Classification of Deep Inferior Epigastric Perforator Courses Based on Computed Tomography Angiography: Incidences and Clinical Implications

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Purpose: Preoperative surgical planning utilizing computed tomography angiography (CTA) has now become a routine in many practices. We analyzed the course of the deep inferior epigastric artery (DIEA) and its perforators (DIEP) that would either facilitate or hinder flap dissection based on CTA to aid surgical planning.

Methods: The 115 consecutive patients who underwent abdominally based free flap breast reconstruction were enrolled in this prospective study. DIEA/P courses were categorized mainly according to their intramuscular courses and their incidences were investigated.

Results: A total of 425 perforators were identified preoperatively on the CTA, with an average number of 3.7 distinctly visualized in the entire flap territory. Eighty-nine perforators (20.9%) had a favorable (less than 1 cm intramuscular course) pattern, namely long submuscular (34.8% of the patients), long subfascial (15.6%), and total circummuscular (13.9%). Overall 56.5% of the patients had at least one favorable DIEA/P. On the other hand, absence of DIEA and absence of adequate (>1 mm) DIEP was reported in 3 and 8 hemiabdomen.

Conclusion: Preoperative CTA evaluation of DIEA/P can be used to identify favorable as well as unfavorable courses for dissection to aid surgical planning.

Key Words: Breast reconstruction, Perforator flaps, Computed tomography angiography
INTRODUCTION

With the advances in the knowledge and technique of the autologous breast reconstruction, maximum safety as well as surgical efficiency is an important issue nowadays\textsuperscript{1-2}. At present, various imaging modalities are utilized to plan and facilitate the selection and dissection of perforators\textsuperscript{3-5}. While the deep inferior epigastric artery (DIEA) is known as anatomically consistent, its perforator (DIEP) varies widely between individuals and sides of the abdomen. Specific anatomic variations have been anecdotally reported, and some variation could affect the difficulty or safety of the operation if unrecognized\textsuperscript{6-10}.

Preoperative evaluation using computed tomography angiography (CTA) can reveal variants that might affect surgical planning, thereby either encouraging or discouraging perforator dissection. We categorized some patterns of DIEA/P that would either facilitate or hinder dissection, and analyzed their incidences. We also provided detailed information about the CTA protocol used in our institution including multiplanar reconstruction (MPR) imaging and maximum intensity projection (MIP) imaging reconstruction, and delineated their usage.

MATERIALS AND METHODS

The following protocol was approved by the Institutional Review Board of Asan Medical Center (IRB No. 2017-1033). All patients who underwent immediate autologous-only breast reconstruction using abdominally based free flap between January 2011 and December 2012 were enrolled in this prospective study. CTA was performed 2 or 3 weeks prior to the surgery unless it was contraindicated for medical reasons or refused by the patient.

1. CT protocols

All included patients were preoperatively imaged using a 64-multidetector computed tomography (CT) scanner (Somatom Definition 64; Siemens Medical Solutions, Erlangen, Germany) using the following settings: 120 kVp, effective 200 mAs, 0.5 second gantry rotation time, 512×512 matrix, 3 mm slice thickness, 3 mm slice interval on MPR imaging, 20 mm slice thickness, and 5 mm slice interval on MIP imaging. Intravenous nonionic contrast agent (100 mL of 400 mg iodine/mL iomeprol: Iomeron®; Bracco, Milan, Italy) was injected at a rate of 4 mL/second. The bolus was tracked through the descending aorta starting at the DIEA. Monitoring was started after a 10 seconds delay, and 1 image was taken every 1.25 seconds. If a threshold of 150 Hounsfield units was reached at the descending aorta, CT was performed after another 10 seconds delay. This delay allowed the distal filling of the peripheral small arteries. The raw data were reconstructed in the axial plane at a 0.75 mm slice thickness and 0.4 mm intervals using standard kernels. The reconstructed images were processed at the workstation (PetaVision for Clinics 2; Asan Medical Center, Seoul, Korea).

2. Perforator identification

This anatomic study was mainly based on the 2-dimensional craniocaudal axial images that were scanned in sequence. Perforators that were distinctly visualized (measured diameter ≥1 mm) on the MPR protocol image were considered as adequate. Perforating vessels piercing the anterior sheath of rectus abdominis muscle from the level of upper margin of the umbilicus to thirty slices (9 cm) below were identified and traced proximally to the point where the main DIEA emerged from the external iliac artery, approximately at the level of the inguinal ligament.

3. Perforator course classification

Intramuscular part of the vessel referred to the course truly surrounded by rectus muscle, and excluded such part passing immediately under the anterior sheath or under the deep (posterior) surface of rectus muscle enclosed by fatty perivascular tissue that was readily distinguishable from the muscle belly. Perforators that would facilitate dissection were categorized as ‘favorable’ perforators which had no or very short (<1 cm longitudinal length)
intramuscular courses. The circummuscular (septocutaneous) perforator did not have any intramuscular course, and thereby either medially or laterally circumvented the muscle (Fig. 1, 2). The perforators with a long subfascial course or a long submuscular course had a very short intramuscular course (<1 cm based on the longitudinal distance of the muscle, or within three CT slices; Fig. 3, 4).

On the contrary, perforators that would hinder or even rule out dissection were categorized as ‘unfavorable’ perforators. The absence of the DIEA meant there was no pedicle enhanced at the level of the inferior margin of the flap, or there was an apparent severance (Fig. 5). The ab-
sence of an adequate DIEP meant that there was no distinct perforator that penetrated into the fascia on the MPR image (Fig. 6). Early muscle penetration referred to a DIEA that entered the rectus abdominis muscle right after it emerged from the external iliac artery without coursing under and/or lateral to the rectus abdominis muscle, and soon arborized into smaller branches, which would result in a long cumbersome intramuscular dissection and unusually small vessel caliber for microanastomosis (Fig. 7).

Fig. 3. Long subfascial course. This perforator ran immediately beneath the fascia (on the surface of the muscle) for a substantial length then pierced the muscle, having a short intramuscular course (arrows).

Fig. 4. Long submuscular course. This perforator pierced muscle almost vertically to have a long submuscular course (arrows).
A total of 115 patients were included as our study cohort. No patients had previously received radiotherapy, and 5 patients were ex-smokers who quit smoking at least 4 weeks prior to surgery. No patients were diagnosed with peripheral vasculopathy or diabetes. The mean age of the patients were 42.4 years (range, 28-61 years), and the mean weight of the mastectomy specimens was 350.5 g (range, 100-737 g).

Sixty-seven patients had no abdominal scars. Low transverse scars were found in 24 patients, laparoscopic scars in 14 patients, right lower quadrant (appendectomy) scars in 6 patients, and vertical scars in 8 patients. Four patients had more than one scar.

An average number of 3.7 perforators (range, 0-7 perforators) were distinctly visualized in the entire flap territory on MPR-CTA. Table 1 and 2 demonstrated the incidences of patterns of perforator course that were either favorable or unfavorable. Out of 425 perforators, 89 perforators (20.9%) had a favorable course. Most common were long submuscular course followed by direct vertical muscle penetration (51 perforators, 34.8% of the patients) which was twice more common in the lateral row perforators. Long subfascial course was observed in about 15.6% of the patients which was also more commonly observed in the lateral position. Perforators that did not have any intramuscular course were found in 13.9% of the patients. Overall 56.5% of the patients had at least one favorable DIEA/P course.

The incidences of the ‘absence of DIEA’ and ‘absence
of adequate DIEP were based on the number of hemiabdomen. Three hemiabdomens in three patients with past surgical history was found to have no DIEA available. There was no adequate perforator (>1 mm on the MPR protocol) in 8 hemiabdomen. One patient had no adequate DIEP on either side of her abdomen. Eleven DIEAs showed the pattern of early muscle penetration: two patients had this pattern of DIEA on both sides of their abdomen. These patients were operated with muscle sparing free transverse rectus abdominis myocutaneous (TRAM) flaps.

All preoperatively selected perforators were of adequate size and demonstrated a visible pulse. Of all the DIEP flaps that were actually performed (n=65), 41.5% were based on the medial perforators and 58.5% were supplied by the lateral perforators.

**DISCUSSION**

The full utilization of various image modalities has been shown to be effective with positive clinical benefits, and CTA is one of the most effective and competitive techniques due to its sensitivity, specificity, availability of 3-dimensional reconstruction, and cost.11-14 Our preferred CTA protocol (MPR imaging) might be less sensitive than MIP reconstruction that can clearly visualize almost every available perforator. We mark the perforator that is distinctly visible in ≥1 slice with a measured diameter >1 mm when penetrating the fascia in MPR image. The actual diameter may differ from as observed on CTA, but

| Table 1. Favorable perforator courses that facilitated dissection |
|---------------------------------------------------------------|
| Perforator pattern                                            | Number of the perforator (% of the patients) |
|---------------------------------------------------------------|-----------------------------------------------|
| Circumvascular perforator                                     | Medial/central 8 | Lateral 18 (13.9) |
| Long Subfascial course                                        | 6 | 14 | 20 (15.6) |
| Long Submuscular course                                       | 17 | 34 | 51 (34.8) |

Circumvascular (septocutaneous) perforator and perforator with long subfascial or submuscular course were classified as favorable perforators. The most common was long submuscular course found in 34.8% of the patients and total circumvascular course was observed in 13.9%. Some patients had multiple favorable perforators.

| Table 2. Unfavorable perforator courses that hindered dissection |
|---------------------------------------------------------------|
| Unfavorable pattern of DIEA/P | Number of perforator (% of hemiabdomen or patients) |
|-------------------------------|-----------------------------------------------------|
| Absence of DIEA (hemiabdomen) | 3 (2.6)                                             |
| Absence of adequate DIEP (hemiabdomen) | 8 (6.1) |
| Early muscle penetration     | 11 (7.8)                                            |

A 2.6% of hemiabdomen did not have available DIEA pedicle and 6.1% of hemiabdomen did not show adequate perforator distinctly visualized in the preoperative CTA. DIEA: deep inferior epigastric artery, DIEP: deep inferior epigastric perforator, CTA: computed tomography angiography.

Fig. 7. Early entrance into the rectus abdominis muscle. Left deep inferior epigastric artery penetrated into the muscle almost immediately after branching from the external iliac artery. Note that right deep inferior epigastric artery was still staying at the lateral side of the muscle (arrows).
we have always encountered a perforator with an arterial diameter >1 mm having visible pulse when using this selection criterion\(^\text{15}\). MIP reconstruction is then utilized to confirm the detailed course of the selected perforators.

Katz et al.\(^\text{16}\) demonstrated a classification scheme. However, only circummuscular pattern was classified as highly favorable, and only obvious absence of the DIEA was classified as hostile. Ireton et al.\(^\text{17}\) also categorized some patterns of DIEA perforators through systematic review. Our findings have been anecdotally reported in the literature as uncommon variations or case reports \(^6,9\). The variations were not uncommonly observed in our present series and aided accurate surgical planning and lead to expeditious and safe harvest of the flap.

We categorized perforators mainly according to their intramuscular course which reflected the convenience of dissection. The circummuscular perforator has been reported as an anatomical variation, with various titles such as subfascial, pararectal, and septocutaneous, with an incidence of as high as 15%. If dissection proceeds in two directions, care should be taken in the anterograde dissection because the lateral circummuscular perforator could be mistaken for a laterally escaping branch \(^{18,19}\).

Perforators which transpierced the muscle within three CTA slices (<1 cm) were labeled as having a short intramuscular course. Those perforators have two typical patterns, either a long subfascial course or a long submuscular course, and passed the muscle almost vertically. A perforator with a long subfascial course can be useful when preoperatively recognized. If unrecognized, an inadvertent fascial incision may damage this valuable perforator. A perforator that takes a long submuscular course was relatively common, and the most common point of emersion was at the tendinous intersection of the lateral row. It corresponds with the common saying that the lateral perforators usually followed a short linear intramuscular course.

There were courses that discouraged perforator dissection, including DIEA and/or adequate DIEP absence, and very early entry into the muscle and division into smaller branches. DIEA absence is reported as an anatomic variation or surgical sequela \(^6,9\). We experienced 3 patients with unilateral absence or discontinuity of DIEA, all of whom had low transverse abdominal scarring. All 3 patients had previously undergone a hysterectomy prior to 1995. Whilst a Pfannenstiel incision is theoretically and clinically harmless to DIEA, a Maylard incision routinely severs the rectus abdominis muscle and could potentially damage the vessel \(^\text{20}\).

We encountered 1 patient who did not have an adequate perforator in either side and thus free muscle-sparing (MS) TRAM was planned and performed. We believe that MS free TRAM with a small piece of muscle is still a safe and reasonable option when adequate DIEP is not identifiable on preoperative CTA. When carefully selected, free DIEP flaps and muscle sparing free TRAM flap resulted in comparable surgical outcome \(^{21,22}\).

One inherent limitation of our study is that this anatomic study is mainly based on CTA images. Although we encountered all the pre-identified perforators intraoperatively, the contralateral side of the flap could only be evaluated by the images. Also smaller perforators that were not visualized in our MPR protocol could not be identified nor classified.

**CONCLUSION**

In conclusion, preoperative CTA evaluation of DIEA/P can be used to identify favorable as well as unfavorable courses for dissection to aid surgical planning. Overall 56.5% of the patients had at least one favorable DIEA/P course pre-identified by the CTA, most common being long submuscular course followed by long subfascial course.

**CONFLICTS OF INTEREST**

The authors have nothing to disclose.

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컴퓨터 단층 촬영 혈관 조영술을 이용한 심하복벽 혈관과 천공지의 박리 용이성에 따른 분류

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목적: 우리는 미세혈관 유방 재건술 수술 계획에 참고하기 위하여 컴퓨터 단층 촬영(computed tomography, CT) 혈관 조영술을 이용하여 심하복벽혈관과 천공지의 주행을 세부 유형으로 나누어 보고 영상 및 임상 소견의 상관성과 각 유형의 빈도를 보고하고자 한다.

방법: 하복부 조직을 이용한 유방 재건을 받은 연속한 115명의 환자를 전향적으로 분석하였다. 심하복벽동맥과 천공지를 주로 근육 내 주행의 특징에 따라 박리하기 용이한 것과 박리에 곤란한 것으로 특징짓고 각각의 빈도를 조사하였다.

결과: 확인된 425개의 천공지 중 89개(20.9%)의 천공지는 박리에 용이한 주행을 하였으며 긴 근육 아래 주행(34.8%), 긴 근막 아래 주행(15.6%), 근육 주위 주행(13.9%)이 그에 속하였다. 반면 심하복벽동맥이 없거나 적절한 천공자가 조영되지 않는 경우가 3예와 8예에서 보고되었다. 총 65명(56.5%)의 환자가 적어도 한 개 이상의 박리가 용이한 천공지를 가지고 있었다.

결론: 수술 전 CT 혈관 조영술을 통하여 심하복벽동맥과 천공지의 주행을 분석하여 박리에 용이한 유형과 곤란한 유형을 미리 파악함으로써 수술 계획의 수립에 도움을 받을 수 있다.

색인단어: 유방재건, 천공지피판, 컴퓨터 단층 촬영 혈관조영

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