



Perforator Vessels of the Upper Chest: New Evidence from an Anatomic Study

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Abstract

Introduction: Vascularized tissue transfers based on perforator vessels have been proven to be reliable and versatile reconstructive procedures. In upper chest, such surgical procedures provide efficient post tumor extirpation or trauma defect reconstruction as well as improved aesthetic and quality of life outcomes. In this study the anatomic characteristics of the perforator vessels in the upper half of the breast are presented and analyzed.

Methods: The dissection of 15 female adult fresh-frozen cadavers was performed. Perforators found during the deep subcutaneous/suprafascial dissection were marked, preserved and traced down to their origin at the intra- and submuscular level. All perforator vascular pedicles (arteries and veins) greater than 0.4 mm were preserved and marked. All measurements were taken in millimeters using a micrometer.

Results: The diameter of the dominant internal mammary artery perforator was 0.8 mm to 1.9 mm, and of the accompanying vein, 1.2 mm to 2.8 mm. Average sizes of lateral thoracic artery perforators was $1.40 \text{ mm} \pm 0.25 \text{ mm}$ one main thoracoacromial artery perforator was usually identified in most subjects.

Conclusion: The identification of upper chest perforator vessels and the confirmation of their anatomic characteristics through comparative analysis with existing literature have a fundamental comprehensive role leading to efficient surgical planning.

Keywords: Perforator vessels; Autologous breast augmentation; Breast oncoplastic and reconstructive surgery; Microsurgery; Internal mammary perforators; Thoracoacromial artery; Lateral thoracic artery; Perforator pedicles

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Introduction

The use of local perforator flaps is a relatively new concept in breast oncoplastic and reconstructive surgery. The advantages of their use include: a) allowing the repair of local defects with neighboring, well vascularized full thickness tissue that does not require preoperative expansion or another type of regional or distal tissue transfer, b) enabling the complex restoration without imposing strenuous surgical procedures to a patient with concomitant trauma and/or impaired general condition, c) facilitating autologous breast augmentation in post bariatric surgery/massive weight loss patients d) providing excellent recipient vessels for free tissue transfers in selected cases of extensive post trauma, burn or oncology defects with limited available tissue donor sites.

Design and preoperative planning of flaps in microsurgery are foundational steps for successful outcome. Determining the location of perforators and defining their course through the tissues has been and still is a major challenge for the reconstructive surgeon especially when surgical planning includes the restoration of local defects. Finding the most appropriate perforator, in many cases is so far depended on the experience of the surgeon in recognizing anatomical relations.

Hand-held Doppler imaging, color Doppler imaging, computed tomographic angiography and magnetic resonance angiography are methods that have been successfully used for the perioperative identification of perforators [1-4] and they have been shown to decrease operative time and donor-site morbidity [5].

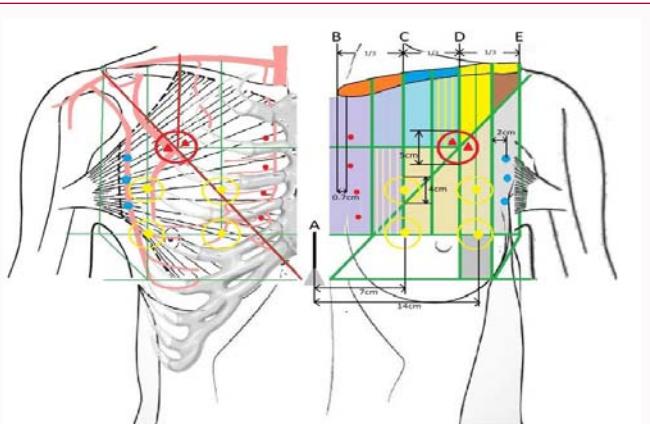


Figure 1: Illustration of the basic perforator location. The clavicle has been divided in thirds (orange, blue, yellow). Red circle-triangle: the area more likely to find thoracoacromial artery perforators, yellow circle-rhomboid: the area more likely to find anterior intercostal artery perforators, blue dots: basic lateral thoracic artery perforator location, red dots: basic internal mammary artery perforators' location (average distance from lateral sternal border: 7 mm, see text). Line A: mid-sternal/xiphoid process, line B: paramedian line passing from the lateral sternal border – medial clavicular end, line C: paramedian line passing from the junction of the medial and medium clavicular third, line D: paramedian line passing from the junction of the medial and lateral clavicular third. Further measurements explanation in the text.

However, the modalities and equipment required is not often available and extra specialized personnel to handle and interpret adequately the results are usually needed. Small defects following breast conservation surgery in the medial quadrants are usually repaired using the anterior intercostal artery perforator flap and outer quadrants using the lateral intercostal artery perforator flap [6].

For the repair of larger defects, a thoracodorsal artery perforator or a latissimus dorsi flap is preferred to restore the bulk and the new breast mound. The flap can be mobilized in either V-Y or a propeller fashion with a maximum angle of 90 degrees, eventually sacrificing minor perforators to obtain better breast shaping. The flap is used with a skin island but can also be de-epithelialized with its superior border cranially anchored to the pectoralis major fascia or to the skin.

Additionally, the upper half of the breast involves aesthetically and functionally important units dictating the need for more specific, locally based reconstructive solutions. The sound anatomical knowledge of the presence, distribution and characteristics of the perforator vessels at the upper half of the breast is therefore fundamental. In this study we aim at investigating and describing the perforator vessels of the upper breast area which will in turn help defining skin and soft tissue territories that can serve as donor sites for local perforator flaps.

Anatomical Study- Methods

The dissection of 15 female adult fresh-frozen cadavers (30 cadaveric hemitrunks) took place on a consecutive manner. All study protocols were approved by the research and bioethical committee of the National and Kapodistrian University of Athens Medical School. The specimens were obtained from the University affiliated Public Forensics Laboratory. We aimed at investigating the upper half of the breast and chest wall. Only specimens without history of systemic vascular disease (obtained from their medical records e.g. peripheral artery disease, vasculitis and autoimmune vascular involvement) or macroscopically visible scars, trauma or injury, deformity or lesion



Figure 2: Internal mammary artery perforators. One primary perforator in the second and two primary perforators in the third intercostal space.

Table 1: Mean diameters of the left and right IMAs in each intercostal space.

IMA (mean \pm SD, mm)	Left	Right
1 st ICS	2.61 \pm 0.35	2.90 \pm 0.50
2 nd ICS	2.33 \pm 0.32	2.50 \pm 0.50
3 rd ICS	2.10 \pm 0.35	2.23 \pm 0.45
4 th ICS	1.95 \pm 0.35	1.85 \pm 0.40

IMA: Internal Mammary Artery; ICS: Intercostal Space; SD: Standard Deviation

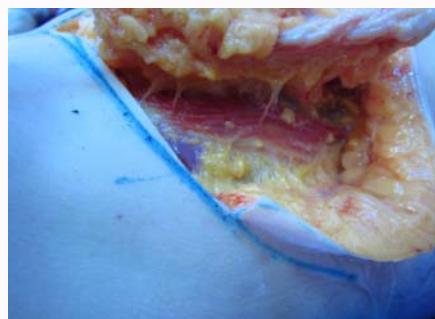


Figure 3: Two groups of intercostal artery perforators. The first group on the left at approximately 7 cm and the second group on the right at about 14 cm from the midsternal line. See text for further details.

of any kind in the region were included in the study. The cadaver age range was from 43 years to 95 years (mean=80.6 years).

The upper skin incision was made along the lower border of the clavicle and the lower skin incision was placed along the lower border of the 4th intercostal space. The medial skin incision was performed along the midsternal line from the sternal notch down to the level of a horizontal line tangential to the lower border of the 4th intercostal space. The suprafascial dissection was performed bilaterally from the midsternal line towards and up to the midclavicular line on both sides. The lateral skin incision was made on each side along a line 2 cm lateral to the lateral border of the pectoralis major muscle, parallel to the anterior axillary line and the suprafascial dissection proceeded to the closest to the areola lateral point until the midclavicular line was reached and the level of dissection from the lateral approach, joined.

Perforators found during the deep subcutaneous/suprafascial dissection were marked, preserved and traced down to their origin at the intra and submuscular level.

Suprafascial, subfascial and submuscular dissection was performed under 4 × loupe magnifications, and the first to forth intercostal spaces were revealed to identify the internal mammary,

Table 2: Previous studies and findings on the position of principal IMA perforators.

ICS	Munhoz et al. [21], anatomical (n=22)	Palmer and Taylor [16], anatomical (n=40)	Rosson et al. [17], anatomical (n=20)	Paes et al. [18], anatomical (n=27)	Schellekens et al. [20], anatomical (n=27)
1 st	5%	23%	10%	6%	15%
2 nd	63%	57%	50%	83%	67%
3 rd	27%	10%	25%	11%	19%
4 th	5%	10%	10%	0%	N/A

ICS: Intercostal Space; N/A: Not Reported; IMA: Internal Mammary Artery

Table 3: Average Diameter of the Arterial Perforators.

ICS	Average Diameter	Standard Deviation
1 st	1.10 (0.25–2.00)	0.4
2 nd	1.55 (0.55–2.80)	0.6
3 rd	1.41 (0.40–3.00)	0.53
4 th	1.15 (0.33–1.75)	0.35

ICS: Intercostal Space

intercostal, thoracoacromial and lateral thoracic vessel perforators.

Fine dissection was performed to obtain enough vessel length. No colored latex injections were used due to National law regulations and because the natural condition and size of vessels without latex expansion was required.

All specimens were placed in supine decubitus position for dissection, which was performed from the medial sternal and the anterior axillary line to the mid clavicular line on each side. All perforator vascular pedicles (arteries and veins) greater than 0.4 mm were preserved and marked. All measurements were taken in millimeters using a micrometer.

Statistical analysis

Descriptive statistics were used to calculate means and standard deviations for distances between the perforator origins. Simple regression analysis was used to determine correlations between measurements (distances, diameters). Statistical significance was for $p<0.05$. Statistical analysis was performed using SPSS Version 21.0 (IBM Corp, Armonk, NY).

Results

Internal mammary artery (IMA) perforators

Internal mammary perforators branch off the IMA at the dorsolateral border of the sternum, course through the intercostal space, enter the pectoralis major muscle at its medial border, and finally perforate the overlying fascia. Then they course to the surface, displaying a tortuous course through thoracic adipose tissue. Perforators greater than 0.4 mm in diameter were bilaterally evaluated on account of their distance from the sternal border to the point of branch origin under the muscle, the maximal external diameter and the length between the point of origin and the point of entrance to the fat layer. The mean diameter of internal mammary arteries was $2.50 \text{ mm} \pm 0.80 \text{ mm}$ with a range between 1.10 mm to 4.10 mm on the right side and $2.09 \text{ mm} \pm 0.70 \text{ mm}$ with a range between 0.90 mm to 3.75 mm on the left side. The mean diameters are shown in Table 1. The difference between left and right IMA and IMA perforator's diameters and number was not statistically significant.

There was a single dominant perforator in 80% of cases, which was at least twice the size of any other perforator, while in the other 20% there was codominance, with two perforators of comparable size. The diameter of the dominant perforator has been reported as 0.8 mm to 1.9 mm, and the accompanying vein, 1.2 mm to 2.8 mm.

Table 4: Double internal mammary artery perforators and their location.

ICS	Hemi-thoraces	Number of additional perforators*
1 st	1	1
2 nd	1	1
1 st and 2 nd	2	4
1 st and 3 rd	1	2
1 st and 4 th	1	2
2 nd and 3 rd	3	6
2 nd and 4 th	1	2
Total	10	18

*additional to the 4 perforators (one per examined ICS) in each hemi-thorax, ICS: Intercostal Space

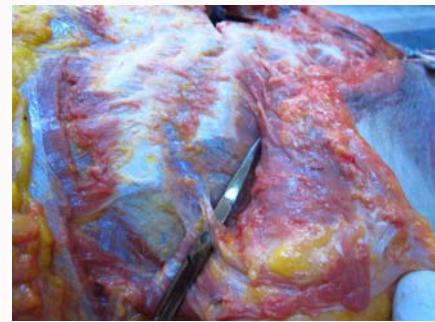


Figure 4: One large lateral thoracic artery perforator in the third intercostal space.

The IMA perforator from the second intercostal space was the largest in all cases but 2 in which the perforator from the third intercostal space was bigger. Previous studies and findings on the position of principal IMA perforators are shown in Table 2.

The mean distances of the IMA perforators from the ipsilateral sternal border were $7.0 \text{ mm} \pm 3.10 \text{ mm}$ (range: 2.80 mm to 13.00 mm) on the left side and $6.90 \text{ mm} \pm 3.35 \text{ mm}$ (range: 2.10 mm to 13.20 mm) on the right side (Figure 1 and 2). The mean diameters of all IMA perforators were $1.45 \text{ mm} \pm 0.40 \text{ mm}$ (range: 0.80 mm to 1.90 mm) on the left side and $1.42 \text{ mm} \pm 0.35 \text{ mm}$ (range: 0.90 mm to 1.80 mm) on the right side, while mean lengths of all IMA perforators were $18.00 \text{ mm} \pm 6.50 \text{ mm}$ (range: 9.80 mm to 35.00 mm) on the left side and $18.45 \text{ mm} \pm 3.30 \text{ mm}$ (range: 11.00 mm to 23.00 mm) on the right. The average diameters per intercostal space are shown in Table 3.

A total of 138 IMA perforators in 30 hemitrunks were identified and mapped. Perforators were found in all hemi-thoraces and all 4 examined intercostal spaces had at least one perforator. A single perforator per intercostal space was found in 20 hemi-thoraces, double perforator in one intercostal space was found in 2 hemi-thoraces and double perforator in two intercostal spaces was found in 8 hemi-thoraces. The distribution and number of perforators are

Table 5: The number hemi-thoraces with 1,2 or 3 perforators found in the 3rd and 4th ICS and the total number of anterior intercostal artery perforators.

perforators	3 rd ICS	4 th ICS
single	in 12 of 30 hemithoraces	in 12 of 30 hemithoraces
double	in 11 of 30 hemithoraces	in 13 of 30 hemithoraces
triple	in 7 of 30 hemithoraces	in 5 of 30 hemithoraces
Total per ICS	55	53
Total	108	

ICS: Intercostal Space

shown in Table 4.

A pair of anterior intercostal arteries originates from the internal mammary artery in each of the first six intercostal spaces. We examined the first 4 intercostal spaces in each hemithorax. We identified anterior intercostal artery perforators in the 3rd and 4th intercostal spaces. The distribution of perforators is shown in Table 5. Perforators were identified within a radius of 2.0 cm from two points, the first 7 cm and the second 14 cm from the medial sternal line (Figure 3).

Thoracoacromial artery (TCA) perforators

The thoracoacromial artery exits as a large vessel from the axillary artery at the midportion of the clavicle and courses medial to the insertion of the pectoralis minor. It gives rise to the deltoid, acromial and clavicular branches which supply the superior integument of the anterior chest wall and to the pectoral branch which supplies the middle region of the sternocostal head of pectoralis major muscle by entering the deep surface of the upper border of the pectoralis muscle approximately at its midpoint.

The pectoral branch descends between the two pectoral muscles and gives rise to three secondary branches, lateral, medial and inferior which course in the fat on the under surface of the pectoralis major muscle in oblique-lateral, medial and caudal direction respectively [6]. Despite minor anatomic variations, the lateral branch continues its course and anastomoses with the terminal branches of the lateral thoracic artery and the medial and inferior branches anastomose with anterior intercostal branches or perforators of the internal mammary artery at about the fourth intercostal space.

The pectoral branch gives origin to a consistent number of septo-and musculocutaneous perforators that pierce the septum between the clavicular and sternocostal heads of pectoral major muscle and enter the skin. These perforators were consistently observed within a radius of 2.5 cm around the intersection of a line joining the acromion to the xiphoid process with a perpendicular line drawn from a point at the border between the lateral and the medial clavicular third (Figure 1). One main perforator was usually identified in 27 out of 30 hemi-thoraces, 2 perforators were found in two hemi-thoraces and 3 perforators in one hemi-thorax. All perforating pedicles were dissected for 3 cm intramuscularly.

Lateral thoracic artery (LTA) perforators

Lateral thoracic artery may arise from the axillary artery or from one of its branches, the subscapular or the thoracodorsal artery. It has a fasciocutaneous course passing obliquely caudally and medially to supply the skin and subcutaneous tissue of the upper lateral chest wall. The proximal 3 cm to 4 cm of the lateral thoracic artery courses deep below the lateral edge of the pectoralis major muscle, then lies on the fascia of the serratus anterior muscle before perforating this, roughly above the level of the nipple. It usually gives off branches to

the pectoralis major and then gives smaller perpendicular perforators towards the skin being the dominant supply to the lateral half of the female breast. Lateral thoracic artery was not identified in 4 out of 30 hemi-thoraces. In all these cases, branches from the thoracodorsal artery were found coursing further anteriorly instead. One large perforator was found in the 2nd, 3rd and 4th intercostal space of the remaining 26 hemi-thoraces. These three perforators (per hemithorax) were found approximately in the middle of and along a narrow vertical area between the lateral crease of the breast and the anterior axillary line. The distance from the lateral breast crease was approximately 2 cm. Average size was 1.40 mm ± 0.25 mm (Figure 4).

Discussion

The anterior thoracic wall comprises of many aesthetically significant anatomic territories and areas which complicate regional reconstructive surgery [6].

Several types of flaps have been used in the repair of local defects including pedicled, free, preexpanded, chimeric flaps but also perforator flaps based on the deep vascular system through the underlying muscles or intermuscular septa [7]. It is of paramount importance that the color, texture and all properties of the skin of the transferred flap, match with the recipient area, especially in breast reconstruction following partial or total mastectomy. Therefore, sound knowledge of the anatomic relations and distribution of suitable perforator pedicles that can support the appropriate choice of transferrable tissue, is required.

Having previously studied the anatomy of the intercostal vessels and the course and irrigation areas of the cutaneous perforators of the anterior intercostal vessels, Daniel et al. suggested the use of the intercostal musculocutaneous flap based on the corresponding neurovascular pedicle. They also reported that the intercostal neurovascular segment of the anterior intercostal vessels under the inframammary fold and anterolateral breast region is the longest and gives rise to 5-7 musculocutaneous perforators [8]. Similarly, Badran et al. described the lateral intercostal neurovascular free flap based on the same neurovascular pedicle and avoiding the use of abdominal vessels [9]. Perforator flaps based on the lateral intercostal perforator and dorsal intercostal vessels were described by Hamdi et al. while the anatomy and use of the anterior intercostal artery perforators were described by several other authors [10-14]. Perforators from the third and fourth intercostal spaces also tend to be large as they contribute to the arterial supply of the breast in females [15].

Palmer and Taylor reported comparable results with our findings regarding the single dominant IMA perforator and its diameter [16]. We found dominant IMA perforators to come from the second intercostal space in almost all our cases but any of the first 4 intercostal spaces could contain a perforator greater than 1 mm in diameter. The chest size of the subjects also affects the diameter and the dominance of the perforators with larger chests having larger perforators and a higher possibility to have the dominant perforator at a lower intercostal space or have a second dominant perforator there. Due to their size, IMA perforators can also be considered for successful anastomosis with recipient vessels during free tissue transfer for breast (post mastectomy) or soft tissue reconstruction [17]. Advantages of the IMA perforators over the IMA include the shorter dissection and preparation time, no need for costal cartilage or rib resection, preservation of the IMA for future use and easier intraoperative microscope positioning. However, it is often not possible to identify a large IMA perforator following mastectomy or

oncological excision [18].

Hefel et al. [19] suggested that direct anastomosis of a free flap recipient vessel to the IMA during breast reconstruction should be at the level of the 4th intercostal space. Conversely, according to our observations, we believe that anastomoses would more preferably take place at the level of the 2nd or 3rd intercostal space because the mean IMA diameter was consistently larger than 2 mm than in lower levels. Additionally, the presence of a dominant IMA perforator which could alternatively be used, is much more likely on these lower levels [20,21].

The anterior intercostal artery perforators were more thoroughly recognized in the 3rd and 4th intercostal space. We hypothesize that one reason for this is the larger diameter of the anterior intercostal branches in the lower intercostal spaces and the longer course of the intercostal vessels which allows more (and larger) cutaneous perforators to branch off. The anterior intercostal artery perforator flap is usually drawn below the inframammary fold according to hand-held Doppler findings and in order to use an area with adequate skin laxity [22,23].

Lateral thoracic artery perforators are sometimes difficult to identify not only due to the anatomic variations of the lateral thoracic artery but also because of their overlapping region with thoracodorsal artery perforators and lateral intercostal artery perforators [24]. They usually form the most anterior 'vertical' row of perforators next to the lateral side of the breast. Thoracodorsal artery perforators often form a parallel row, more posteriorly [24,25].

Korovessis et al. [26] found that the diameters of the left and right IMAs were 2.5 cm and 2.7 cm, respectively, in the second and third intercostal spaces in adolescent female scoliotic patients, using color Doppler ultrasonography, which were comparable to our findings.

Similarly Han et al. [27] reported an average IMA diameter of 2.1 mm by using sonography and two-dimensional CT and also found that the average diameter of the right side was larger than that of the left side, which is in agreement with our findings.

The anatomic relationship between the size and course of the lateral thoracic artery and the intercostal perforators was described and confirmed by Salmon's Law of Equilibrium [28] according to which the number of vascular pedicles for a specific anatomical area is relatively constant. Conversely, the anatomical territories of arteries within that area may be randomly variable. In our study we found that while the arterial territories varied significantly, a certain pattern of vessels was consistently present in both the skin and underlying muscle.

Key notes

1. The increased use of perforator flaps and tissue transfers based on perforator vessels has raised the need for comparative anatomic studies that further elucidate the anatomic aspects of perforator vessels. This study provides additional insight on the location and characteristics of perforator vessels of the upper breast, where successful reconstructive surgery following injury or tumor extirpation is in high demand.

2. Our findings confirm that in most cases, there is a single dominant IMA perforator in the second intercostal space, 0.8 mm to 1.9 mm in diameter. It was also shown that TCA perforators were typically found within a radius of 2.5 cm around the intersection of a line joining the acromion to the xiphoid process with a perpendicular

line drawn from a point at the border between the lateral and the medial clavicular third. Additionally, we also reported that LTA perforators were not a constant finding in 20% of the cases and that one large perforator with a mean diameter of 1.4 mm was found in the 2nd, 3rd and 4th intercostal space of the rest of the cases. All these findings are in agreement with previous studies.

3. However, we report unique diameters and distribution of perforator vessels as shown in the text which offer additional insight and improve our understanding in prospective surgical planning on the area.

Limitations of the current studies include the relatively small sample, the inability to obtain full medical and surgical history in many cases which led to their exclusion and the lack of obtaining additional findings through clinical or anatomical investigations from other centers. Another limitation is that there are additional perforators that were not included in this study because they are located outside the area under investigation.

Conclusion

The perforator pedicles supplying the upper chest half and breast area were investigated and a statistically confirmed pattern was presented.

Being able to know where and what to expect during local reconstructive surgery, greatly improves the conditions for successful free tissue transfer.

Our study demonstrates and reports average values (distances, diameters and numbers) in relation to common bony landmarks, providing an accurate plane of dissection for recipient and perforating vessel exposure. This could decrease morbidity and improve outcomes in breast and upper chest reconstruction, for surgeons especially in the initial stages of performing these operations.

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