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A cadaveric study on abdominal wall perforators from the deep inferior epigastric artery: application to flap surgery

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SUMMARY

The deep inferior epigastric perforator (DIEP) flap is based on the perforator arteries of the deep inferior epigastric artery. The rectus abdominis muscle provides an excellent myocutaneous flap, either pedicled or free, because of the rich vascularity provided by the epigastric vessels and separation of muscle belly from the surrounding tissue within the rectus sheath. The study was conducted on 30 adult cadavers. The length and width of the rectus abdominis muscle and length, direction, muscular branches of the perforator, branching pattern and termination of the inferior epigastric artery were observed. The diameter of inferior epigastric artery at the point of origin was between 2.1 and 3.5 mm. The artery dividing into two major branches was seen in 11 cases, the lateral branch being dominant in 3 cases, the medial branch in 3, both branches having equal caliber in 5 cases and in 19 cases there was one central axis with multiple side branches. The total number of perforators was 243. In 101 cases diameters were between 0.5 mm and 1.0 mm, and 139 cases exceeded 1.0 mm. The average running distance was 7.20 mm. Fifty-one percent perforators were present above the level of the umbilicus and 49% below. On each side 43% ideal perforators were present. A majority of ideal perforators (72%) was concentrated 4 cm superiorly, 7 cm inferiorly and 5 cm laterally to the umbilicus. Our data indicate that 43% of all perforators with diameters over 1 mm are ideal perforators, and most that are located about a 5 cm radius around the umbilicus can easily be dissected.

Key words: Deep inferior epigastric perforator (DIEP) flap – Inferior epigastric artery – Rectus sheath

INTRODUCTION

Perforator or fasciocutaneous flaps of the deep inferior epigastric artery (DIEA) are routinely used in reconstructive surgeries for defects of the upper and lower extremities, head and neck, breast and genital organs. Abdominal flaps have been the first option for breast reconstruction, because their texture is similar to that of the natural breast.

The Italian surgeon Tanzini (1906), the first to use a musculocutaneous flap for breast reconstruction, developed a pedicled flap of skin and underlying latissimus dorsi muscle, which he transferred to the mastectomy site. However, the DIEA

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perforator (DIEP) flap has come to be preferred for reconstructive procedures, owing to its minimal donor site morbidity. The rectus abdominis muscle provides an excellent myocutaneous flap, either pedicled or free, because of the excellent vascularity provided by the epigastric vessels, and because the muscle belly is separated from the surrounding tissue within the rectus sheath. The upper half of the muscle can be used for breast reconstruction or augmentation of lost tissue in the anterior thorax. The lower half can be used in the thigh region, and can be rotated on its lower attachments, passed through the pelvis and delivered into the perineum for reconstruction after radical pelvic and perineal resections (Standring, 2009). The tendinous rectus sheath is formed from the aponeuroses of three anterolateral abdominal muscles: the external oblique abdominis, the internal oblique abdominis and the transversus abdominis. It has anterior and posterior walls that enclose the rectus abdominis muscle and its neurovascular bundle.

The transverse rectus abdominis musculocutaneous (TRAM) flap is a technique for breast reconstruction described almost 30 years ago by Holmstrom (1979) as a free flap. It was later popularized by Hartrampf (1982), who independently conceived of its use as an abdominal island flap for breast reconstruction. Parts of this muscle were harvested, because it was generally considered that the deep inferior (free TRAM) and superior (pedicled TRAM) epigastric vessels and their paraumbilical perforating branches, which run through the muscle and supply the overlying lower abdominal skin and subcutaneous fat, could not be isolated.

The inferior epigastric artery arises from the external iliac artery, curves forward and then ascends obliquely along the medial margin of the deep inguinal ring, pierces the fascia transversalis and posterior rectus sheath, and finally ascends between the rectus abdominis and the posterior lamina of the sheath. It divides into numerous branches, which anastomose above the umbilicus with the superior epigastric branch of the internal thoracic artery and with the lower six posterior intercostal arteries. The inferior epigastric may arise from the external iliac at a higher point than usual; it has been found 6 cm above the inguinal ligament. It may arise from the femoral artery below the inguinal ligament or from the profundus femoris artery, or as a common trunk with the circumflex iliac. The inferior epigastric may be doubled (Bergman, 1988). The inferior epigastric artery is larger in caliber than the superior epigastric. However, the DIEA can vary markedly in location, branching pattern, intramuscular course and number of perforators, even between the two sides of the same individual. Hence it is important to plan the location, course and caliber of suitable perforators preoperatively.

In the Free TRAM flap technique, a muscle-sparing flap removes a small, central segment of the rectus muscle and fascia from the lower abdomen. The circulation is based on the inferior epigastric vessels. The flap is transferred to the chest. Microvascular anastomoses are completed end to end with the thoracodorsal or internal thoracic arteries. The flap is inset at the mastectomy defect (Thorne et al., 2007).

The pedicled or free transverse rectus abdominis myocutaneous (TRAM) flap has the esthetic appearance of the donor area and is superior to other flaps; its main disadvantage remains the sacrifice of smaller (free TRAM) or larger (pedicled TRAM) parts of the rectus abdominis muscle.

In deep inferior epigastric perforator (DIEP) flaps, the skin and fat are removed from the lower abdomen and transferred to the chest to reconstruct a breast after mastectomy, with no sacrifice of abdominal muscles. The free deep inferior epigastric perforator (DIEP) flap is the first of a new generation of arterialized skin flaps called ‘perforator’ flaps. Koshima and Soeda (1992) were the first to describe the ‘inferior epigastric artery skin flap without rectus abdominis muscle’. Three years later, Koshima et al. renamed the same flaps ‘free thin paraumbilical perforator-based flaps’. These flaps were small, and were used to reconstruct soft tissue defects other than breasts.

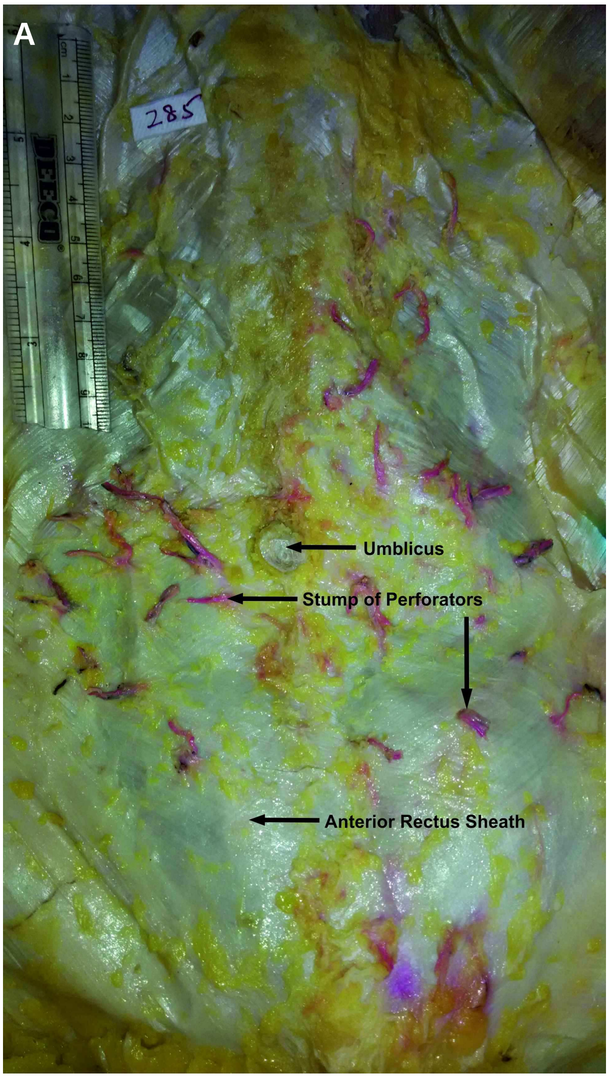
There are more blood vessels in the deep layer of fat, but the largest lie in the superficial fat. The mid layer of fat has the fewest vessels, the smallest vessel diameters, and the least total vascular area. Thus, excising the intermediate and deep layers of fat from the TRAM flap prevents fat necrosis without compromising the vascularity of the superficial fat or skin of the flap (El-Mrakby, 2003).

Basic anatomical knowledge of the distribution of perforator patterns, and of the area most likely to yield perforators suitable for surgery, could help the surgeon to select an ideal flap. Therefore, the present study was conducted to describe the distribution pattern (course of the deep inferior epigastric artery) and size of its perforators.

MATERIALS AND METHODS

The study was conducted on 30 sides of adult cadavers (8 males, 7 female) with an average age of 77 years at death, available in the Department of Anatomy, PGIMER, Chandigarh. Cadavers with gross abdominal anomalies, history of abdominal surgery or presence of abdominal scars were excluded.

The abdominal wall was reflected down by making a transverse incision from the xiphisternum up to the midclavicular line bilaterally, and then carrying it vertically downward to the iliac crest. The inferior epigastric artery was dissected near its origin from the external iliac. Colored latex was injected into it and left for 24 h to solidify. The length (xiphisternum to pubic crest) and width (at



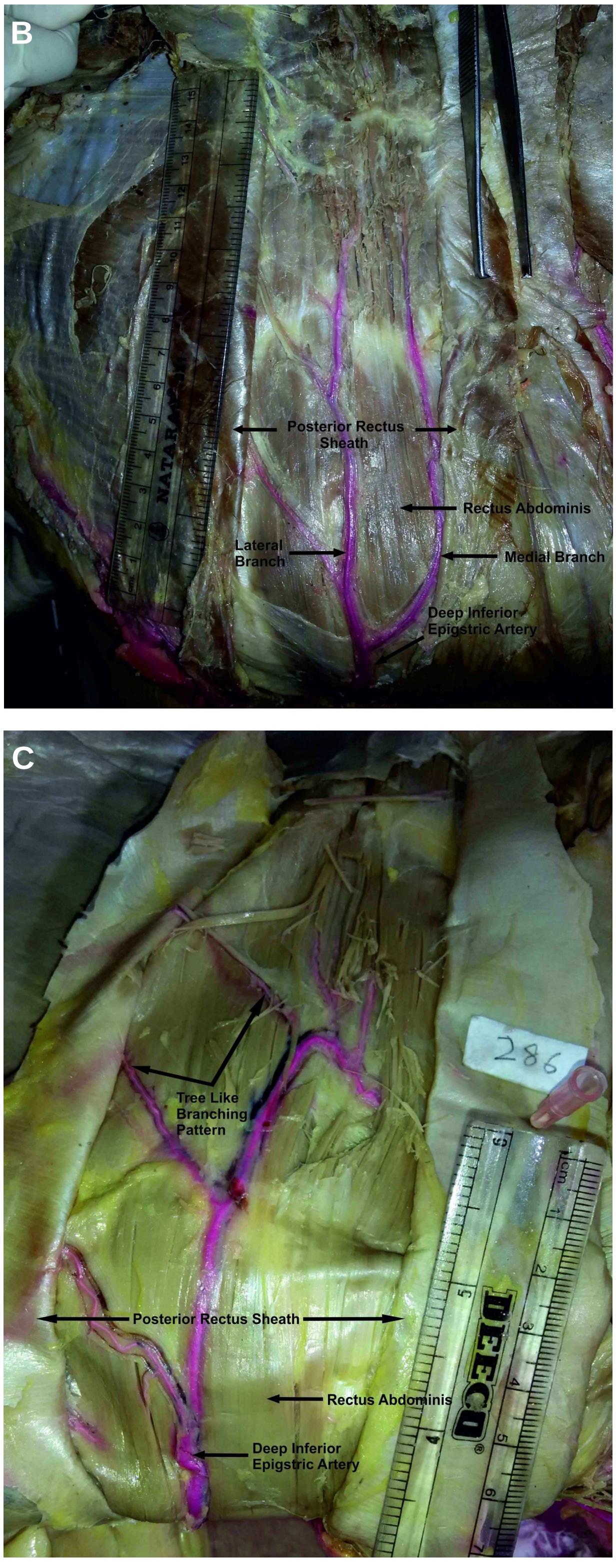


Fig. 1. **(A)** Stumps of the perforators piercing through the anterior rectus sheath. **(B)** A type 2 (bifurcation into medial and lateral divisions having equal caliber) inferior epigastric artery. **(C)** A type 1 (single main trunk with tree like branching) inferior epigastric artery.

the level of the umbilicus) of the rectus abdominis muscle was noted bilaterally.

Careful dissection in the subcutaneous plane was conducted to identify the perforators leaving the rectus sheath. Each perforator was cut carefully, flush with the skin, and reflected to expose the rectus sheath and the stumps of perforators coming out of it (Fig. 1A). A transparent sheet with a 1 cm square grid was placed on the rectus sheath and the umbilicus and pubic crest were marked on it. The location of each perforator according to its size was drawn on the sheet bilaterally. The external diameter of each perforator was noted.

Anteriorly, the rectus sheath was excised laterally and the following features were noted:

1. Running distance (i.e. length of perforator between muscle and rectus sheath).
2. Direction.
3. Whether the perforator gave muscular branches while passing through the muscle.

The posterior rectus sheath was dissected to note the branching pattern and termination of the inferior epigastric artery.

RESULTS

In all 30 sides in our study, the DIEA originated from the external iliac artery above the inguinal ligament, curved forward in the extraperitoneal tissue, and then ascended obliquely along the medial margin of the deep inguinal ring. In its upward course it pierced the fascia transversalis giving 2-3 peritoneal branches, then ascended between the rectus abdominis and the posterior rectus sheath. The external diameter at the point of origin was between 2.1 and 3.5 mm. The pattern of the artery was symmetrical on both sides in 10% cases. In these cases the artery penetrated the muscle immediately. In the remaining cases it entered the muscle near the umbilicus or just below it.

In the literature (Blondeel, 1999), the course of the artery is described as a main trunk dividing into two major branches, medial and lateral, which divide further and end by anastomosing with terminal branches of the superior epigastric artery. In our study, this pattern was seen in 11 cases (37%), the lateral branch being dominant in three cases, the medial branch in three, and both branches having equal caliber in five (Fig. 1B). In the remaining 19 cases (63%) there was one central axis with multiple side branches (Fig. 1C). The artery finally divided into numerous branches, which anastomosed above the umbilicus with the superior epigastric and the lower intercostal arteries.

DIAMETER: Among 30 sides of rectus sheath we found 243 perforators, three of which had diameters less than 0.5 mm, 101 had diameters between 0.5 mm and 1.0 mm, and 139 exceeded 1.0 mm.

LENGTH: After piercing the rectus abdominis muscle, the perforators travelled for some distance before piercing the rectus sheath. The average running distance was 7.20 mm (1.3 – 26.61 mm). As the rectus sheath adhered to the intermuscular septa, the perforators passing through it had no muscular branches and followed a vertical course. The running distance could not be measured in these cases. Some perforators went around the edge of the rectus abdominis, not through the muscle itself.

The perforators followed various directions between piercing the RA and RS based on quadrant: 120 were directed superiorly (36 vertically upwards, 47 superiomedially, 32 superiolaterally, 32 inferiorly (16 vertically downwards, 10 inferiomedially, six inferiolaterally), 25 medially and 18 laterally. Forty-nine passed through the intermuscular septa and followed a vertical course.

DISTRIBUTION: In total, 124 perforators (51%) were present above the level of the umbilicus and 120 (49%) below (Fig. 2A).

On studying the distribution pattern of all the perforators, we found that 69% were concentrated 5 cm superiorly, 7 cm inferiorly and 5 cm laterally to the umbilicus. On further analysis we found the following:

Perforators with diameters more than 1 mm: 54% were present supraumblically and 47% infraumblically.

Perforators with diameter between 0.5 mm and 1 mm: 51% were present supraumblically and 49% infraumblically.

Perforators suitable for surgery (Kikuchi et al., 2001): Perforators without muscular branches and diameters exceeding 0.5 mm were deemed suitable for surgery; 176 were found overall, averaging six per side.

Ideal perforators (Kikuchi et al., 2001): (Fig. 2B):

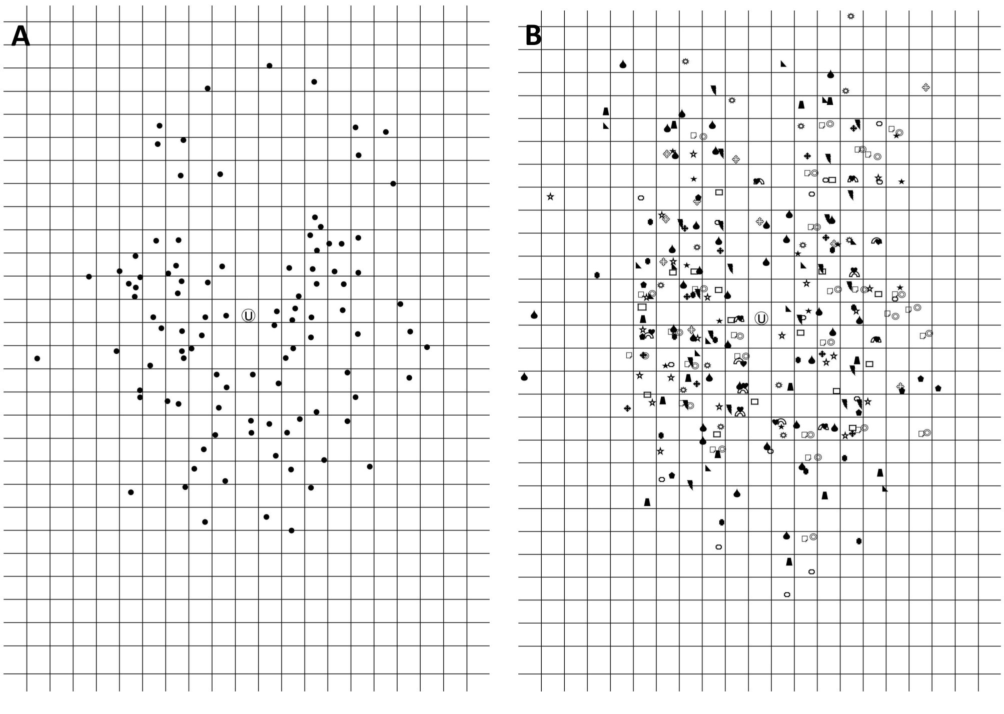


Fig. 2. (A) Grid (1 x 1 cm) with all 244 perforators marked with every case represented with different symbol. **(B)** Grid (1 x 1 cm) showing distribution of ideal perforators with U representing umbilicus.

Perforators with diameters more than 1 mm and no muscular branches were deemed ideal perforators. They totaled 105: 23 in the right upper quadrant, 26 in the right lower, 31 in the left upper and 25 in the left lower. They were most concentrated 4 cm superiorly, 7 cm inferiorly and 5 cm laterally to the umbilicus. On average, 43% (4) ideal perforators were found per side.

It is very difficult to specify the exact area supplied by a particular perforator on a cadaver, because of vessel patency and the limitations of macroscopic dissection. In a few cases, we were able to trace the course of a larger perforator up to the dermis (Fig. 3); the field it supplied was marked on the grid and the area was calculated. Such perforators could travel up to 7-10 cm underneath the dermis and supply an average area of 8 cm^2.

DISCUSSION

The deep inferior epigastric perforator (DIEP) flap is based on the perforator arteries of the deep inferior epigastric artery. There is less abdominal wall morbidity such as laxity or hernia, because the rectus abdominis muscle is not harvested.

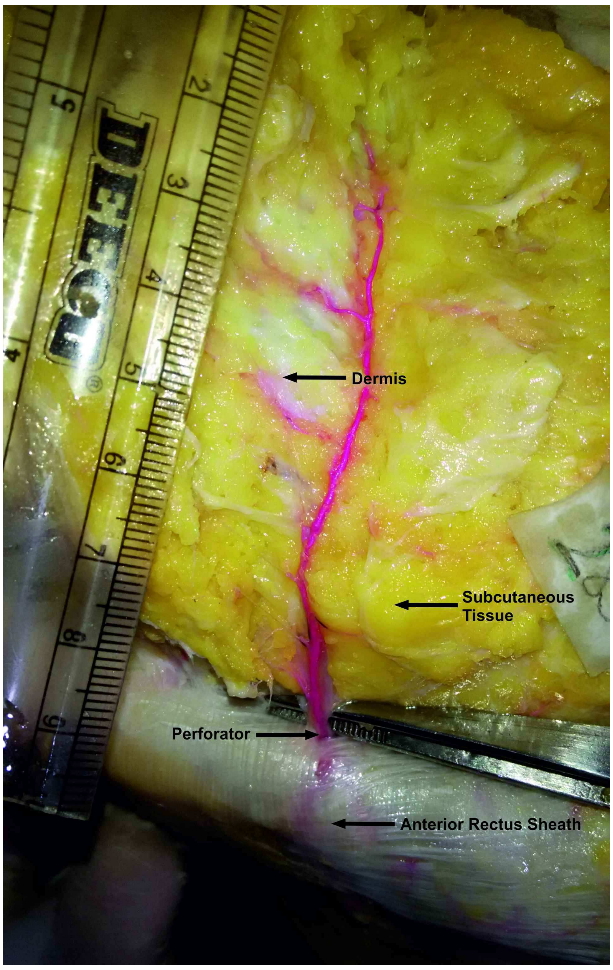


Fig. 3. The perforator coming out of the rectus sheath, piercing the subcutaneous tissue and then traveling on the dermis supplying it.

Garvey et al. reported earlier recovery and less abdominal pain than with TRAM flap reconstructions (Garvey et al., 2006). Previously (Kroll, 2000) it was thought that the risk of fat necrosis was higher than with the TRAM procedure, but recent studies contradict this (Ramon et al., 1997). Patient selection depends upon patient weight, abdominal fat, breast volume, and the location and dimension of perforators (Nahabedian et al, 2002). Most plastic surgeons now prefer DIEP flaps for selected patients.

The inferior epigastric artery has been used as an alternative conduit in coronary artery bypass graft surgery, and as a source of microvascular grafts to replace injured or diseased arterial segments.

In the present study, the average diameter of the DIEA at its origin was 2.79 mm, similar to the findings of Colohan et al. (3.2 mm) (2012). The average diameters are fairly constant from the origin to the point of bifurcation. A larger-caliber trunk provides a more favorable pedicle. It can be used as a source of microvascular grafts because of size matches, improved handling characteristics, and superior patency rates (Rockwell et al., 2007).

We injected colored latex to define the vascular anatomy of the DIEA. Cadaveric studies cannot mimic actual vascular conditions such as nervous, hormonal and local factors, but they can provide useful information about anatomical details and variations, which can be clinically significant (Wong et al., 2010).

Moon and Taylor (1988) distinguished three main types of the DIEA. Types I (single DIEA) and II (bifurcation into two branches) are more frequent than type III (division into more than two branches). Types I and II have perforators with shorter intramuscular segments. The lateral branches in types II and III cannot be dissected because of the risk of muscle denervation. Kikuchi et al. distinguished six patterns of the DIEA, depending on level of division and whether the medial or lateral branch anastomosed with the superior epigastric artery.

We observed the maximum incidence of a single main trunk with multiple small tree-like branches (Type 1) in 63% of cases, in contrast to Moon and Taylor (1988) who observed the type I pattern in 29%, but in agreement with Molina et al. (56%) (2012). We observed no trifurcations. In 10%, the DIEA became intramuscular as it entered the rectus sheath. Any intramuscular course makes dissection more difficult (Fig. 4). In all cases the DIEA formed anastomoses with the superior epigastric artery, in agreement with a previous study (Kikuchi et al., 2001), though some authors disagree (Rockwell et al., 2007; Itoh and Arai, 1993; Milloy et al 1960).

There are conflicting views about the diameters of perforators, some authors classifying perforators with diameters greater than 0.5 mm as large (El-

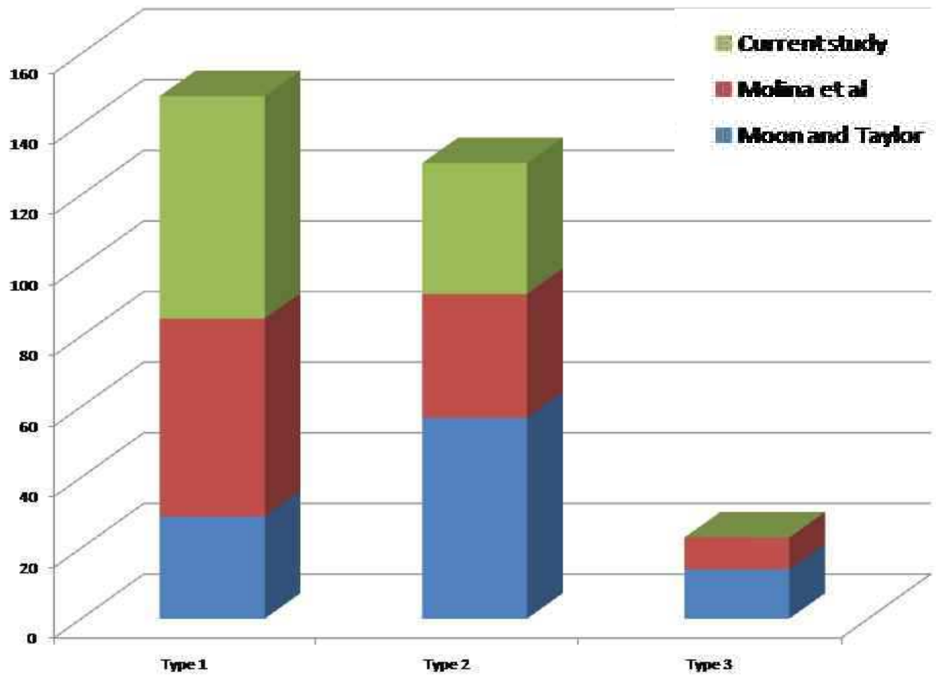


Fig. 4. Comparison of branching pattern of DIEA with previous studies.

Mrakby et al., 2002; Itoh et al., 1993, Ohjimi et al., 2002), others taking 1 mm as the threshold for 'large' (Heitmannet al., 2000; Rozen, 2007), still others using 1.5 mm as the threshold (Munhoz et al., 2004; Rozen et al., 2008). The larger the diameter of the perforator, the less the chance of necrosis of the flap, because vascularization is better (Rozen et al., 2008).

Kikuchi et al. (2001) classified perforators with diameters over 1.0 mm as 'large', those with courses parallel to the muscle with no large muscular branches as 'suitable', and those with both characteristics as 'ideal'. In the present study there were on average eight perforators on each side, five of them being large (>1 mm) and four ideal. In two cases there were no large perforators. Mirela et al. (2012) found 141 ideal perforators (average 7) in 20 infraumblical specimens, compared to four in the present study.

Ideal perforators were more concentrated and evenly distributed in the area defined as 4 cm superior and 5 cm lateral to the umbilicus. Inferiorly they were evenly distributed up to 7 cm inferior to the umbilicus. This area contained 72% (31% in the supraumblical region and 41% in the infraumblical) of the ideal perforators. We found that 43% of all perforators were ideal and 72% were suitable, in contrast to a previous study (10.6% and 21.9%, respectively) (Kikuchi et al., 2001).

Some perforators that penetrate the musculotendinous intersection have no intramuscular segment, so they require less dissection. In the present study, 20% of perforators passed through the musculotendinous intersection. Oblique intramuscular segments require more dissection of the muscle and can cause muscle weakness.

Radiologically, the subfascial segment can be confused with the subcutaneous segment. A longer subfascial segment or running distance requires careful dissection of the rectus sheath to avoid injury to the perforator. In the current study the average running distance was 7.20 mm, in accordance with the average of 6.5 mm reported by Kikuchi et al. (2001). Most perforators (47%) have subfascial segment lengths between 5 and 10 mm (Fig 5).

In the current study, only 15% of the perforators in the infraumblical region were directed downwards; in contrast, Kikuchi et al. (2001) found most of the perforators in the infraumblical region followed a downward course. In the supraumblical region 40% of the perforators had a superior course, whereas Kikuchi et al. (2001) observed that most perforators followed an upright course. They mentioned no perforators with horizontal courses; in our study, 18% followed a horizontal course.

Mrakbyand Milner (2003) found most blood vessels in the deep layer of fat but the largest ones in the superficial fat; the mid fat layer had the fewest and smallest blood vessels. The authors explained the bimodal distribution of blood vessels: the subdermal plexus supplies the superficial fat via large direct perforators, while the deep subcutaneous vascular plexus supplies the deep fat via small, indirect perforators. Thus, excising the intermediate and deep layers of fat for the TRAM flap could avoid fat necrosis without compromising the blood supply to the superficial fat or skin. The differences in observations among authors could be attributed

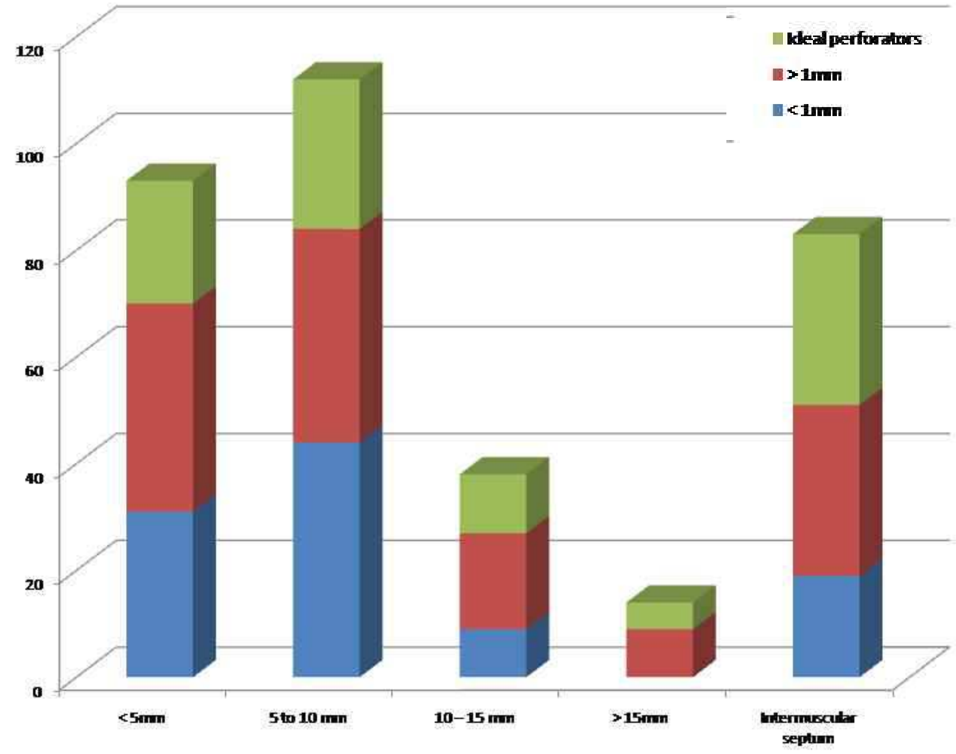


Fig. 5. Graph showing running length and diameter of perforators.

to different techniques (injection and gross) and atherosclerotic changes.

We inferred from our data that 43% of all perforators with diameters over 1 mm are ideal perforators, and most are located about a 5 cm radius around the umbilicus. The lowest part of the muscle near the pubis contains few perforators. A 1-1.5 cm strip lateral to the umbilicus contains a very few large perforators, but when present these are easy to dissect because of their short intramuscular course. One of the tendinous intersections of the rectus abdominis is level with or just below the umbilicus; the rectus sheath is attached to it here and large perforators were seen leaving it. These had no muscular branches and could easily be dissected.

During DIEP, a Doppler or color Duplex scan is the preoperative choice of investigation to identify the perforator with the best position, course and caliber. Some studies (Blondeel et al., 1999; Giunta et al., 2000) suggest that owing to different amounts of fat and skin tension, Doppler can be misleading. Direct intraoperative observation of the perforators can be very delicate and even dangerous if excessive tension is placed on them. An individualized approach is therefore necessary, and our cadaveric data could provide a baseline for it.

Further studies of the perforators in cadavers and preoperative investigations are needed to improve knowledge for vascular microsurgery and reduce the chances of postoperative complications such as flap necrosis.

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