect

Clinical Radiology

journal homepage: www.clinicalradiologyonline.net

Review

# The lumbar artery perforator flap: clinical review and guidance on image reporting

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ARTICLE INFORMATION

*Article history:*
Received 26 February 2019
Accepted 31 May 2019

The lumbar artery perforator (LAP) flap is a relatively new procedure that can be utilized to manage lumbosacral defects in addition to reconstructing distal body parts as well, such as breast reconstruction. This fasciocutaneous flap is designed based on the LAPs small arteries that emerge from the lumbar arteries then move superficially piercing overlying tissues to perforate the lumbar fascia and supply the skin and subcutaneous tissue; However, anatomical and clinical studies regarding the LAP flap and its perforators are sparse in the literature, and the results are even contradicting. This article will discuss the LAP flap, the anatomy of its perforators, and the clinical aspects about its usage. In addition, we explore its preoperative imaging evaluation, and deliver a guide on image reporting and radiological data that will benefit the surgeon most during the procedure.



## Introduction

Tissue flaps are utilized when a simpler closure technique, such as primary closure, secondary intention, or skin graft, are not capable of providing a functionally and/or cosmetically acceptable solution.[1] A flap is defined by the transfer of tissue with its vascular bundle (artery and vein) from one body part (donor) to another (recipient). Transferred tissue receives blood supply through its associated vascular bundle rather than depending on the recipient bed (as skin grafts would do). Flaps are highly versatile and can be used to reconstruct body parts after surgery or cover large defects over joints and dependent areas.[2] A tissue flap can be designed to contain as many or as few layers as needed: skin, fascia, muscles, nerves, and bone could be included.[1] Multiple classifications are used to define the flap design, for example, based on knowledge of the blood supply, a flap can be either random or axial (with known supplying vessel); based on the anatomical relation between the donor and recipient sites, flaps are either local, regional, or distant; composition of tissue layers included in the flap also defines its type (e.g., musculocutaneous, fasciocutaneous); the technique of tissue transfer is also another definer (e.g., rotation, advancement).[3] Flaps can also be pedicled when the original blood supply is kept uninterrupted, or free when the

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https://doi.org/10.1016/j.crad.2019.05.032
0009-9260/

supplying vessels are cut from donor site and microsurgically anastomosed with recipient vessels in the new location. Donor site morbidity is dependable on the type of flap, but in general, fasciocutaneous flaps have less morbidity and better preserve function at the donor site compared to musculocutaneous flaps.[4,5]

The introduction of the perforator-based flaps and expanding knowledge regarding vascular anatomy of body have unveiled a nearly endless array of possible perforator flaps, such as the lumbar artery perforator (LAP) flap.[6–8] A perforator artery (e.g., LAP) emerges from a larger artery (e.g., lumbar artery) and then moves superficially through tissue layers, including muscles, to supply the skin and subcutaneous tissue.[9,10] A perforator flap is a fasciocutaneous flap supplied by a perforator artery that is dissected out of the tissues it perforates during the procedure, such as muscle. This technique allows large fasciocutaneous flaps to be harvested from the same area of conventional musculocutaneous flaps, while leaving the muscle behind, this decreases functional deficit and likely pain at donor site[11,12]; however, perforator flaps are technically demanding; flap survival and size depends on dissecting and including a large enough vessel to appropriately supply the flap tissue at the new site. Recent advances in anatomical studies have facilitated the recognition and characterization of dominant perforator vessels and their vascular territory or "perforasome" in different body parts, which has paved the way for the era of perforator flaps.[7] The LAP flap is an emerging highly versatile flap that can be used as a pedicled flap for loco-regional deficit reconstruction, or as a free flap to reconstruct distant structures, such as breast following mastectomy; however, anatomical studies about LAPs are still sparse and results are widely diverse between studies.

### *The LAP flap*

In 1978, Hill described a transverse lumbosacral flap, based on axial proximal blood supply and subdermal vascular plexus, in order to manage sacral defects.[13] They retrospectively analysed its use in 20 patients and suggested it is most useful for management of sacral pressure sores; however, they did not detail the axial pattern and flap dimensions, in addition, the investigators faced some technical limitations.[14] In 1988, Kroll & Rosenfield described the first LAP flap in a series of five cases, where they used a fasciocutaneous flap based on an unnamed perforator to manage defects in the midline lower back.[15] Later in 1999, Kato *et al.* first illustrated the anatomical path and vascular territory of the LAPs in a cadaveric and clinical study where they lifted four LAP flaps, the largest of which measured $8\times27$ cm and extended over the anterior axillary line at its distal end.[16] Afterwards, De Weerd & Weum reported performing a successful double LAP flap in a "butterfly" design to cover a large sacral defect with preserved sensation.[17]

### *What is the LAP flap used for?*

Currently, the LAP flap provides a durable solution with reliable blood supply to cover even large defects regionally or at distant areas, while the donor site is managed by primary closure.[14,18–21] A LAP flap size of up to $12\times27$ cm may be harvested on a single perforator.[22] Because of the presence of multiple perforators, as discussed below, another LAP flap might be elevated from the ipsilateral side in case of further reconstructive needs.[23] As a pedicled flap, the LAP flap provides a durable solution to reconstruct lumbosacral defects such as that caused by oncological resections, pressure sores, trauma, or congenital anomalies (Fig 1). This provides a like-for-like solution with similar tissue colour and thickness while preserving sensation, and is a better alternative to free flaps with shorter operation time as there is no microsurgical anastomosis needed. In addition to muscle preservation, no deeper dissection is needed as in the subcostal perforator flap, resulting in minimal donor site morbidity.[22,24]

The LAP flap can also be used as a free flap for breast reconstruction following mastectomy. The large size of the LAP flap and the ample amount of subcutaneous tissue in this area is usually enough to create a breast of a sufficient volume, and the sensate nerve could be sutured to the intercostal nerve to make a sensate flap.[18] Typically, when selecting a flap for autologous breast reconstruction, the first choice is the deep inferior epigastric artery perforator flap; however, in cases of contraindications or unavailability of the abdominal site (such in slender patients), alternative perforator flaps are considered.[25] These include the superior gluteal artery perforator flap, the lateral thigh perforator flap, and the transverse myocutaneous gracilis flap, in addition to the LAP flap, that was added recently to this group of alternatives.[18,26] The gluteal fat in the superior gluteal artery perforator flap is, however, of a firm texture, which can make breast shaping difficult, in addition to the occasional need for contralateral buttock left to correct the asymmetry produced by this type of flap. To the contrary, lumbar fat is softer and more pliable, which eases the shaping process and evades the need for revision.[18] The limited amount of fat tissue and the sacrifice of the gracilis muscle are disadvantages to the transverse myocutaneous gracilis flap.[27]

## Anatomy and preoperative imaging

Only a handful of studies have been published in the literature regarding the LAP flap since it was first described in 1987. To date, there are at least six anatomical studies describing the anatomy of LAPs. These studies have used a combination of cadaveric dissection and imaging in addition to perioperative patient imaging in order to describe the radiological and surgical anatomy of the LAPs and evaluate the microvasculature in the lumbar region.[14,18,20,28] Imaging studies included two-dimensional (2D) and three-dimensional (3D) angiography in addition to computed tomography angiography (CTA) with added 3D reconstruction in some studies. The aim was to evaluate the perforators' diameter, course, and dominance in addition to the number of perforators arising from each LA and length of the pedicle (the connection containing the blood supply

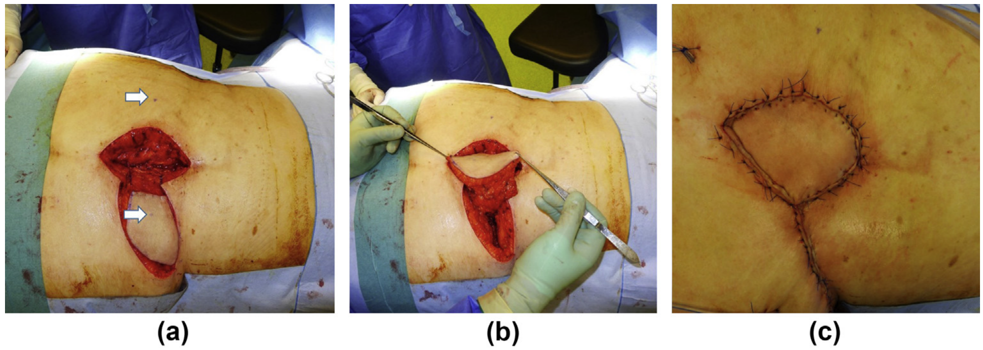


**Figure 1** LAP flap procedure for covering a midline lumbar defect. The location of perforators was marked on skin before the start of the procedure (arrows on a).

of the flap); however, a high level of discrepancy can be observed between the reported results of these studies. This could be in part due to different methods used for evaluation with variable measurement criteria in addition to the confusion about the anatomical nomenclature. It was also suggested that smaller perforators tend to be visualized on cadaveric dissection, but not on CTA.[14,18] In general, the size, path, and number of LAPs can be somewhat variable, although still predictable, and a preoperative imaging evaluation using CTA or magnetic resonance angiography (MRA) can provide a tailored vascular anatomy scheme for individual patients.[14,18,22,23,29] This will provide the surgeon with individualized vascular mapping (diameter, location, dominance, etc.) about the suitable perforator to supply the flap, which in turn, will assist in flap design and harvest, shorten the operation time, decrease complications, and improves the success rate.

The lumbar region is the rectangular shaped area enclosed laterally by the two posterior axillary lines, superiorly by a horizontal line passing through the cranial side of L1 vertebra, and inferiorly by a line passing through L5–S1 vertebral articulation.[14] Four lumbar arteries (LAs) arise from each side of the posterolateral surface of abdominal aorta opposite to the bodies of upper four lumbar vertebrae; however, the number varies from three to five LAs on either side, in addition to other individual variations in the origin and path.[30–32] Once arisen, LAs run posterolaterally on the vertebral bodies in between the transverse processes, and posterior to the sympathetic trunks and the tendinous arches of the psoas major muscle. Arteries on the right side pass posterior to the inferior vena cava. Along their path, LAs give branches to supply paralumbar muscles, fasciae, osseous structures, intervertebral discs, and the spinal cord.[33] Between the transverse processes, LAs then give a dorsal branch that runs posteriorly and anastomoses with other dorsal branches to supply muscle and skin of the lumbar region.[28] LAs (i.e., abdominal braches) of L1 to L3 then run in the plane between the quadratus lumborum muscle (QL) anteriorly and erector spinae muscle (ES) posteriorly, whereas that of L4 passes directly anterior to QL. Immediately lateral to ES, LAs pierce the aponeurosis of transversus abdominis to run anteriorly between this muscle and internal oblique.[32] LAPs can take two possible routes after arising from LAs and moving toward the skin, septocutaneous, by passing between the QL and ES, or musculocutaneous, by piercing muscles (QL or ES; Figs 2 and 3).[14,28] Perforators arising from the first pair of LAs are more likely to follow a musculocutaneous course, whereas perforators form the fourth pair of LAs are more likely to take a septocutaneous course. LAPs then pierce the

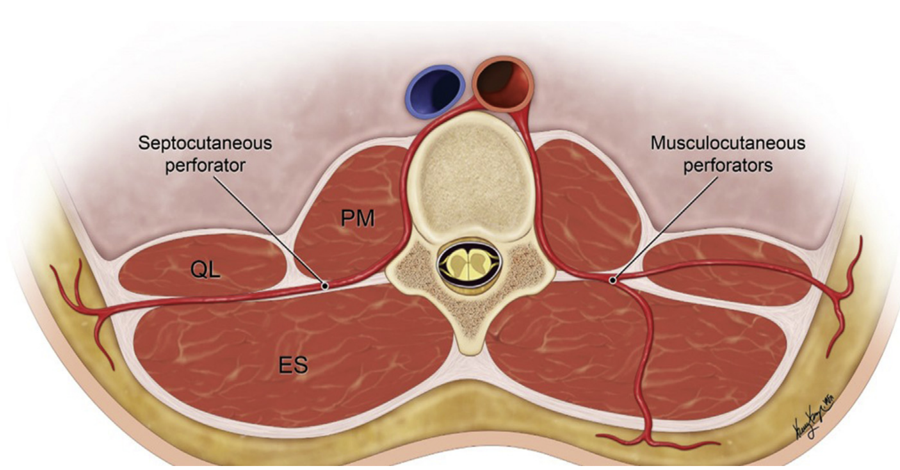


**Figure 2** Schematic illustration showing the septocutaneous course of LAP and possible musculocutaneous courses.

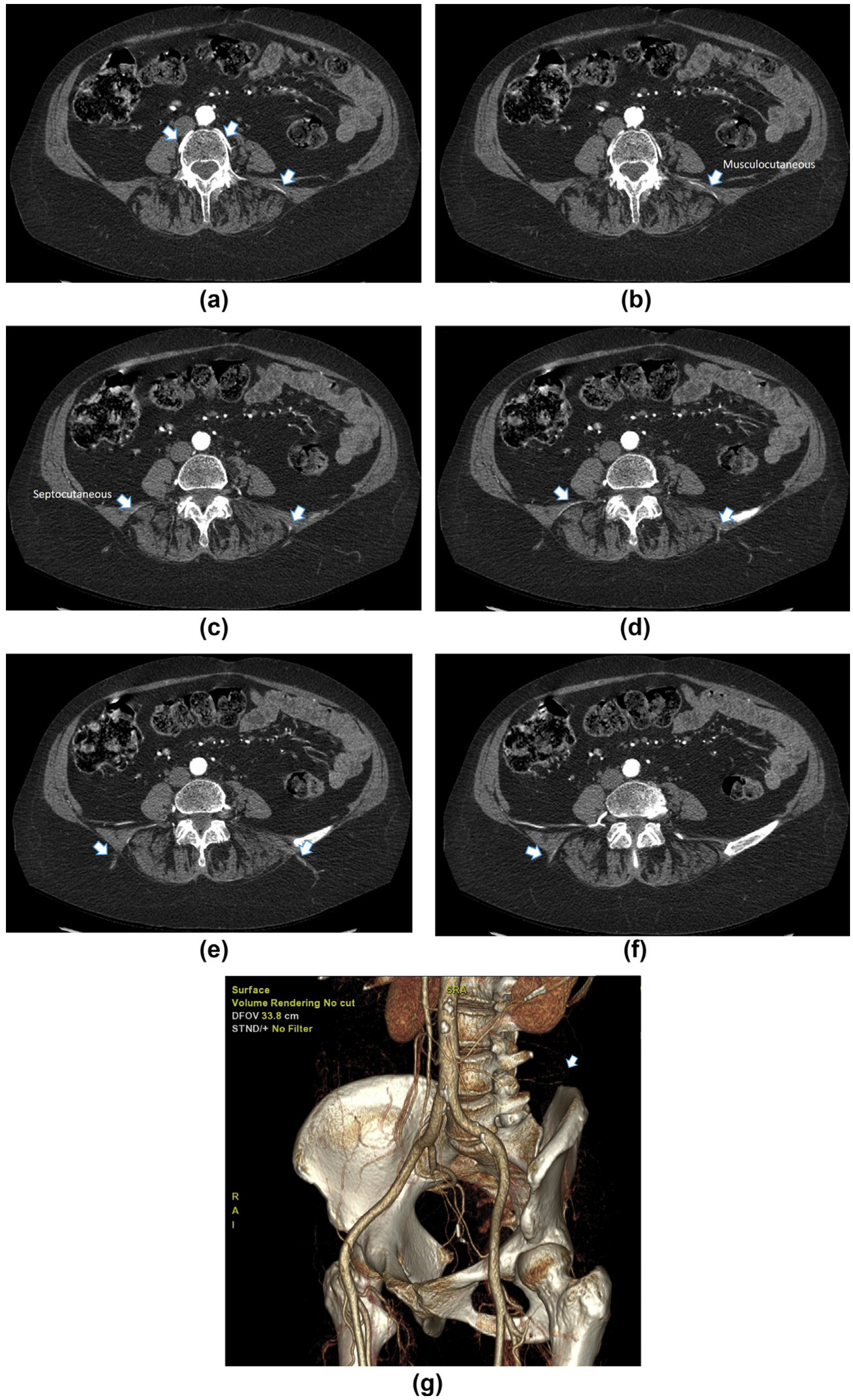


**Figure 3** CTA of the abdomen. Axial images, arterial phase, arrows on images A to F follow the courses of same L4 arterial perforators on both sides of the body. A septocutaneous course is shown on the right side, while a musculocutaneous course is shown on the left side. (g) A 3D image. Imaging technique: The patient was positioned supine and scanned in the caudal to cranial direction. Contrast medium was injected intravenously with an 18 G needle placed antecubital using 140 ml iohexol (Omnipaque 350, GE Healthcare, Marlborough, MA, USA) followed by a 60 ml saline flush, both at an injection rate of 4 ml/s. Bolus tracking was utilized with a region of interest placed at the aortic bifurcation, 7 seconds delay from time of injector to contrast monitoring and 200 HU threshold for triggering. Images were acquired on GE HD750 (GE Healthcare, Waukesha, WI, USA) at 120 kVp, fixed 179 mA, 0.8 seconds rotation time, 64×0.625 collimation and 1.38 pitch. Generation of axial, sagittal, and coronal images were created from the 0.625 projection data using the manufacturer provided “standard” reconstruction kernel. A display field of view of 380 mm was used to create two axial series: 1.25 mm section thickness and 1 mm interval for detail and 2.5 mm section thickness and 2 mm interval for surveillance imaging. Maximum intensity projection (MIP) and 3D volume rendered (3D VR) images were generated on the Advantage Workstation server (version 3.2, GE Healthcare) using the 1.25 mm section thickness and 1 mm interval “standard” reconstructed images with anatomical coverage from the bottom of the kidneys through the pelvis. MIP images were created at 10 mm section thickness and 2 mm spacing for the axial, sagittal and coronal planes. The 3D VR images were post-processed using five degrees of rotation.

**Table 1**
Radiology report checklist template.

| | |
|---|---|
| Examination: | CTA or MRA of chest, abdomen and pelvis |
| Clinical History: | ex., post resection of a plexiform fibrohistocytic tumour of back |
| Indication: | ex., local defect reconstruction |
| Technique: | |
| Findings: | Right and left 4th lumbar arteries give rise to dominant perforators, on either side, details below<br>Right L4 perforator:<br>1. Diameter at origin: 1.1 mm<br>2. Course: musculocutaneous or septocutaneous<br>3. Location of perforation at lumbar fascia on axial imaging: (series x, image xx)<br>4. Midline distance:<br>5. PSIS distance:<br>Left L4 perforator: |

thoracolumbar fascia accompanied by the vein and nerve to supply the skin and subcutaneous tissue; however, the exact route of each perforator can be variable, and not all LAs give perforators.[18] There is an average of 5±2 perforators per person, with an equal number on the right and left sides, but some LAs are more likely to give perforators than others. There is still some controversy between studies about which LAs give more and/or larger perforators. Some studies found that there are significantly more perforators arising from L1 and L4 vessels and with longer pedicle (mean approximately 10 cm) as compared to L2 and L3 vessels.[16,28] Pedicle length is measured from the vertebral bodies to thoracolumbar fascia perforation site. In addition, perforators from the L1 artery were found to be of greater diameter (mean 1.2 mm) as compared to other perforators (mean 0.8 mm). Other studies found a higher number of perforators with slightly larger diameter arising from the L3 and L4 arteries as compared to others, and reported a mean pedicle length for free LAP flaps of 6 cm.[18] The location at which perforators pierce the thoracolumbar fascia is also variable and differs by the level of the source LA; perforators form L1 artery are more likely to be seen along a diagonal line extending from the inferomedial insertion of the trapezius-to the iliac crest at the insertion of external oblique muscle, whereas perforators from the L2 and L3 arteries are seen clustering over the bony landmarks of the L2 and L3 vertebrae.[28] Lastly, L4 artery perforators can be seen piercing the fascia along a line drawn between the two posterior superior iliac crests. Once they pierce the thoracolumbar fascia, LAPs may bifurcate or trifurcate to supply the subcutaneous fat and skin[18,28,34]; however, this may occur later within the subcutaneous fat. These variations again highlight the importance of preoperative vascular imaging for each patient.

## Guidelines for reporting preoperative imaging findings

In this section, we will highlight the anatomical information that the surgeon will be looking for in the radiology report based on the literature review and the experience of our institution. Details of interest differ by the intended usage of the flap, whether the flap is planned to be used locally or as a free flap, and providing specific values within the radiology report will facilitate flap design and harvest. These details are summarized in Table 1. Knowing the diameter of the perforator artery and vein at their origin from the lumbar artery and vein, respectively, is important for determining vascular dominance and also for planning the anastomosis in free flaps, as it may anticipate if a vascular interposition graft will be needed. Deciding the course of the perforator (septocutaneous or musculocutaneous) and delineating the anatomical path it takes, in addition to highlighting important branches (a late branching spinal artery for example), is crucial for a safe and smooth flap harvest. Compromising the spinal cord blood supply by accidentally injuring a spinal artery may cause ischaemia and devastating complications. Providing a 3D reconstruction image of the vasculature is a valuable tool as it provides the surgeon with a visual summary of the data (Fig 3g).[28] Detailing the location of where the perforator pierces the lumbar fascia will facilitate the process of vessel isolation, and can be reported in two dimensions on the horizontal and vertical plans; the midline distance and the posterior superior iliac spine distance “PSIS distance”, which is the distance from a line passing by the two PSIS

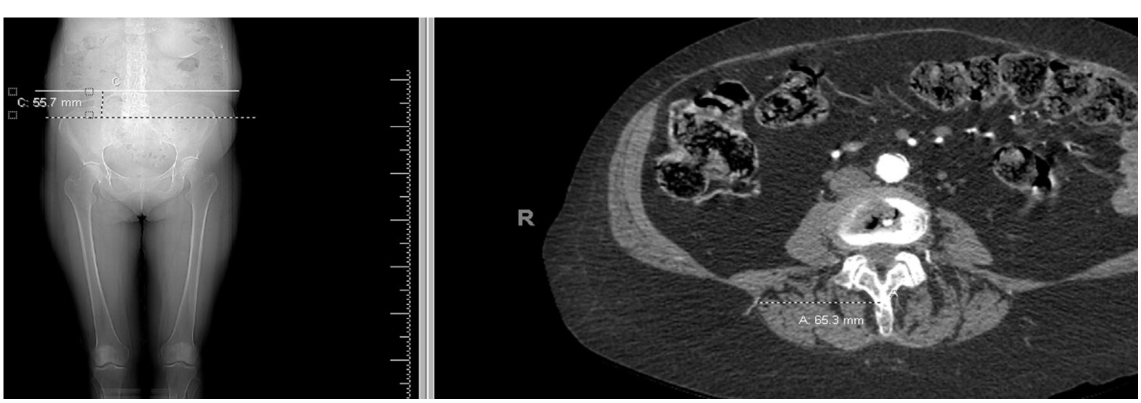


**Figure 4** An axial CTA abdomen image is linked with the scout image to determine the PSIS distance. The midline distance is also measured on the axial image.

"PSIS line". These landmarks can be easily palpated on the patient during the operation. The distance from the midline is simply measured on an axial image. Distance from the PSIS line can be measured as follows: the PSIS line is drawn on a scout image, then the location of fascial perforation is determined on an axial image, and the two views are linked (Fig 4). Afterwards, on the scout image, the "PSIS distance" can be measured. This location can also be confirmed in the operation theatre by handheld Doppler ultrasound. Lastly, for free flaps harvested for breast reconstruction, the thickness of the subcutaneous fat at the lumbar region is a good attribute to measure.

## Limitations and complications of the LAP flap

In general, the most common cause of failure of any flap is vascular compromise.[35,36] This could result from failure to adhere to the angiosome/perforasome concept, which may result in partial flap loss if too much tissue is included in the flap beyond the anatomical boundaries of its blood supply. Vascular compromise could also result from twisting of the pedicle or vascular thrombosis at the micro-anastomosis site in free flaps.[22] Compromise of the flap's blood supply can be identified through clinically monitoring the flap (colour, capillary refill, temperature) or via Doppler ultrasound to evaluate arterial and venous signals.[37] Using a tissue oximeter device is also gaining approval and appears to improve flap salvage rates.[38]

The limiting factor of the LAP flap is the relatively short length of LAPs which equated to a short pedicle length, resulting in limited rotation axis in island pedicled flaps or requiring deeper dissection at the recipient cite for free flaps. A short pedicle length limits the rotational arc of the flap as a wide angel of rotation may cause venous kinking and congestion, threatening the viability of the flap. Rather a two-step procedure with secondary closure may be then needed.[22] In the instance of free flap for breast reconstruction, because of the short length of the LAP, resection of one costal cartilage and over dissection of the internal mammary vessels by 3–4 cm are needed to ease the micro-anastomosis process.[18] If that is not sufficient or in cases of a perforator with small diameter, a vascular interposition graft could be harvested from the deep inferior epigastric vessels. Another limiting attribute, which is related to the technique used with free LAP flap for breast construction, is that the patient needs to be turned around on the operation table after harvesting the flap from the back to attach it anteriorly. In general, minimal complications were noted with the LAP flap. One complication with free LAP flap was postoperative seroma formation at the donor site (78% in one study[18]), mostly due to damage to medial lymphatics at the level of thick deep fascia over the paraspinal muscles. A more anterior flap design preserves these lymphatics and was found to have a significant effect on seroma formation. Numbness at donor site was also reported, and is probably due to proximal transection of sensory nerves during flap harvest.[14] Lastly, harvesting a large amount of tissue for a free flap may require contralateral liposuction to adjust waist contour symmetry.[18]

## Conclusion

The LAP flap is a versatile flap with a reliable blood supply and an ample amount of tissue for local and distant reconstruction. Associated risks of the LAP flap are low, and can be further reduced with preoperative imaging, such as CTA or MRA, in order to evaluate the perforator course and facilitate flap design on an individual patient basis.

## Conflicts of interests

The authors declare no conflict of interest.

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