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Myth-Busting the DIEP Flap and an Introduction to the Abdominal Perforator Exchange (APEX) Breast Reconstruction Technique: A Single-Surgeon Retrospective Review

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Background: Anatomical variations in perforator arrangement may impair the surgeon's ability to effectively avoid rectus muscle transection without compromising flap perfusion in the deep inferior epigastric artery perforator (DIEP) flap.
Methods: A single surgeon's experience was reviewed with consecutive patients undergoing bilateral abdominal perforator flap breast reconstruction over 6 years, incorporating flap standardization, pedicle disassembly, and algorithmic vascular rerouting when necessary. Unilateral reconstructions were excluded to allow for uniform comparison of operative times and donor-site outcomes. Three hundred sixty-four flaps in 182 patients were analyzed. Operative details and conversion rates from DIEP to abdominal perforator exchange ("APEX") arms of the algorithm were collected. Patients with standardized DIEP flaps served as the controlling comparison group, and outcomes were compared to those who underwent abdominal perforator exchange conversion.
Results: The abdominal perforator exchange conversion rate from planned DIEP flap surgery was 41.5 percent. Mean additional operative time to use abdominal perforator exchange pedicle disassembly was 34 minutes per flap. Early postsurgical complications were of low incidence and similar among the groups. One abdominal perforator exchange flap failed, and there were no DIEP flap failures. One abdominal bulge occurred in the DIEP flap group. There were no abdominal hernias in either group. Fat necrosis rates (abdominal perforator exchange flap, 2.4 percent; DIEP flap, 3.4 percent) were significantly lower than that historically reported for both transverse rectus abdominis musculocutaneous and DIEP flaps.
Conclusions: This study revealed no added risk when using pedicle disassembly to spare muscle/nerve structure during abdominal perforator flap harvest. Abdominal bulge/hernia was nearly completely eliminated. Fat necrosis rates were extremely low, suggesting benefit to pedicle disassembly and vascular routing exchange when required.   (*Plast. Reconstr. Surg.* 143: 992, 2019.)
CLINICAL QUESTION/LEVEL OF EVIDENCE: Therapeutic, III.

Autologous breast reconstruction has undergone progressive evolution since introduction of the transverse rectus abdominis musculocutaneous (TRAM) flap in 1979.[1] Major shifts have been a reflection of improved technique and understanding of anatomy. Within this

Disclosure: *Authors have no financial interest in any of the products or devices drugs mentioned in this article. No funding was received for this article.*

timeline, development of the deep inferior epigastric artery perforator (DIEP) flap represented a significant step forward. Its foundational premise was based on the concept of structural preservation of the rectus abdominis in contradistinction to its predecessor, the TRAM flap. Thus, the advent and popularization of abdominal perforator flap breast reconstruction, as surgeons adopted the technique to deliver natural-tissue breast reconstruction with the implied surety of protecting the abdominal wall from sacrificial damage. There has subsequently been much comparison of the DIEP to the TRAM flap in an effort to define the benefits relative to the added technical complexity.

Despite these analyses, significant questions remain regarding technique for the DIEP flap. Anatomical variations in perforator arrangement may hinder the operator's ability to effectively avoid muscle and motor nerve transection without impairing flap perfusion. In addition, to date, no standard has been adopted to define the point where rectus fiber transection in the DIEP flap harvest equates to a muscle-sparing TRAM flap equivalent. This remains a confounding factor for patient disclosure, counseling, and outcomes reporting. The wide variability of muscle wall preservation and opinions on flap perfusion requirements among different surgeons has resultantly clouded uniform reporting.[2–5] Not all DIEP flaps are the same, and to make fair comparisons, one must know *how* the flaps were harvested with objective reference standards. Our study aims to address and overcome these obstacles. We introduce an option for meeting the challenge of merging quality perfusion with full rectus preservation. Multiple, misaligned abdominal perforators are included in the dissection through "exchange" of their native routing patterns with pedicle disassembly and vascular rerouting to preserve interposed muscle/nerve structure. This report, and associated introduction of the abdominal perforator exchange ("APEX") flap, is an effort to improve flap and donor-site outcomes for women undergoing abdominally based autologous breast reconstruction.

PATIENTS AND METHODS

A retrospective review of a single surgeon's (F.J.D.) experience was undertaken on consecutive patients undergoing bilateral abdominal perforator flap breast reconstruction over 6 years. Unilateral breast reconstructions were excluded to allow for uniform comparison of operative times and donor-site outcomes among the differing flap groups. A total of 364 flaps in 182 patients were performed between 2011 and 2017. Patient histories were collected from office charts. Intraoperative decisions for flap conversion and supercharging were based on our algorithm (Fig. 1), and the flap selected was classified according to our nomenclature system (Table 1). Operative details, including surgical times, perforators selected, rectus structure impact, and conversion rates within the arms of our algorithm, were recorded. Early postsurgical outcomes/complications were collected from hospital charts.

Patients lost to follow-up before 3 months were excluded from the analysis. Fat necrosis and abdominal bulge/hernia occurrences were identified and recorded by the primary author (F.J.D.) during follow-up clinical examination. Fat necrosis was defined as a palpable nodule greater than or equal to 1 cm according to the Rao grading system.[6]

Technique

Incisional planning is carried out with attention toward dropping the pattern low enough to leave the scar line at a level fitting for the desired aesthetic. The upper limb is typically drawn at the level of the umbilicus or just below it (Fig. 2).

Although preoperative computed tomographic angiography is used to direct attention to larger perforators and reveal iatrogenic vascular injury in nonvirgin abdomens, each perforator is inspected visually for its arterial and venous composition and associated location in the flap base (Fig. 3). (**See Video, Supplemental Digital Content 1**, which demonstrates the abdominal perforator exchange conversion technique, available in the "Related Videos" section of the full-text article on PRSJournal.com or, for Ovid users, at *http://links.lww.com/PRS/D341*.) The algorithm is then followed to direct which vessels merit inclusion and which flap technique is used. (**See Video, Supplemental Digital Content 2**, which demonstrates the abdominal perforator exchange algorithm review, available in the "Related Videos" section of the full-text article on PRSJournal.com or, for Ovid users, at *http://links.lww.com/PRS/D342*.) Criteria for supercharging are subjective
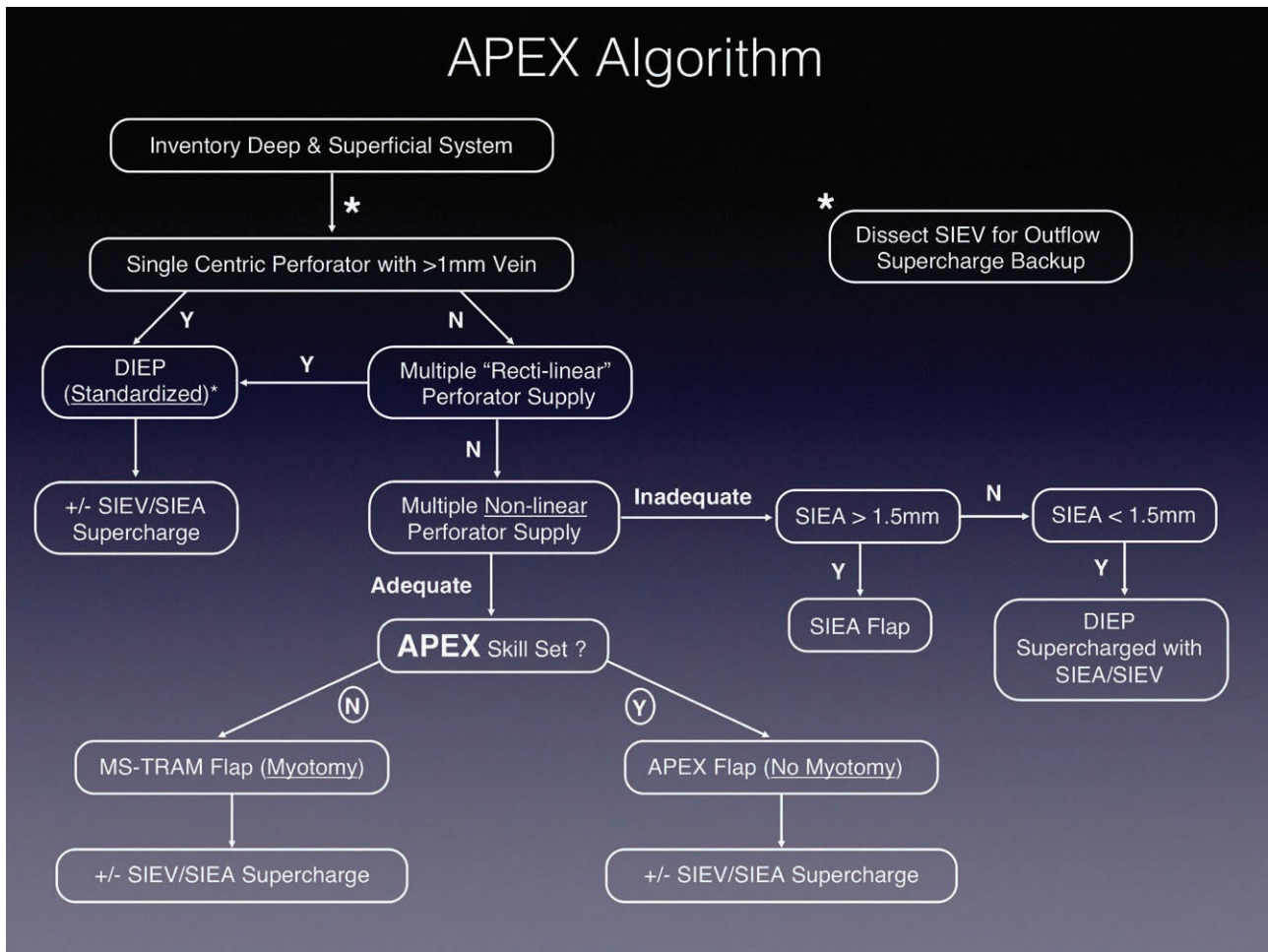
Fig. 1. Abdominal perforator exchange (*APEX*) algorithm. *SIEV*, superficial inferior epigastric vein; *SIEA*, superficial inferior epigastric artery; *N*, no; *Y*, yes; *MS*, muscle-sparing.

Table 1. Standardized Flap Classification System

| Technique	Muscle Wall Impact
MS-0 TRAM	Full width rectus myotomy/partial length
MS-1 TRAM	Preservation of lateral segment rectus
MS-2 TRAM	Preservation of lateral and medial segments rectus
DIEP	Preservation of full rectus (up to 1-cm partial thickness myotomy*; if >1-cm partial thickness or any full-thickness myotomy, MS-0, MS-1, MS-2 TRAM vs. APEX conversion)
APEX	Preservation of full rectus (no myotomy) and segmental nerves with pedicle disassembly

MS, muscle-sparing; APEX, abdominal perforator exchange.
*See Figure 9.

and based on flap performance observations of the surgeon during harvest. Irrespective of these considerations, the superficial inferior epigastric vein is *always* dissected to length, when present, to serve as a venous outflow lifeboat.[7,8]

If two or more perforators are selected, no concern is had for whether they appear to be in different "rows." The fascial incision is angled from one perforator's emergence point to the next to produce a continuous single access line. At this point, the decision is made to convert to an abdominal perforator exchange flap or continue with a DIEP flap harvest (Table 1). When selected perforators fall into a single muscular cleavage line, a DIEP dissection pattern follows without myotomy (Fig. 4). When the selected perforators *do not* fall in the same intramuscular fiber line, consideration of abdominal perforator exchange conversion ensues (Fig. 5). Transection of any full-thickness muscle was found to have invariably required a greater than 1-cm impact, and therefore any full-thickness myotomy requirements led to abdominal perforator exchange conversion or muscle-sparing TRAM flap classification.

When the abdominal perforator exchange arm of the algorithm is followed, the *primary pedicle* is disassembled beneath the interposed muscle bundle (Fig. 6) and each perforator is slipped
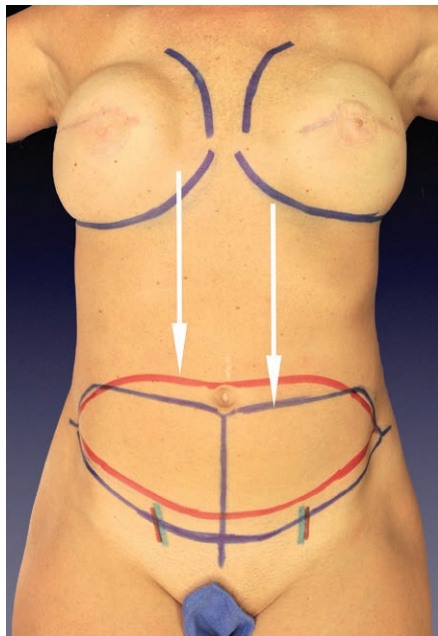
Fig. 2. Abdominal incision pattern lowered (*blue*) with abdominal perforator exchange option for inclusion of multiple medial and lateral perforators lower on the abdominal wall without interim muscle transection. An improved aesthetic versus patterns (*red*) that leave a high-riding scar line is delivered.

from its respective muscular dissection plane, preserving intervening muscle and associated motor nerves (Figs. 7 and 8). A photograph of the harvest site is taken before the fascia is closed as an objective record of dissection quality. Continuity is restored at the disassembly point on a sterile side table using 1.5-mm venous couplers and

hand-sewn arterial anastomosis. Anastomosis to the recipient internal mammary system follows. Implantable Doppler monitoring was used on the primary arterial anastomoses only in this series; however, monitoring may be adjusted to operator preference.

Statistical Analysis

Statistical analysis was performed on continuous variables with the Wilcoxon rank sum and Welch two-tailed t test, depending on data distribution within tested groups. Dichotomous outcome variables were compared using chi-square or Fisher's exact test, depending on the frequency of targeted data. Results with a value of $p < 0.05$ were regarded as significant.

RESULTS

Patient characteristics and comorbidities were similar among the treatment groups, with a notable exception of a lower body mass index in the abdominal perforator exchange–only subset ($p = 0.01$) and the one DIEP/one abdominal perforator exchange ($p < 0.001$) subset (Table 2). One hundred ninety-four flaps (53 percent) were DIEP flaps, whereas 151 flaps (42 percent) were converted to the abdominal perforator exchange technique (Table 3). The remaining 5 percent (19 flaps) were superficial inferior epigastric artery flaps. An average of 2.09 ± 0.45 perforators were included in the abdominal perforator exchange flaps and 1.82 ± 0.44 perforators were included in the DIEP flaps ($p < 0.001$). Twelve percent of our
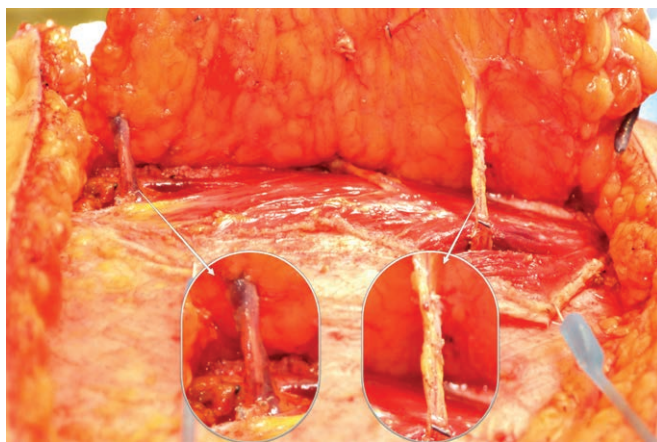
Fig. 3. Perforators surgically "inventoried" to direct the algorithm decision pathway. (*Left*) Peripheral perforator superior edge of flap base with substantial venous component. (*Right*) Lower perforator of similar gross overall size made up of large sensory nerve and arterial flow element but underdeveloped venous outflow component.

Video 1. Supplemental Digital Content 1, which demonstrates the abdominal perforator exchange conversion technique, is available in the "Related Videos" section of the full-text article on PRSJournal.com or, for Ovid users, at ***http://links.lww.com/PRS/D341***.
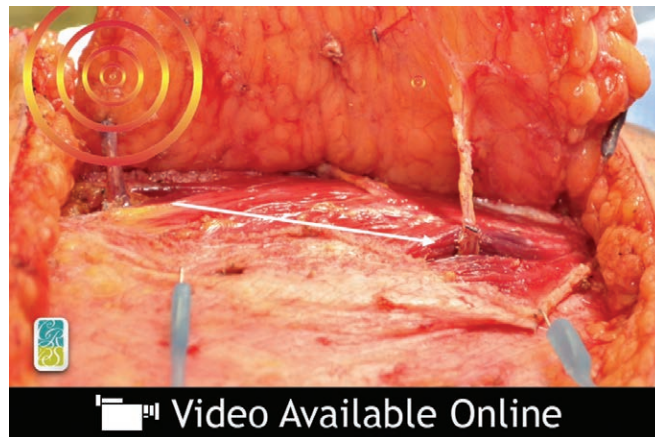

Video 2. Supplemental Digital Content 2, which demonstrates the abdominal perforator exchange algorithm review, is available in the "Related Videos" section of the full-text article on PRSJournal.com or, for Ovid users, at ***http://links.lww.com/PRS/D342***.

flaps were based on a single perforator. Eleven DIEP flaps (5.6 percent) were supercharged with the superficial inferior epigastric artery and 18 (9.1 percent) with a superficial inferior epigastric vein; 2.7 percent of abdominal perforator exchange flaps were supercharged with the superficial inferior epigastric artery and 5.3 percent were supercharged with a superficial inferior epigastric vein.

Of those patients meeting criteria for myotomy (34 percent), the average width of transected muscle was 0.68 ± 0.16 cm, and all were partial thickness (Fig. 9). Sixty-six percent of DIEP flaps were harvested with no myotomy. The average width of muscle spared, as a result of abdominal perforator exchange conversion, was 2.56 ± 0.88 cm, and all were harvested without rectus fiber transection (Fig. 10). No patients were converted to TRAM or muscle-sparing TRAM flaps.

The added operative time for an abdominal perforator exchange flap versus a DIEP flap was 34 minutes on average (Table 4). Hospitalization averaged 3.5 ± 0.83 days and did not differ significantly among the various patient subsets. There were three flap failures (0.8 percent of 364 flaps performed): two occurred in the immediate postoperative period and one presented at the time of the second stage with diffuse fat necrosis. There were no DIEP flap failures. Excluding superficial inferior epigastric artery flaps, the overall DIEP/
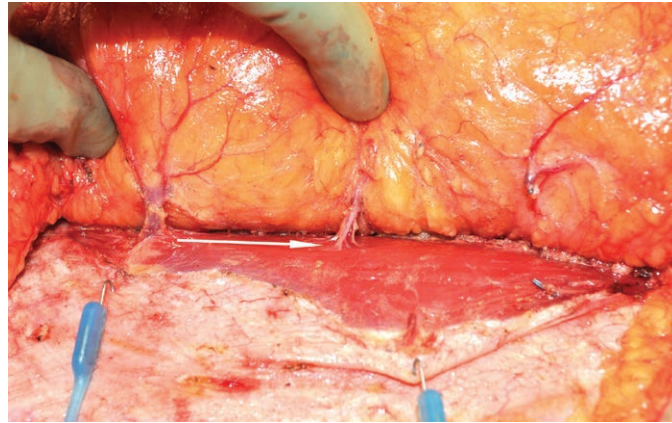
Fig. 4. Multiple perforators aligned in single rectus fiber line ("rectilinear").
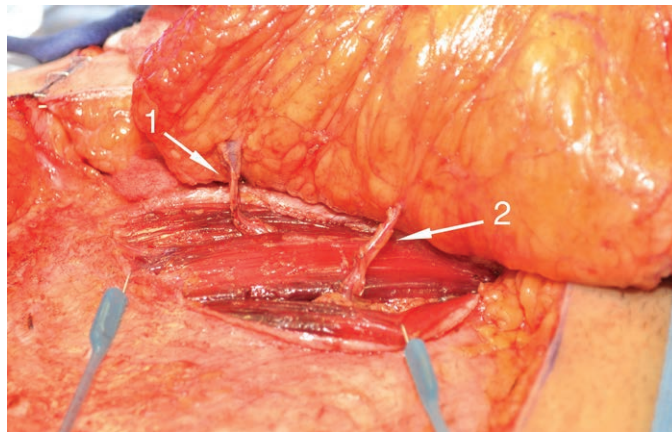
Fig. 5. Perforators emerging from different muscular fiber cleavage lines. (*1*) Superior perforator with well-developed venous component but eccentric location. (*2*) Centric perforator with underdeveloped venous component.

abdominal perforator exchange flap failure rate was 0.27 percent. There were 12 hematomas requiring operative evacuation; the majority of these were immediate reconstructions with bleeding from the mastectomy wound bed. There were no other significant early flap complications (Table 5).

Overall, long-term follow-up averaged 383 days. One patient presented at the second stage with a clinically detectable, unilateral abdominal bulge in the DIEP flap group. There were no bulges in the abdominal perforator exchange or superficial inferior epigastric artery flap groups, and no patients developed abdominal hernias during the study period. Fat necrosis did not differ significantly among the flap types produced from the algorithmic decision pathway. Minor clinically detectable areas between 1 and 3 cm were found in 3.4 percent of standardized DIEP flaps and 2.4

percent of abdominal perforator exchange flaps (Tables 3 and 6).[2,3,5,6,9–17]

DISCUSSION

Anatomy

Varied descriptions of the vascular anatomy of the DIEP flap have been a source of bewilderment with respect to standardization of technique. The anatomical description of the transverse and oblique routes perforators take as they course through the rectus described by Rozen et al. was cited as support of the argument that fibers must be routinely divided when harvesting a DIEP flap.[18] Others have reported similarly, with commentary on the unpredictable routes perforators take as they pass through rectus structure.[14,19,20] These findings are in stark contrast to reports by Munhoz
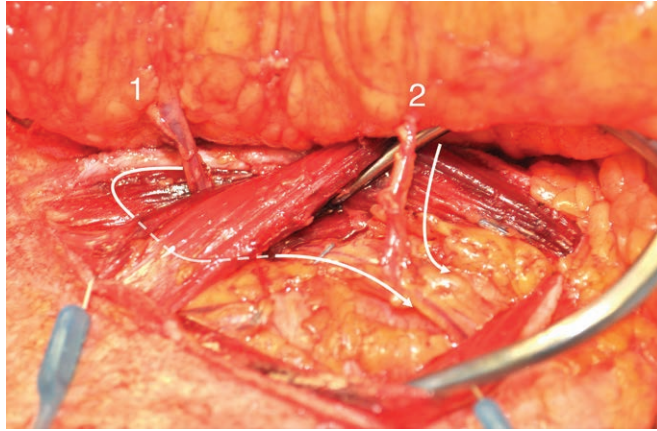
Fig. 6. Perforators *1* and *2* followed to the common deep inferior epigastric vascular source beneath an interposed 4-cm-wide muscular bundle.
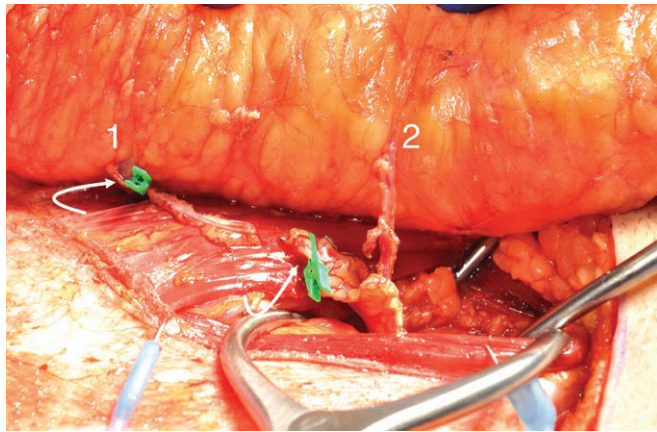
Fig. 7. Deep inferior epigastric pedicle disassembled between desired perforators and slipped from respective muscular fiber planes, leaving interposed muscle and segmental motor nerves intact.
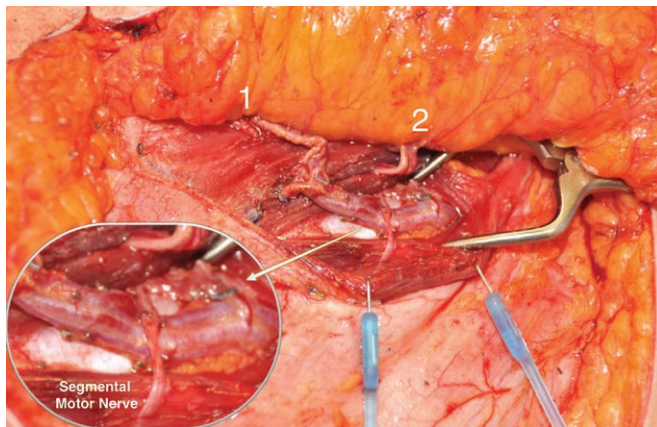
Fig. 8. Segmental nerve preservation demonstrated, as facilitated by abdominal perforator exchange technique. The primary pedicle may be divided beneath nerve and muscle fibers to allow for preservation of structural components.

Table 2. Patient Demographics

Demographics/Medical History	Total (%)	DIEP Only (%)	APEX Only (%)	p*	1 DIEP/1 APEX	p*	1 DIEP/1 SIEA	p*	1 APEX/1 SIEA	p*	SIEA Only	p*
No. of patients	182	62 (34.1)	44 (24.2)	—	60 (33.0)	—	10 (5.5)	—	3 (1.7)	—	3 (1.7)	—
Average age, yr	49	48	50	0.26	49	0.76	49	0.86	50	0.75	49	0.94
Average BMI ± SD	28.6 ± 4.8	30.2 ± 4.5	27.6 ± 4.8	0.01	27.3 ± 4.1	<0.001	31.5 ± 6.8	0.96	28.2 ± 1.8	0.48	31.7 ± 8.1	0.83
Immediate reconstruction	118 (64.8)	45 (72.6)	26 (59.1)	0.12	38 (63.3)	0.27	5 (50)	0.27	1 (33.3)	0.20	3 (100)	0.56
Delayed reconstruction	45 (24.7)	11 (17.7)	14 (31.8)	0.12	14 (23.3)	0.44	4 (40.0)	0.20	2 (66.7)	0.10	0	0.99
Immediate/delayed reconstruction	19 (10.4)	6 (9.7)	4 (9.1)	0.99	8 (13.3)	0.53	1 (10.0)	0.99	0	0.99	0	0.99
Hypertension	39 (21.4)	11 (17.7)	12 (27.3)	0.24	13 (21.7)	0.59	3 (30.0)	0.40	0	0.99	0	0.99
Diabetes	12 (6.6)	3 (4.8)	4 (9.1)	0.45	3 (5.0)	0.99	1 (10.0)	0.46	1 (33.3)	0.18	0	0.99
Dyslipidemia	10 (5.5)	3 (4.8)	4 (9.1)	0.45	3 (5.0)	0.99	0	0.99	0	0.99	0	0.99
Previous smoker	74 (40.7)	8 (12.9)	14 (31.8)	0.12	18 (30.0)	0.02	3 (30.0)	0.17	3 (100)	<0.001	1 (33.3)	0.37
Current smoker	3 (1.6)	1 (1.6)	2 (4.6)	0.57	0	0.99	0	0.99	0	0.99	0	0.99
Previous abdominal surgery	131 (72.0)	53 (85.5)	32 (72.7)	0.10	37 (61.7)	<0.001	6 (60.0)	0.07	1 (33.3)	0.07	2 (66.7)	0.40

APEX, abdominal perforator exchange; BMI, body mass index.
*Compared to DIEP-only bilateral reconstruction.

et al. and others that describe orderly, consistent perforator rows that drop directly through aligned muscular cleavage planes to the inferior epigastric system.[21–25] Our observations are that there is no consistent medial or lateral row arrangement of the perforators in the infraumbilical abdominal wall (Fig. 11). Vessels, which may appear aligned in "rows" at the fascial level, frequently take different tracks around muscle fibers as they descend toward the primary pedicle (Fig. 12). Such is the source of the "DIEP dilemma." When multiple perforators are necessary to vigorously perfuse a flap, the operator often finds that interposed bundles of rectus muscle separate them. This dilemma demands that either the muscle be cut to bring perforators together or that the misaligned perforator is sacrificed to maintain muscle structure.[5]

Abdominal Morbidity

To date, no standard has been adopted regarding muscle fiber transection during a DIEP flap harvest. Several authors have written about this issue.[2–5,20,26,27] This reality contradicts the popular perception of the basic advantage of the DIEP flap over the TRAM flap.

Many published studies support the DIEP flap as a means of reducing overall morbidity in the abdominal donor site compared with the TRAM flap, but all have lacked consistency and clarity with respect to muscle fiber transection in the DIEP arm of their reports.[12,13,28–31] Despite this lack of a standard, multiple studies have shown that the DIEP flap produces at least half the risk of hernia/bulge compared with the muscle-sparing TRAM flap.[5,13,28,31–33] The consensus indicates that abdominal wall function is correlated to muscle/nerve/fascia preservation and that patients undergoing the DIEP flap enjoy less overall donor-site morbidity, with quicker recoveries and better overall preservation of abdominal wall strength compared with TRAM flap recipients.[34–38] Shubinets et al. found that the amount of rectus muscle sacrificed correlated with the likelihood of undergoing subsequent surgical hernia repair, and that the added costs to the health care system ranged from $39,704 to $48,378.[39]

Innervation

A number of scholarly articles have touched on the potential impact of rectus motor nerve transection as a contribution to abdominal bulges and weakness.[4,10,40–42] When dissection is confined to a sagittal split along the muscle fiber line, the segmental motor nerves crossing the pedicle may

**Table 3. Algorithmic Flap Selection Product and Associated Performance**

Algorithmic Selection Product and Flap Performance	Total (%)	DIEP (%)	APEX (%)	p*	SIEA (%)	p*	TRAM (%)
Flap selected	364	194 (53.3)	151 (41.5)	N/A	19 (5.2)	N/A	0
Average inset flap weight ± SD, g	722.1 ± 300.3	760.0 ± 300.2	652.8 ± 268.4	<0.001	895.3 ± 412.8	0.22	N/A
Average no. of perforators ± SD	1.93 ± 0.47	1.82 ± 0.44	2.09 ± 0.45	<0.001	N/A	N/A	N/A
Myotomy required	66 (18.1)	66 (34)	0.0 (0)	<0.001	N/A	N/A	N/A
Mean myotomy extent ± SD, cm	N/A	0.68 ± 0.16	0.0 (0)	N/A	0	N/A	N/A
Myotomy avoided by means of APEX pedicle disassembly ± SD, cm	N/A	NA	2.56 ± 0.88	N/A	N/A	N/A	N/A
SIEA supercharge	15 (4.1)	11 (5.6)	4 (2.7)	0.19	N/A	N/A	N/A
SIEV supercharge	26 (7.1)	18 (9.3)	8 (5.3)	0.16	N/A	N/A	N/A
Intraoperative arterial insufficiency†	15 (4.1)	11 (5.7)	3 (2.0)	0.10	0	0.60	N/A
Intraoperative venous insufficiency†	24 (6.6)	18 (9.3)	6 (4.0)	0.05	0	0.38	N/A
Intraoperative arterial thrombosis	1 (0.3)	1 (0.5)	0	0.99	0	0.99	N/A
Intraoperative venous thrombosis	0	0	0	N/A	0	N/A	N/A
Postoperative arterial insufficiency	1 (0.3)	0	1 (0.7)	0.44	0	N/A	N/A
Postoperative venous insufficiency	2 (0.5)	0	2 (1.3)	0.19	0	N/A	N/A
Postoperative arterial thrombosis	3 (0.8)	0	1 (0.7)	0.44	2 (10.5)	0.01	N/A
Postoperative venous thrombosis	0	0	0	N/A	0	N/A	N/A
Flap failure	3 (0.8)	0	1 (0.7)	0.44	2 (10.5)	0.01	N/A
Average length of follow-up days by flap type ± SD‡	382.9 ± 381.1	373.3 ± 384.5	406.0 ± 382.4	N/A	304.0 ± 352.6	N/A	N/A
Flaps with >90 days' follow-up	315 (86.5)	178 (91.8)	124 (82.1)	N/A	13 (68.4)	0.01	N/A
Abdominal donor-site bulge	1 (0.32)	1 (0.56)	0	0.99	0	1.0	N/A
Abdominal donor-site hernia	0	0	0	N/A	0	N/A	N/A
Fat necrosis incidence	10 (3.2)	6 (3.4)	3 (2.4)	0.74	1 (7.7)	0.39	N/A
Average fat necrosis extent ± SD, cm	2.80 ± 1.40	2.83 ± 1.44	2.00 ± 0.50	0.24	5.00 ± N/A	NA	N/A

APEX, abdominal perforator exchange; SIEA, superficial inferior epigastric artery; N/A, not applicable; SIEV, superficial inferior epigastric vein.
*Compared to DIEP flap.
†Corrected with SIEA/SIEV supercharge as indicated.
‡Patients lost to follow-up before 90 days excluded.
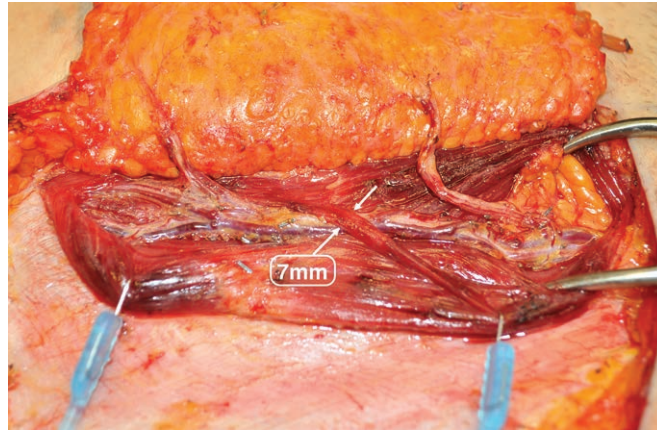
Fig. 9. Perforator course through muscle fiber structure with 7-mm tangential, partial-thickness fiber crossing. Myotomy up to 1-cm partial thickness maintains categorization as a DIEP flap under institutional standard and associated classification system (Table 1).
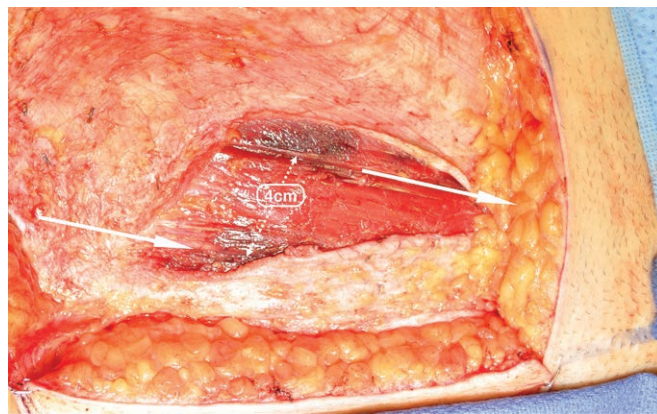
Fig. 10. Dissection field demonstrating full preservation of 4-cm-wide interposed muscle bundle. Photographic documentation of harvest-site quality routinely performed before fascial closure.

Table 4. Total Surgical Time for DIEP versus Abdominal Perforator Exchange Flaps

Procedure*	Average Operative Time ± SD (min)	DIEP vs. APEX, Minutes Total (minutes per flap)
Bilateral delayed		
DIEP	445.7 ± 106.6	
APEX	514.5 ± 43.0	+68.8 (34.5)
Bilateral immediate		
DIEP	476.8 ± 79.2	
APEX	544.3 ± 53.36	+67.5 (33.5)

APEX, abdominal perforator exchange.
*Cases with differing combined flap types and unilateral reconstructions were excluded for uniformity.

be easily identified. If the nerves cross between two perforators that are to be included with an abdominal perforator exchange disassembly, the associated neural structures may be preserved, along with any interposed muscle (Fig. 8).

Fat Necrosis

Fat necrosis is intimately tied to perfusion quality, and provision of perfusion quality is intimately tied to abdominal morbidity. Fat necrosis can mimic recurrent breast cancer both clinically and radiographically.[6,17] It can be painful, and added cost for clinical encounters, imaging, and surgical intervention may be considerable.

The quandary experienced with misaligned perforators has been the vexing decision of whether to cut across muscle to join them or ligate the misaligned vessel and risk fat necrosis and/or venous congestion. A number of authors have studied whether lateral or medial perforators are

Table 5. Postsurgical Course among Flap Combinations

| Complications	Total (%)	DIEP Only (%)	APEX Only (%)	p*	1 DIEP/1 APEX (%)	p*	1 DIEP/1 SIEA (%)	p*	1 APEX/1 SIEA (%)	p*	SIEA Only (%)	p*
Patients	182	62 (34.1)	44 (24.2)	—	60 (33)	—	10 (5.5)	—	3 (1.7)	—	3 (1.7)	—
Average hospitalization ± SD, days	3.5 ± 1.25	3.4 ± 0.83	3.3 ± 0.56	0.97	3.5 ± 0.83	0.21	3.4 ± 0.52	0.58	8.0 ± 7.81	0.10	3.0 ± 0.00	0.30
Hematoma	12 (6.6)	5 (8.1)	4 (9.1)	0.99	3 (5.0)	0.72	0	0.99	0	0.99	0	0.99
Seroma	10 (5.5)	6 (9.7)	3 (6.8)	0.73	0	0.03	0	0.59	1 (33.3)	0.29	0	0.99
Mastectomy skin necrosis	20 (11.0)	9 (14.5)	6 (13.6)	0.90	4 (6.7)	0.24	1 (10.0)	0.99	0	0.99	0	0.99
Wound infection breast	3 (1.7)	1 (1.6)	0	0.99	2 (3.3)	0.62	0	0.99	0	0.99	0	0.99
Wound infection abdomen	3 (1.7)	2 (3.2)	1 (2.3)	0.99	0	0.50	0	0.99	0	0.99	0	0.99
Abdominal wound healing	7 (3.9)	4 (6.5)	2 (4.6)	0.99	1 (1.7)	0.36	0	0.99	0	0.99	0	0.99

APEX, abdominal perforator exchange; SIEA, superficial inferior epigastric artery.
*Compared to DIEP-only bilateral reconstruction.

superior and whether a single-perforator dissection is preferred.[43–46] Baumann et al. found that single-perforator flaps developed fat necrosis more often than multiperforator flaps, as did Garvey et al.[14,16,33] A recent report by Kamali et al. suggests that medial perforators alone are prone to produce fat necrosis nearly three times as often as hemiabdominal flaps that include a lateral row perforator.[42] Mohan et al. reported fat necrosis rates of 9.8 percent in single-perforator flaps and 4.9 percent in multiperforator flaps.[47] Grover et al. found a threefold higher rate of fat necrosis in single-perforator DIEP flaps compared with multiperforator flaps.[48] A single perforator in the base of a DIEP flap constitutes a maximal reduction in blood flow relative to its natural state (thus, the many reports of lesser fat necrosis in TRAM flaps versus DIEP flaps).[11–13,17,33] In some cases, a large, centrally located perforator with a high-quality venous component is adequate to fully perfuse a flap, but as Blondeel pointed out, centricity is important.[49]

In essence, the abdominal perforator exchange conversion delivers the benefit of TRAM flap perfusion quality without the tradeoff of structural sacrifice. Complementing this approach with superficial inferior epigastric artery/superficial inferior epigastric vein supercharging, when necessary, delivers full control of perfusion quality. When compared with the great majority of previous reports, our algorithm for DIEP flap selection and abdominal perforator exchange conversion resulted in a statistically significant lowering of the rate of fat necrosis compared with both DIEP and TRAM flaps in those series (Table 6).[2,3,5,9,11–17,33,50] This suggests meaningful benefit when flap perfusion is tailored to the anatomy on an individual basis.

Various authors have described decision pathways to determine when a DIEP flap should be abandoned in favor of a TRAM flap.[3,4,8,10,13,15,46,51,52] We are in agreement with authors who admit that conversion from a DIEP flap to a TRAM flap is warranted when the only alternative is a poorly perfused flap. The abdominal perforator exchange flap represents an alternative to TRAM flap conversion, and we use it exclusively when the DIEP flap is not the best choice for maximization of perfusion and structural preservation. Our algorithm requires that operator skill be sufficiently advanced to accommodate pedicle disassembly and include supercharging when deemed of benefit (Fig. 1).

The added time and complexity to perform the abdominal perforator exchange flap may,
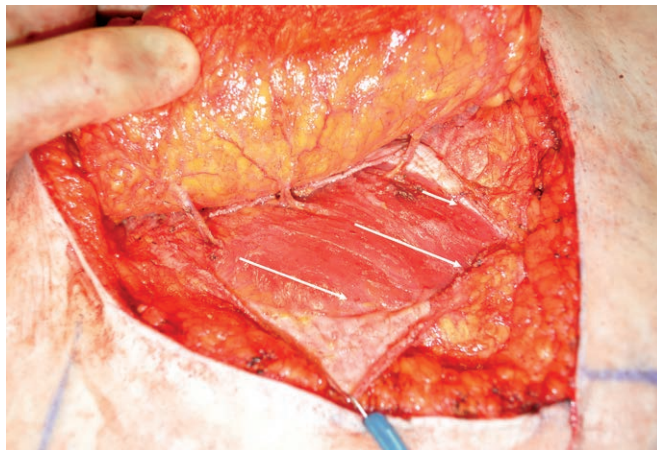
Fig. 11. Deep inferior epigastric perforators emerge from variable points in the rectus fiber structure. Developmental patterns are not productive of classically described perforator "rows" in the clinical setting.
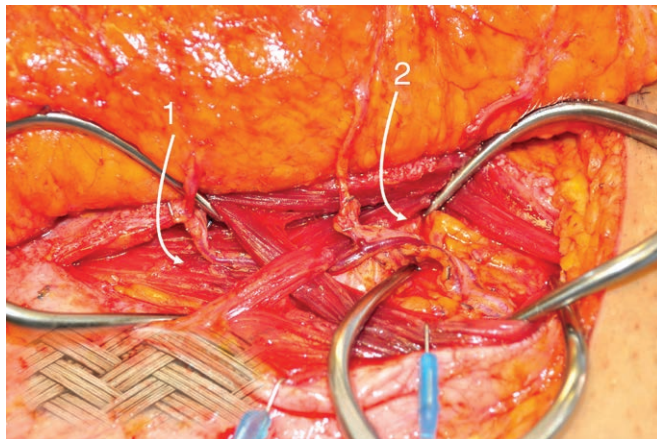
Fig. 12. Courses individual vessels take through rectus structure are confounding when perforators track tangentially from fascial exit points to the primary source. Rectus fiber structure is noted to be woven with crisscrossing, overlapping bundles.

theoretically, be more than offset by the avoidance of ongoing donor-site problems and fat necrosis in the newly reconstructed breast. Disassembling the pedicle did not increase complications compared to flaps without pedicle transection within our patient cohort (Tables 3 and 5). Because pedicle division is undertaken only through the large vessels of the primary trunk between selected perforators, this anastomosis should have no more likelihood of a problem than the anastomoses to the recipient vasculature. The fact that none of our abdominal perforator exchange flaps suffered substantial fat necrosis, as would be expected with interim pedicle anastomosis failure, supports this assertion.

Notably, among the three flap failures, two were superficial inferior epigastric artery flaps and both were of arterial origin (10.53 percent of superficial inferior epigastric artery flaps performed) (Table 3). This reflects the experience of other authors' commentary on arterial mismatch and associated failure rates with the superficial inferior epigastric artery flap.[53–56] The superficial inferior epigastric artery is resultantly a tertiary arm within our algorithm.

Aesthetics

Part of the appeal of the DIEP flap is the byproduct expectation of an improved abdominal aesthetic. However, this does not always translate

Table 6. Fat Necrosis Rate Comparison

Reference	Fat Necrosis DIEP (%)	Total DIEP	Fat Necrosis TRAM (%)	Total TRAM	Author	Fat Necrosis DIEP (%)	Total DIEP	p* DIEP	p* TRAM	Fat Necrosis APEX (%)	Total APEX	p* DIEP	p* TRAM
Kroll, 2000[9]	4 (17.4)	23	36 (12.9)	279	Della Croce	6 (3.4)	178	0.02	<0.001	3 (2.4)	124	0.01	<0.001
Nahabedian et al., 2002[10]	2 (10.0)	20	14 (9.8)	143	"	"	"	0.19	0.02	"	"	0.14	0.01
Nahabedian et al., 2005[2]	7 (6.4)	110	8 (7.1)	113	"	"	"	0.25	0.15	"	"	0.20	0.09
Scheer et al., 2006[11]	36 (42.9)	84	4 (8.7)	46	"	"	"	<0.001	0.13	"	"	<0.001	0.09
Bajaj et al., 2006[3]	5 (11.6)	43	14 (9.3)	150	"	"	"	0.04	0.03	"	"	0.03	0.02
Selber et al., 2010[12]†	65 (25.5)	254	92 (11.3)	812	"	"	"	<0.001	<0.001	"	"	<0.001	N/A
Man et al., 2009[13]†	220 (11.7)	1882	149 (5.6)	2650	"	"	"	<0.001	0.20	"	"	0.002	N/A
Bauman et al., 2010[14]	14 (20.0)	71	7 (7.0)	94	"	"	"	<0.001	0.15	"	"	<0.001	0.10
Selber and Serletti, 2010[5]	2 (2.1)	97	19 (2.8)	569	"	"	"	0.71	0.98	"	"	0.999	0.78
Nelson et al., 2010[15]	6 (5.9)	102	7 (4.6)	154	"	"	"	0.36	0.58	"	"	0.31	0.52
Garvey et al., 2012[16]	36 (7.7)	466	57 (6.0)	952	"	"	"	0.045	0.16	"	"	0.03	0.10
Khansa et al., 2013[17]†	350 (14.4)	2429	167 (6.9)	2423	"	"	"	<0.001	0.07	"	"	<0.001	N/A

APEX, abdominal perforator exchange; N/A, not applicable.
*Versus referenced study DIEP/TRAM flap fat necrosis rates reported.
†Meta-analyses.

within the clinical outcome.[57–59] Incisional patterns that push to include the higher paraumbilical perforators are primarily to blame. Because these perforators often represent some of the larger vessels in the flap base, the want to include them is intrinsic. This drives the surgeon to raise the incisional pattern to capture them.[48] The resultant high-riding scar line is aesthetically displeasing and does not represent the "tummy tuck" that was anticipated (Fig. 13). Abdominal perforator exchange perforator inclusion delivers the liberty to move away from high perforators and associated incisional designs and reliably perfusing flaps with a greater number of lower/multiple perforators (Fig. 14). Our finding of a tendency toward a lower body mass index in our abdominal perforator exchange patients likely resulted, in part, from the dropping of the upper incision height to keep scar lines low in these patients. This pattern shift moved the paraumbilical vessels to the far periphery of these flaps or excluded them entirely, adding greater perfusion requirement from the less well-developed vasculature lower on the abdominal wall.

Standard

The standard described herein addresses issues that have clouded the definition of the DIEP flap and impacted uniform reporting for decades.[5,27] Our institutional definition is simple and offers

Fig. 13. Unfavorable donor aesthetic with high-riding abdominal scar. It is improved with a low-incisional-pattern design as supported by abdominal perforator exchange conversion and inclusion of multiple, lower abdominal wall perforators without muscle sacrifice.

Fig. 14. Before and after abdominal perforator exchange flap with strong abdominal wall and no clinically detectable breast fat necrosis. Donor-site aesthetic is complemented by a low scar line.

a standard against which future reporting may be based. We expand on well-adopted system described by Nahabedian et al.[10] and add specific parameters to clarify what qualifies as a DIEP flap and when abdominal perforator exchange or TRAM flap conversion is the technique product (Table 1). A DIEP flap is defined as a flap that is harvested with full preservation of rectus structure without myotomy or, if myotomy is required to include more than one perforator, it is held to an absolute minimal amount (≤1 cm *and* partial thickness) (Fig. 9). Beyond that, the flap is classified as a muscle-sparing TRAM flap. This institutional standard is biased toward minimization of morbidity and avoiding introduction of complexity for the sake of complexity. We thereby afford standardization of the DIEP flap within the framework of its premise in concert with conceptual and technical reason. Transection of partial-thickness rectus muscle bundles of greater than 1 cm or any full-thickness transection to join more than one perforator to the primary trunk is either classified as a muscle-sparing TRAM flap or is the threshold for which abdominal perforator exchange conversion is encountered. (**See Video, Supplemental Digital Content 3**, which demonstrates the abdominal flap

Video 3. Supplemental Digital Content 3, which demonstrates the abdominal flap nomenclature and classification system review, is available in the "Related Videos" section of the full-text article on PRSJournal.com or, for Ovid users, at ***http://links.lww.com/PRS/D343***.

nomenclature and classification system review, available in the "Related Videos" section of the full-text article on PRSJournal.com or, for Ovid users, at *http://links.lww.com/PRS/D343*.)

Objective measurement, documentation, and reporting of myotomy and motor nerve transection should be included in reports that compare abdominal donor-site morbidity going forward. Only then can we reasonably compare outcomes among procedures that spare structure versus those that do not. This report is not without limitations, and the reader must consider the retrospective nature of outcomes reported along with associated potential for observer bias.

CONCLUSIONS

The abdominal perforator exchange (APEX) algorithm allows the operator to reliably harvest flaps with robust perfusion while preserving structure to the maximum extent possible. Pedicle disassembly delivers the freedom to engineer the vascularity required irrespective of the anatomy encountered. The abdominal perforator exchange conversion option allows the surgeon to exchange the vascular anatomy encountered for the anatomy preferred; to exchange myotomy for intact rectus structure; to exchange neurolysis for motor nerve continuity; to exchange fat necrosis for soft breast flaps; and to exchange high-riding scar lines for lower ones. This advancement delivers a technique to maximize donor-site integrity and improve flap performance. We further describe a new classification system for the standardization of abdominal flap nomenclature, which may provide an opportunity to improve uniform reporting going forward.

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