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Posterior intercostal artery perforator flap for posterior trunk reconstruction: Perforator mapping with high-resolution ultrasound and clinical application☆

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Abstract *Background:* Pedicled perforator flaps have progressively been used for reconstructive purposes of the anterior trunk. However, reports regarding perforator flaps for local reconstruction of the posterior trunk are sparse. The aim of this study was to investigate the vascular basis of perforator flaps based on the posterior intercostal arteries and to highlight the clinical versatility of these flaps for local posterior trunk reconstruction.
Methods: The posterior intercostal artery perforators (PICAP) between the 4th and 12th intercostal space were investigated using high resolution ultrasound in ten healthy volunteers. The location, diameter, suprafascial length and course of the individual perforators was measured.

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PICAP flaps were used in a series of ten cases for defect reconstruction of the posterior trunk to demonstrate their clinical versatility.
Results: A total number of 100 perforators was investigated. The mean diameter was 0,7 ± 0,24 mm with an average length until arborisation of 0,8 ± 0,8 cm. Perforators were located at 2,4 ± 1,8 cm from the midline on average. Only 16% of all measured perforators were identified as major perforators (diameter ≥ 1 mm). In ten patients (mean age at surgery 61,7 years, f:m = 3:7) a PICAP flap was used for defect reconstruction at the back with a mean follow-up of 2,9 years. Flap dimensions ranged from 7 × 3 to 16 × 7 cm. In three cases, a complication was observed (one seroma, one hematoma, one marginal tip necrosis).
Conclusion: In the present study, a reliable vascular basis of the posterior intercostal artery perforator flap could be demonstrated. Clinically these flaps replace "like with like" and may be transposed in a propeller - or V to Y - fashion. The donor site can be closed primarily in most cases, thus resulting in a favorable donor side morbidity.

Introduction

Defect reconstruction of the trunk represents a challenging problem in reconstructive surgery. Pedicled perforator flaps have increasingly been used for reconstruction of the anterior trunk.[1,2] The internal mammary artery perforator (IMAP) flap has been recently described for coverage of defects in the ventral neck and thoracic region.[3,4] Perforator flaps based on the superior epigastric artery (SEAP flap) have been newly reported for locoregional reconstruction of the anterior lower thoracic and upper abdominal wall.[5,6] The deep inferior epigastric artery perforator (DIEAP-) flap, which represents the workhorse for reconstructive surgery especially in free flap breast reconstruction, has also been employed as a pedicled flap for defect coverage of the lower trunk and pelvis.[7] At the lateral trunk a thoracodorsal artery perforator (TDAP) or lateral intercostal artery perforator (LICAP) flap may be used.[8,9] However, elegant reconstructive options based on perforator flaps for the posterior trunk are sparsely described in the literature.

Defects of the posterior trunk may result from tumor surgery, infections, decubitus ulcers, congenital conditions or from exposed hardware after spine surgery.[10,11] Traditionally, the latissimus dorsi flap, its "reverse" variation, the trapezius myocutaneous flap or paraspinous muscle-advancement flaps have been used for reconstruction of these defects.[10] Only recently the posterior intercostal artery perforator (PICAP) flap has been described as a viable alternative to these muscle- or myocutaneus flaps.[12,13] Despite growing clinical evidence of the importance of these flaps for posterior trunk reconstruction, the vascular basis of the individual PICAP flaps has not been investigated extensively.

In plastic and reconstructive surgery high resolution ultrasound (HRUS) has been increasingly used for diagnostic purposes in peripheral nerve pathologies[14,15] and preoperative perforator identification.[16,17] This evolving imaging technique allows for detailed anatomic descriptions as well as for dynamic and in vivo visualization of delicate structures <1 mm using >15 MHz probes. Thereby HRUS has emerged as a notable alternative to computed tomography or magnetic resonance imaging techniques for many indications.[15]

The purpose of this study was to examine the vascular basis, location and size of the individual perforators deriving from the dorsal branch of the posterior intercostal arteries with HRUS, and to highlight the clinical applications of the versatile flaps based on these vessels for posterior trunk reconstruction.

Patients and methods

Ultrasound study

Ultrasound examination of the perforators of the dorsal branch of the posterior intercostal arteries was performed in 10 healthy volunteers in prone position by a single senior radiologist (T.M.) using HRUS (Epic 7G, Philips Healthcare, Best, Netherlands). The 4th to the 12th spinous process were identified and marked to define the examination area. The corresponding perforators were assessed proceeding from the upper to the lower back on both sides. A 18 Mhz probe (L18-5, Philips Healthcare, Best, Netherlands) was used for visualization of the following parameters of the individual perforators: paramedian distance, diameter, suprafascial length until arborisation and angulation of vessel course. The presence of a major perforator (diameter ≥ 1 mm) was particularly noted. Data was recorded on a datasheet and subsequently entered into a database for further analysis.

Clinical case series

In ten patients, a PICAP flap was used for defect reconstruction in the upper back region. There were seven male and three female patients with a mean age at surgery of 61,7 years (range 28-86 years). The defects were caused predominantly by tumor resections ($n = 7$), one exposed intrathecal pain pump, one after spine surgery and another from decubital ulcer. The defects were located in the midline or paravertebral region of the posterior thoracic wall (see Table 3 for details). Perforators were dissected under loupe magnification and flaps were elevated in a subfascial plane.

Table 1 PICA-Perforators – HRUS overall results.

	Perforators	Diameter (mm)	Distance to midline (cm)	Length (cm)	Angle[a] (°)
Mean	11.1 ± 2,6	0,7 ± 0,2	2,4 ± 1,8	0,8 ± 0,8	98 ± 47
Range	7-15	0,3-1,3	0,3-9,5	0,1-3,5	0-280

Data presented as mean ± standard deviation.
PICA – posterior intercostal artery.
HRUS – high resolution ultrasound.
[a] Angulation in relation to midline.

Table 2 Data of individual PICAP in relation to the intercostal space.

ICS	Total number	Diameter (mm)	Distance to midline (cm)	Length (cm)	Angle* (°)
T04	13	0,78 ± 0,29	2,8 ± 2,1	0,9 ± 1,1	108 ± 39
T05	14	0,67 ± 0,3	2,2 ± 1,6	1,1 ± 0,9	91 ± 37
T06	15	0,74 ± 0,27	2,1 ± 1,5	0,7 ± 0,8	92 ± 13
T07	9	0,74 ± 0,14	1,8 ± 1,1	1 ± 0,7	125 ± 72
T08	9	0,62 ± 0,11	2,4 ± 1,7	0,7 ± 0,4	107 ± 58
T09	11	0,75 ± 0,24	2,5 ± 2,5	1 ± 1	90 ± 37
T10	10	0,61 ± 0,21	2,3 ± 1,5	0,7	121 ± 73
T11	7	0,56 ± 0,24	2,2 ± 1,3	0,3 ± 0,3	85 ± 49
T12	12	0,77 ± 0,24	3 ± 2,6	0,6 ± 0,5	69 ± 34
Total	100	-	-	-	-

Data presented as mean ± standard deviation.
PICAP – posterior intercostal artery perforator.
ICS – intercostal space.
T – thoracic.

Results

Ultrasound findings

Ten healthy volunteers (five male and five female) with a mean age of 26,5 years and a mean body mass index of 21,5 ± 2,5 kg/m^2 were investigated. Time for ultrasound assessment averaged 56,6 ± 23,6 min. The total number of measured perforators was 100 (left to right distribution = 54:46).

The mean diameter of the assessed perforators was 0,7 ± 0,24 mm (range 0,3-1,3 mm) with an average length until arborisation of 0,8 ± 0,8 cm (range 0,1-3,5 cm). The perforators showed an average angulation of 98 ± 47° in respect to the midline, thus following the orientation of the adjacent ribs. Perforator angulation was highly variable with a range of 0°-280°.

Generally, 87% of the perforators were located in an area between 0 and 4 cm from the midline (76% in 0-3 cm). The mean location of deep fascia penetration was at a paramedian distance of 2,4 ± 1,8 cm (range 0,3-9,5 cm) lateral to the spinous processes (see Table 1). However, perforating points were encountered as lateral as 9,5 cm from the midline.

The largest mean diameters were found in the 4th, 6th, 7th, 9th and 12th ICS measuring ≥0,7 mm. Perforators from the 11th and 12th ICS seemed to be oriented in a more laterocranial direction on average (85° and 69° respectively, see Table 2 for detailed data of individual ICS). Only 16 major perforators (diameter ≥ 1 mm) were found in six of the 10 volunteers. These dominant perforators were distributed as follows: 4 × 4th ICS, 4 × 5th ICS, 3 × 6th ICS, 1 × 7th ICS, 2 × 9th ICS and 2 × 12th ICS.

Clinical outcome (see Tables 3 and 4, Figure 1)

Mean follow-up after surgery was 2,9 years (range 0,8-7,5 years). The individual flap dimensions ranged from 7 × 3 to 16 × 7 cm. All flaps except patient 06 (2 perforators) were based on one single perforator and were transposed in a propeller type fashion 90° or 180° into the defect. If the defect was located adjacent to the midline, a contralateral perforator was selected, whereas in more laterally located defects an ipsilateral perforator was chosen. In seven patients, the flaps healed uneventfully. In one patient, initial venous congestion of the flap was observed, which ultimately led to marginal tip necrosis. This was successfully managed by local excision and flap advancement. Other complications included one hematoma and one seroma at the donor site which were managed by surgical evacuation and needle aspiration respectively (Table 4). The donor sites were closed primarily in all cases using either a V-Y procedure or the short end of the propeller flap for partial donor site closure. At follow-up no further complications were encountered.

Discussion

Traditionally the trapezius musculocutaneous flap and the latissimus dorsi muscle flap – either on its dominant thoracodorsal pedicle or in it is "reversed" version based

Table 3 Synopsis of patient data.

Patient	Age	Sex	Follow-up[a]	Location	Cause of defect
01	28	f	90	T11/L	Exposed intrathecal pain pump
02	30	m	57	T2/M	Myofibroblastic sarcoma
03	40	f	54	T5/R	Dermatofibrosarcoma protuberans
04	75	f	34	T4/M	Dermatofibrosarcoma protuberans
05	73	m	34	T7/R	Ulcerated basal-cell carcinoma
06	86	m	24	T12/L	Ulcerated squamous cell carcinoma
07	73	m	19	T4/M	Basal-cell carcinoma
08	81	m	19	T8/M	Spine surgery
09	55	m	13	T10/L	Cutaneous metastasis
10	76	m	9	T10/L	Decubital ulcer
Mean	61.7	-	35.3	-	-

T - thoracic.
L - left.
R - right.
M - midline.
[a] In months.

Table 4 Surgical procedures and outcomes.

Patient	Side of perforator	Flap	Flap dimensions	Type of transposition	Complications
01	Right	PICAP	7 × 3 cm	Propeller 90°	None
02	Left	PICAP	8 × 5 cm	Propeller 90°	None
03	Left	PICAP	12 × 7 cm	Propeller 180°	None
04	Left	PICAP	13 × 7 cm	Propeller 180°	None
05	Right	PICAP	13 × 5 cm	Propeller 180°	Tip necrosis
06	Left	PICAP	16 × 7 cm	Propeller 90°	Seroma
07	Left	PICAP	14 × 6 cm	Propeller 180°	None
08	Right	PICAP	5 × 3 cm	V to Y	Hematoma
09	Right	PICAP	8 × 6 cm	V to Y	None
10	Left	PICAP	10 × 8 cm	Propeller 90°	None

PICAP - posterior intercostal artery perforator.

on segmental intercostal perforators - have been the workhorse flaps for posterior trunk reconstruction.[10] Especially the posterior cervical-, upper- and mid thoracic regions are comfortably within reach of these flaps. Fasciocutaneous flaps, and in particular perforator flaps based on discrete perforating vessels, have only recently been described as a viable alternative for defects in these anatomic locations.[12,13,18] In the lumbar region, most likely due to the lack of viable alternatives, the lumbar artery perforator flap has already emerged as the flap of first choice for local defect coverage in recent literature.[10,19,20]

During the elevation of a perforator flap the deep underlying structures such as the underlying muscles will remain intact, thus minimizing donor site morbidity. This directly results in preserved muscle function and mobility. Furthermore, the preserved muscle may serve as a back up option in case of defect recurrence (i.e. in case of pressure sores or tumors) or flap failure.[10,11] Furthermore, the PICAP flap may be raised as a sensate flap to provide protective sensation to the area of reconstruction, if during dissection of the pedicle an accompanying segmental nerve is identified and preserved.[21]

The blood supply of the upper back has been studied by Geddes et al.[22] The individual perforasomes are based on the thyrocervical trunk superiorly, on the subscapular system laterally and on the posterior intercostal arteries medially. The posterior intercostal arteries branch of the thoracic aorta and travel below the fourth to twelfth rib ultimately communicating with the anterior intercostal arteries. Their course may be divided into four segments (vertebral, intercostal, intermuscular and rectal segments).[18] The first - vertebral - segment gives rise to the dorsal branch which passes the paraspinous muscles as a medial and lateral branch that emerge in a paravertebral region to supply the overlying skin.[22,24]

The potential of flaps based on the intercostal vessels for trunk reconstruction had already been recognized in the late 70s by Daniel and Kerrigan.[23,25] However, perforator flaps based on the dorsal branches of the posterior intercostal artery have only recently been described as a valuable alternative to traditionally employed muscle flaps.[12,13,18] In 2015, Zang et al. described the potential of flaps based on perforators of the intercostal artery as a favorable option in reconstruction of the trunk.[26]

Despite their clinical usefulness, the detailed anatomic basis of these flaps is still an area of ongoing research. In an anatomical dissection of 2 lead oxide-gelatin injected specimen Minabe and Harii noted diameters of the dorsal intercostal artery perforators at the level of the deep fascia "in the range of 0.5 to 1 mm".[12] This is consistent with

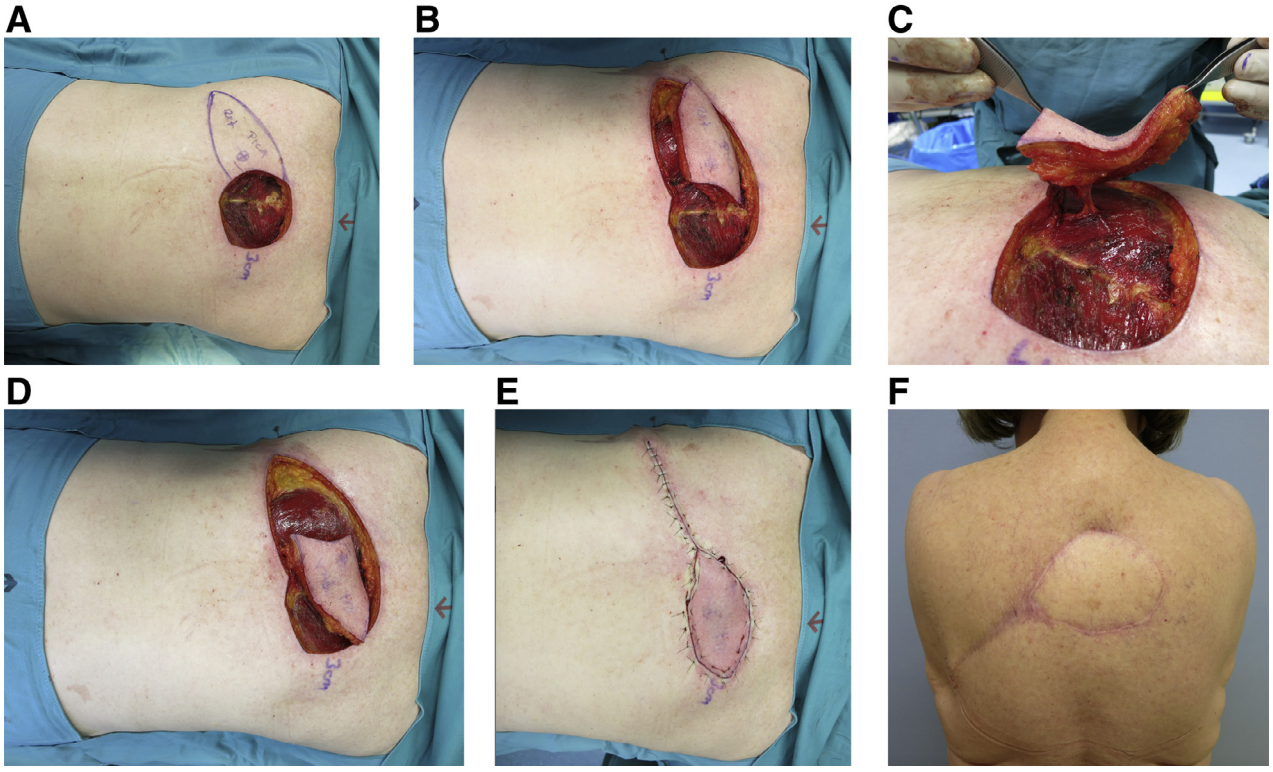

Figure 1 A–F Case 04: A 75 years old lady required full thickness removal of a dermatofibrosarcoma protuberans slightly lateral to midline at T4 exposing the spinous processus. A left 13 × 7 cm PICAP flap was elevated on a single pedicle and deflected 180° into the defect. The patient is shown intraoperatively and at follow-up six months after the procedure.

the present study demonstrating the mean diameter to be 0,7 ± 0,24 mm at the level of the deep fascia. The largest perforator diameters in our study were encountered for the 4,6,7,9,12th PICA perforator measuring ≥ 0,7 mm on average with dominant perforators located in the 4–6th intercostal space. This corroborates the findings of Ogawa et al. who described the dominant PICA perforators to be predominantly located in the 6th and 7th intercostal space without commenting on their exact diameters.[27]

Our study demonstrated that 87% of the measured PICA perforators were located in an area 0–4 cm from the midline. Specifically, the perforators penetrated the deep fascia at a mean paramedian distance of 2,4 ± 1,8 cm lateral to the spinous processes (see Tables 1 and 2). However, perforating points were encountered as lateral as 9,5 cm from the midline. Hence, if clinically during dissection no or just insufficient medial perforators of the dorsal branch are identified, further dissection more laterally may finally locate a suitable lateral perforator of the dorsal PICA branch. Generally, because of the great variability in perforator distribution and size, we recommend preoperative perforator mapping with HRUS to select the most appropriate perforator adjacent to the defect. If the defect is located at the lower back or thoracolumbar junction, flaps should be preferably based on the 12th or subcostal perforator as the adjacent 10th and 11th PICAP were rather small in diameter.

In the present study the suprafascial length of the PICA perforators until arborisation was relatively short being only 0,8 mm on average (see Tables 1 and 2). Minabe et al. measured the subfascial lengths of the perforators as being 1 to 3 cm in upper and 4–10 cm in lower dorsal intercostal artery perforators flaps.[12] Thus, overall pedicle length and transposition distance of a PICAP-flap might be considerably enlarged by further subfascial dissection of the pedicle, which may be of importance especially if a V to Y - flap design is used. On the other hand, extensive dissection of the short suprafascial vascular pedicle might result in unwanted damage of the subcutaneous branches of the perforator. In our series, all flaps were dissected in a subfascial plane and used in an either 90° or 180° propeller or V-Y fashion (see Figure 1). A part of the propeller flap was used for closure of the donor site. The remaining donor site was closed primarily in all cases, which may be comfortably achieved up to 8 cm. However primary closures after elevation of flaps up to 40 × 15 cm have been reported.[28]

The angulation of perforators pointed in a moderate laterocaudal direction, thus roughly following the adjacent ribs (see Tables 1 and 2). For the course of the 11th and 12th PICAPs a slight upward angulation was noted (see Table 2). This is somewhat in contrast to the findings of Minabe et al., who found the lower intercostal arteries to have more vertical axiality than the upper perforators.[12] However, those angulations were measured subfascially vs. suprafascially in our study. Additionally, the exact determination of the suprafascial angulation of a very short vessel with high resolution ultrasound is challenging which represents a limitation to our findings.

In a preliminary study, the authors failed to sufficiently visualize and measure PICAPs employing multidetector row computed tomography (MDCT) in patients undergoing

angiography of the thoracic aorta for other reasons. This may be attributed either to vessel compression in supine position, small vessel size or technical limitations. Furthermore, MDCT carries the risk of radiation exposure as well as the use of contrast medium, which makes HRUS an especially attractive option for preoperative assessment. In anatomical specimens results may also be deviated by tissue compression due to storage in supine position and an arduous dissection and measurement of the small vessel caliber.

HRUS has previously been described an effective tool for the various applications in plastic surgery including peripheral nerve pathologies and perforator mapping with high anatomical correlation.[13-16] This non-invasive imaging technique allows for detailed anatomical evaluations as well as for dynamic and in vivo visualization of delicate soft tissue structures using 18 MHz probes without the need of additional contrast agent application. Therefore, HRUS was chosen for evaluation of the perforators in the present report enabling assessment in vivo.

In our clinical series, a contralateral perforator was preferred, if the defect was located adjacent to the midline, whereas in more laterally located defects an ipsilateral perforator was selected. According to Zang et al. the design of the PICAP propeller flap may be modified using the flap not only in an horizontal orientation but also in an oblique and vertical direction.[26] In one patient with the defect situated more laterally at T7 (Case 05), an ipsilateral perforator was identified for flap perfusion. However, due to the location and configuration of the defect, the flap was designed over the midline to the contralateral side. In this case, initial venous congestion led to marginal tip necrosis, which was ultimately managed by local excision and flap advancement. This may be attributed to the flap design traversing the midline, which could represent a watershed area between left and right PICAP perforasomes, a phenomenon previously described for perforasomes of the anterior trunk.[4] Therefore, we recommend avoiding extension of PICAP flap design beyond the midline. Furthermore, minor complications such as hematoma and seroma occurred once each in our patient group (see Table 4), which is comparable to other lumbar artery perforator flaps performed studies.[13,18,26]

Conclusion

This study provides a detailed in vivo analysis of the vascular basis of the posterior intercostal artery perforators using high resolution ultrasound. The corresponding flaps represent an excellent clinical choice for soft tissue reconstruction of the back. It replaces “like with like” sparing the underlying musculature with favorable outcomes. Consequently, the posterior intercostal artery perforator flap has become the flap of first choice for reconstruction of suitable defects in the back at our institution.

Conflict of interest

None of the authors has a financial interest in any of the products, devices, or drugs mentioned in this manuscript.

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