Breast Reconstruction with the DIEP Flap or the Muscle-Sparing (MS-2) Free TRAM Flap: Is There a Difference?

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The advantages of breast reconstruction using the deep inferior epigastric perforator (DIEP) flap and the muscle-sparing free transverse rectus abdominis musculocutaneous (TRAM) flap (MS-2) are well recognized. Both techniques optimize abdominal function by maintaining the vascularity, innervation, and continuity of the rectus abdominis muscle. The purpose of this study was to compare these two methods of breast reconstruction and determine whether there is a difference in outcome. The study considered 177 women who have had breast reconstruction using muscle-sparing flaps over a 4-year period. This includes 89 women who had an MS-2 free TRAM flap procedure, of which 65 were unilateral and 24 were bilateral, and 88 women who had a DIEP flap procedure, of which 66 were unilateral and 22 were bilateral. The total number of flaps was 223. Mean follow-up was 23 months (range, 3 to 49 months). For all MS-2 free TRAM flaps ($n = 113$), outcome included fat necrosis in eight (7.1 percent), venous congestion in three (2.7 percent), and total necrosis in two (1.8 percent). For the women who had an MS-2 free TRAM flap, an abdominal bulge occurred in three women (4.6 percent) after unilateral reconstruction and in five women (21 percent) after bilateral reconstruction. The ability to perform sit-ups was noted in 63 women (97 percent) after unilateral reconstruction and 20 women (83 percent) after bilateral reconstruction. For all DIEP flaps ($n = 110$), outcome included fat necrosis in seven (6.4 percent), venous congestion in five (4.5 percent), and total necrosis in three (2.7 percent) patients. For the women who had DIEP flap reconstruction, an abdominal bulge occurred in one woman (1.5 percent) after unilateral reconstruction and in one woman (4.5 percent) after bilateral reconstruction. The ability to perform sit-ups was noted in all women after unilateral reconstruction and in 21 women (95 percent) after bilateral reconstruction. These results demonstrate that there are no significant differences in fat necrosis, venous congestion, or flap necrosis after DIEP or MS-2 free TRAM flap reconstruction. The percentage of women who are able to perform sit-ups and the percentage of women who did not develop a postoperative abdominal bulge is increased after DIEP flap reconstruction; however, this difference is not statistically significant. (*Plast. Reconstr. Surg.* 115: 436, 2005.)

Breast reconstruction with the deep inferior epigastric perforator (DIEP) flap has received considerable attention since it was introduced in 1989 and popularized in 1994.[1,2] The prin-

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cipal advantages of and indications for the DIEP flap are to completely preserve the rectus abdominis muscle and the anterior rectus sheath to reduce the incidence of abdominal morbidity such as bulge, hernia, and weakness. To fully appreciate this benefit, comparisons to other abdominally based flaps are necessary. The abdominal flap that is most comparable to the DIEP flap is the free transverse rectus abdominis musculocutaneous (TRAM) flap because of identical blood supply and similar harvesting techniques.[3,4] Numerous comparisons between these two flaps have been made and have included abdominal strength, abdominal contour, selection criteria, costs for the procedures, and postoperative pain, all of which have demonstrated an advantage with the DIEP flap.[5–12] A limitation of these studies is that most do not distinguish among the various types of free TRAM flaps that are based on the amount of rectus abdominis muscle removed. The classification of the various muscle-sparing techniques has been previously described and include the MS-0, MS-1, and MS-2 free TRAM flaps.[4,5] It is the MS-2 free TRAM flap that utilizes the least amount of muscle and fascia while maintaining muscle continuity and is most similar to the DIEP flap (MS-3).

Despite the advantages of the DIEP flap, its use for breast reconstruction remains controversial.[5,13–15] This is based on the assumption that the risks of the procedure outweigh the benefits. Some of these risks include flap failure, venous congestion, and fat necrosis, all of which are related to the blood supply of the DIEP flap. The incidence of these risks ranges from 1 to 4 percent for flap failure, 4 to 10 percent for fat necrosis, and 3 to 6 percent for venous congestion.[5,13,14] Our previous study compared the free TRAM (MS-0, MS-1, and MS-2) to the DIEP flap and demonstrated no difference in flap failure, fat necrosis, venous congestion, or the ability to perform sit-ups.[5] There was a significant increase in abdominal bulge with the MS-0 and MS-1 free TRAM flaps but not with the MS-2 free TRAM flap when compared with the DIEP flap.

The purpose of this study was to compare equal numbers of women and flaps and to focus on specific subsets of flaps that included only the MS-2 free TRAM and the DIEP flap. The specific outcomes tested included the ability to perform sit-ups, postoperative abdominal bulge/hernia, total flap necrosis, fat necrosis, and venous congestion.

PATIENTS AND METHODS

Demographics

From June of 1999 to June of 2003, a total of 386 women had breast reconstruction after mastectomy. Of these women, 177 women had breast reconstruction using muscle-sparing flaps that included the DIEP flap and the MS-2 free TRAM flap. The DIEP flap was performed on 88 women, of whom 66 had unilateral procedures and 22 had bilateral procedures (110 flaps). The MS-2 free TRAM flap was performed on 89 women, of whom 65 had unilateral procedures and 24 had bilateral procedures (113 flaps). The total number of flaps was 223. The information related to intercostal nerve preservation, timing of the reconstruction, recipient vessels, tobacco use, use of abdominal mesh, number of perforators, and diabetes mellitus is provided (Table I). Analysis of outcomes related to flap loss, venous congestion, fat necrosis, abdominal bulge, and ability to perform sit-ups was performed. Mean

TABLE I
Patient Data

	Unilateral DIEP	Unilateral MS-2 Free TRAM	Bilateral DIEP	Bilateral MS-2 Free TRAM
Flaps	66	65	44	48
Women	66	65	22	24
Mean age (yr)	49.1	49.6	45.9	43.8
Immediate flaps	46	55	32	40
Delayed flaps	20	10	12	8
Internal mammary	26	40	34	9
Thoracodorsal	11	54	10	39
Tobacco use	7	8	0	6
Diabetes mellitus	1	0	2	2
Nerve sparing	66	52	44	42
Abdominal mesh	0	0	0	3

DIEP, deep inferior epigastric perforator flap; MS, muscle sparing; TRAM, transverse rectus abdominis musculocutaneous flap.

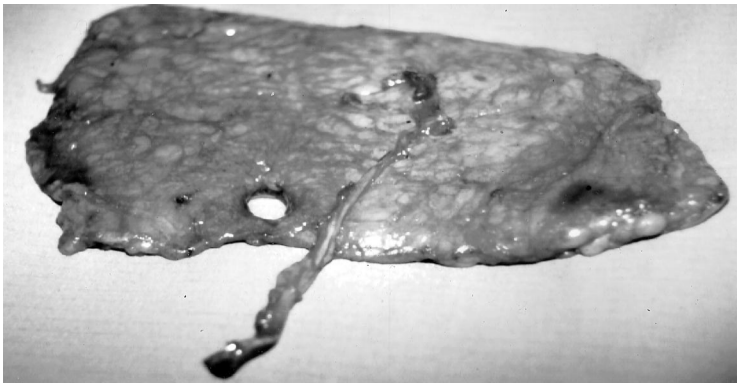

FIG. 1. View of a single-perforator deep inferior epigastric perforator flap. No muscle or fascia has been removed.

follow-up was 23 months (range, 3 to 45 months).

Choice of Flap

The selection criteria for use of the MS-2 free TRAM or DIEP flap have been previously described.[5,16,17] Photographs of the harvested flap and the abdominal wall after the MS-2 free TRAM and DIEP flap procedures are shown in Figures 1 through 4. The frequency of use for each type of flap is provided in Figure 5. The increase in frequency of use for the DIEP flap is partly a reflection of the learning curve for performing the DIEP flap. Early in our experience, it was the primary intent to perform an MS-2 free TRAM flap and to perform a DIEP flap only under ideal anatomic circumstances. With an increased understanding of the anatomy and physiology of the DIEP flap, however, it became the intent of the surgeon to perform a DIEP flap primarily and the MS-2 free TRAM as a back-up procedure. Thus, the selection criteria has been modified from our initial manuscript such that the volume requirement of the breast is no longer a factor justifying a DIEP flap or MS-2 free TRAM flap. The most important factor for performing a DIEP flap is the diameter of the perforator and the most important factor that determines the size and volume of the flap is adequate bleeding from the skin edges. All operations were performed by the primary author to minimize variations in technique.

For unilateral reconstructions, the goal was to almost always design a flap that would result in symmetry with the contralateral breast. In some cases, women would choose to have a smaller reconstructed breast and to have a contralateral reduction mammaplasty. To create a breast with symmetry, considerations related to flap volume and vascular perfusion were important. Preoperative assessment of the volume requirement and intraoperative assessment of the caliber, number, and location of the perforating vessels were routinely performed. The perforators based on the right and left inferior epigastric vessels were visualized. The side with the largest perforator was chosen. When the diameter of the perforators was inadequate (<1.5 mm), consideration was given toward dissecting more than one perforator or for performing an MS-2 free TRAM flap as an alternative means of including more perforators. The dimensions of the removed segment of the rectus abdominis muscle ranged from 2 to 3 cm in width and 3 to 5 cm in length. For the unilateral reconstruction, vascular perfusion of the flap was based on bleeding from the dermal edges. Analysis of the blood supply to these territories has been reported.[18] For bilateral reconstructions, the volume requirement

FIG. 2. View of the abdomen after a bilateral deep inferior epigastric perforator flap procedure. The rectus abdominis muscle is in continuity after longitudinal myotomy, and the anterior rectus sheath is partially reflected.

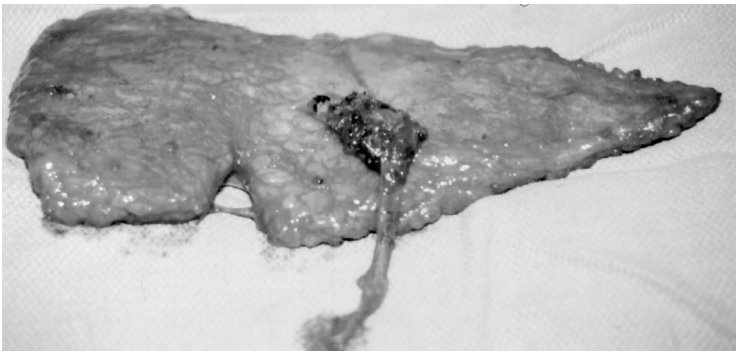

FIG. 3. View of an MS-2 free transverse rectus abdominis musculocutaneous flap demonstrating a 3 × 4-cm segment of the rectus abdominis muscle.

for obtaining symmetry was usually not a factor because the abdominal flaps were divided equally in the midline.

The technique for closure of the anterior abdominal wall after breast reconstruction with the MS-2 free TRAM and DIEP flaps has been previously reported.[19,20] The anterior rectus sheath was reapproximated with nonabsorbable sutures that were placed in an interrupted fashion. The use of Marlex mesh to reinforce the strength and support of the anterior rectus sheath was considered when the fascia was poorly developed or weak. The Marlex mesh, when necessary, was applied in an onlay fashion and secured with nonabsorbable sutures.

Statistical Analysis

Statistical analysis was performed using the FREQ procedure of the SAS system (SAS Institute, Cary, N.C.) based on the chi-square test of association. Fisher's exact test was used when the frequency of a cell was below 5. Statistical analyses of associations between the type of flap (free TRAM or DIEP) and flap loss, venous congestion, fat necrosis, abdominal bulge, and the ability to perform sit-ups were performed separately for the two groups of women who received unilateral and bilateral flaps. The unit of analysis for abdominal bulge and the ability to perform sit-ups was women, and the unit of analysis for fat necrosis, venous congestion, and flap loss was the breast. For bilateral reconstructions, analysis of fat necrosis, venous congestion, and flap loss assumed that the two breasts were independent.

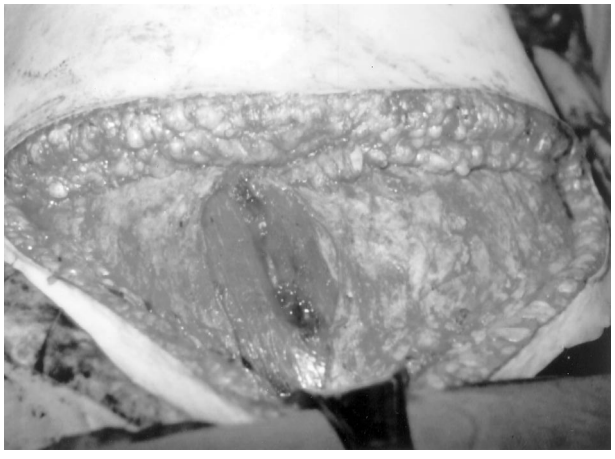

FIG. 4. View of the rectus abdominis muscle after an MS-2 free transverse rectus abdominis musculocutaneous flap procedure. Note that the muscle is in continuity and there is a small central gap.

RESULTS

Overall

The results are provided in Table II and are based on the number of flaps and the number of women. For all MS-2 free TRAM flaps (n = 113), outcome included fat necrosis in eight (7.1 percent), venous congestion in three (2.7 percent), and total necrosis in two (1.8 percent). Of all women having unilateral MS-2 free TRAM flap reconstruction (n = 65), an abdominal bulge occurred in three women (4.6 percent) and the ability to perform sit-ups was documented in 63 (97 percent). Of all women having bilateral MS-2 free TRAM reconstruction (n = 24) an abdominal bulge occurred in five (21 percent) and the ability to perform sit-ups was documented in 20 (83 percent).

For all DIEP flaps (n = 110), outcome included fat necrosis in seven (6.4 percent), venous congestion in five (4.5 percent), and total necrosis in three (2.7 percent). Of all women having unilateral DIEP flap reconstruction (n = 66), an abdominal bulge occurred in one

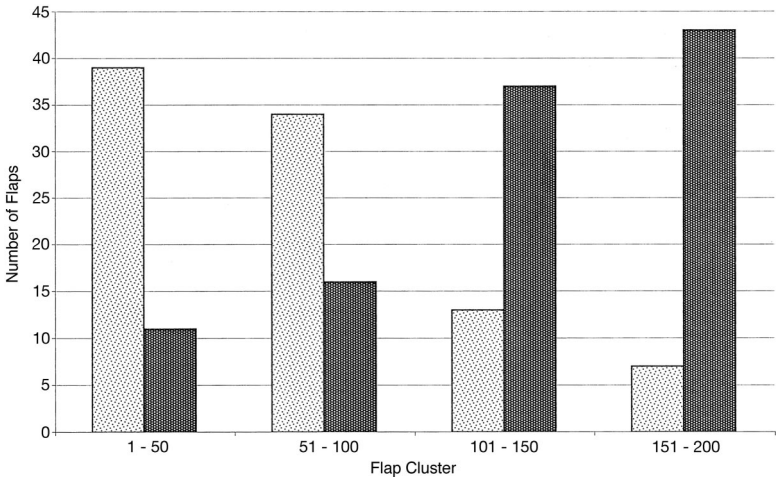

FIG. 5. Frequency of flap type. ■, Deep inferior epigastric perforator flaps; □, free transverse rectus abdominis musculocutaneous flaps.

TABLE II
Results

	Unilateral DIEP	Unilateral MS-2 Free TRAM	Bilateral DIEP	Bilateral MS-2 Free TRAM
Flaps	66	65	44	48
Women	66	65	22	24
Fat necrosis	6 (9%)	7 (11%)	2 (5%)	1 (2%)
Venous congestion	1 (2%)	2 (3%)	4 (9%)	1 (2%)
Flap failure	1 (2%)	2 (3%)	2 (5%)	0
Abdominal bulge	1 (2%)	3 (5%)	1 (5%)	5 (21%)
Ability to perform sit-ups	66 (100%)	63 (97%)	21 (95%)	20 (83%)

DIEP, deep inferior epigastric perforator flap; MS, muscle sparing; TRAM, transverse rectus abdominis musculocutaneous flap.

woman (1.5 percent) and the ability to perform sit-ups was documented in all (100 percent). Of all women having bilateral DIEP flap reconstruction ($n = 22$), an abdominal bulge occurred in one (4.5 percent) and the ability to perform sit-ups was documented in 21 (95 percent). The number of perforators and the relationship to fat necrosis, venous congestion, and flap failure is provided in Table III.

MS-2 Free TRAM versus DIEP Flap

Statistical analysis of the various comparisons is provided in Table IV. Comparing the unilateral MS-2 free TRAM to the unilateral DIEP demonstrates no significant difference with regard to fat necrosis, venous congestion, flap loss, abdominal bulge, and ability to perform sit-ups. Comparison of the bilateral MS-2 free TRAM to the bilateral DIEP flap demonstrates no significant difference with regard to fat necrosis, venous congestion, flap loss, abdominal bulge, and ability to perform sit-ups. The incidence of abdominal bulge after bilateral MS-2 free TRAM reconstruction was 21 percent, whereas the incidence after bilateral DIEP reconstruction was 5 percent. This difference was not statistically significant.

TABLE III
Results by Number of Perforators

	1 Perforator	2 Perforators	3 Perforators
No. of DIEP flaps	84 (76%)	24 (22%)	2 (2%)
Fat necrosis	5 (6%)	2 (8.3%)	0 (0%)
Venous congestion	4 (4.8%)	1 (4.2%)	0 (0%)
Flap loss	2 (2.4%)	1 (4.2%)	0 (0%)

DIEP, deep inferior epigastric perforator.

DISCUSSION

The free TRAM flap and the DIEP flap for breast reconstruction after mastectomy were both described in 1989 and have been extensively studied and compared.[1,3] Our previous study compared the DIEP flap to all types of free TRAM flaps that included the MS-0, MS-1, and MS-2 methods of harvesting the rectus abdominis muscle.[5] A criticism and limitation of this study was that the number of women who had DIEP flaps ($n = 17$) was small relative

TABLE IV
Statistical Analysis

	Unilateral DIEP versus Unilateral Free TRAM	Bilateral DIEP versus Bilateral Free TRAM
Fat necrosis	$p > 0.74$	$p > 0.60$
Venous congestion	$p > 0.61$	$p > 0.18$
Flap loss	$p > 0.61$	$p > 0.22$
Abdominal bulge	$p > 0.36$	$p > 0.18$
Ability to perform sit-ups	$p > 0.24$	$p > 0.34$

DIEP, deep inferior epigastric perforator flap; TRAM, transverse rectus abdominis musculocutaneous flap.

to the number of women who had free TRAM flaps ($n = 118$).[21] In the present study, nearly equal numbers of women were compared and included the DIEP flap in 88 and the MS-2 free TRAM flap in 89. The type of TRAM analyzed was limited to the MS-2 flap because this constitutes the ideal comparison to the DIEP. Both flaps maintain continuity of the rectus abdominis muscle, limit the amount of anterior rectus sheath removed, and usually preserve all branches of the lateral intercostal motor innervation. It could be argued that the superficial inferior epigastric artery flap should be included in this comparison; however, it was not included because elevation of the superficial inferior epigastric artery flap does not require a myotomy or an incision in the anterior rectus sheath and it is based on a different vascular system. In contrast, the DIEP and muscle-sparing free TRAM flaps are both based on the deep inferior epigastric vascular system and both require that the anterior rectus sheath and rectus abdominis muscle be incised. These structures are the principal determinants that are responsible for abdominal contour and strength.

Postoperative abdominal strength after DIEP or muscle-sparing free TRAM flaps is dependent on a variety of factors that includes maintaining the lateral intercostal innervation to the remaining rectus abdominis muscle, minimizing the amount of rectus abdominis muscle removed, the residual vascularity to the muscle, and the amount of scar tissue that form within the muscle.[5,12,22] To understand how these factors can influence postoperative function, a basic understanding of the normal anatomy and function of the rectus abdominis muscle is necessary.

The rectus abdominis is a unique muscle in that it is segmentally innervated, has blood supply based on the inferior and superior epigastric vessels and the intercostal vessels, and has tendinous inscriptions. There are two to three tendinous inscriptions and four to six intercostal nerves throughout its length. During the elevation of the DIEP and the MS-2 free TRAM flaps, alterations in the normal anatomy of the rectus abdominis muscle will occur. With both flaps, the intercostal innervation is usually preserved laterally and divided centrally at the crossover point with the deep inferior epigastric artery and vein. This usually occurs in the middle segment of the rectus abdominis muscle. Given the segmental nature of the innervation of the rectus abdominis muscle, some surgeons believe that division of one or two nerves at the crossover point should not affect the contractile properties of the rectus abdominis muscle; however, others believe that it will.[22] Although numerous studies have demonstrated that denervated muscles can neurotize, this had not been adequately studied in the rectus abdominis muscle after DIEP flap harvest until recently. Bottero et al.[23] have demonstrated that the rectus abdominis muscle will reinnervate when the full width of the muscle and sufficient segmental motor innervation are preserved. This was based on electromyographic examination of the rectus abdominis muscle after unilateral DIEP flap reconstruction demonstrating a return of muscle activity that was 50 percent at 2 months and 70 percent at 15 months when compared with the contralateral nondissected muscle.

The final components of postoperative abdominal strength relate to the remaining vascularity and the amount of intramuscular scar formation. The remaining vascularity is derived primarily from branches of the superior epigastric artery and vein and the remaining intercostal vessels. It has been our observation that the residual vascularity was sufficient to meet the nutritional requirement of the muscle. The amount of scar that forms within the muscle correlates with the length of the muscle segment removed with the MS-2 free TRAM and the length of the myotomy performed with the DIEP flap that is based on a single perforator. For these two situations, the amount of scar tissue that forms within the muscle is generally the same. When more than one perforator is dissected with the DIEP flap, the need to perform parallel myotomies or perpendicular myotomies results in an increase in the amount of scar tissue that is generated within the rectus abdominis muscle.

The evaluation of postoperative abdominal strength after breast reconstruction using abdominal flaps is controversial. Some surgeons believe that isolated testing of the rectus abdominis should be performed using electromyography, myosonographic dynamometry, or isokinetic dynamometry.[11,22–24] These methods are certainly highly specific in assessing the strength of the rectus abdominis muscle. For this study, however, abdominal strength was analyzed based on the ability to perform sit-ups. The authors continue to use this method because it is simple, practical, and allows for comparisons with other types of abdominally based flaps. In addition, most women who choose to have DIEP flap reconstruction are ultimately interested in maintaining postoperative abdominal strength based on the ability to perform sit-ups.

This study has demonstrated that the ability to perform sit-ups is not significantly different among the various groups compared. There does seem to be a trend toward improved abdominal strength after the bilateral DIEP flap, however, as compared with the bilateral MS-2 free TRAM flap. One possible explanation for this observation is that because that the contractile properties of the rectus abdominis muscle are diminished after a myotomy and division of the motor nerves at the crossover point,[23] the reduced width of the muscle that occurs with the MS-2 free TRAM may further limit the strength of the rectus abdominis muscle. This is not clinically evident after the unilateral MS-2 free TRAM because of the ability of the nondissected rectus abdominis muscle to compensate. It becomes clinically evident after the bilateral MS-2 free TRAM because both rectus abdominis muscles are affected.

The contour abnormalities that can occur with the free TRAM and DIEP flaps have been well studied and previously described.[4,5,12,16] This study has reinforced the results of our previous study demonstrating no difference in contour between the MS-2 free TRAM and the DIEP flap. There does seem to be a trend toward an increase in the bulge rate after the bilateral MS-2 free TRAM flap, however, as compared with the bilateral DIEP flap. The authors believe that maximal preservation of the anterior rectus sheath with a strong suture closure will minimize problems with abnormal abdominal contour. After the MS-2 free TRAM, there is usually a 2 × 4-cm segment of anterior rectus sheath that is excised with the rectus abdominis muscle. Removal of this fascia after unilateral reconstruction does not seem to make a difference because there is often redundant fascia and plication of the fascia usually results in good contour. There seems to be a predisposition toward abnormal contour after bilateral reconstruction using the MS-2 free TRAM. Possible explanations include a change in the normal dynamics of the anterior rectus sheath that is created with the fascial excision and repair, an inherent weakness in the strength of the anterior rectus sheath resulting in facial attenuation, and a fascial constriction that occurs after the excision of the fascia with the flap and its repair. The need to reinforce the anterior abdominal wall with a synthetic material such as Marlex mesh at the time of the breast reconstruction is occasionally necessary and was applied in three women after bilateral MS-2 free TRAM but was never used after the unilateral MS-2 free TRAM, the unilateral DIEP flap, or the bilateral DIEP flap. During the repair of a postoperative bulge, Marlex mesh is always used to reinforce the anterior abdominal wall after plication of the anterior rectus sheath. The authors recognize that the range of follow-up beginning at 3 months for evaluation of a postoperative bulge could be considered early. It has been our observation that abnormal abdominal contour is present by 3 months after these operations. This was the case for all women included in this study.

Analysis of flap-related morbidity that included fat necrosis, venous congestion, and total necrosis demonstrated no significant difference between the MS-2 free TRAM flap and the DIEP flap. This was also observed in our previous study.[5] To minimize flap-related morbidity, it is the authors practice to be selective in the performance of the MS-2 free TRAM flap and the DIEP flap. The final decision occurs in the operating room after assessment of the perforating vessels. This practice of selecting appropriate women for the DIEP flap has also been reported by others.[16,17] It seems that as surgeons become more comfortable with harvesting the DIEP flap and understand the anatomic and physiologic alterations that regulate flap perfusion, the frequency of usage increases. Perforator diameter has become the principal determinant affecting DIEP flap performance. The diameter of the perforators that have been used has ranged from 1.5 to 4 mm. The diameter usually correlates with the volume of abdominal tissue present. Bleeding

from skin edges of the flap usually confirms that perfusion is adequate.

With the recent "Gent" consensus of perforator flap terminology, explanations for untoward outcomes are facilitated.[25] Of the five types of perforators described, three have been routinely observed with the DIEP flap. These include indirect perforators traversing through muscle to the flap (type 2), indirect perforators with a smaller branch supplying the flap (type 3), and indirect perforators that course medially around the muscle to the flap (type 5). The perforator topography has been well characterized and found to include a short intramuscular course in 65 percent, a long intramuscular course in 9 percent, a subfascial course in 5 percent, a paramedian course in 5 percent, and a perforator at the tendinous inscription in 16 percent.[26] Although venous congestion is uncommon with the MS-2 free TRAM and DIEP flaps, it has been our experience to observe this phenomenon more often in the case of a type 3 perforator in which the flap is supplied by small branch from an indirect perforator. These perforators are generally of smaller caliber when compared with all other perforators. Unfortunately, the type of perforator is recognized after the commitment to a DIEP flap and the factors related to flap perfusion can no longer be controlled. Other explanations for fat necrosis and venous congestion include a dominant superior epigastric venous system when compared with the inferior epigastric venous system that is the basis for these flaps.[14] Fat necrosis has been found to occur equally in the MS-2 free TRAM and the DIEP flaps and is a reflection of the blood supply to and from the flap. Analysis of specific factors associated with anastomotic failure and total flap necrosis after microvascular reconstruction of the breast has been previous studied and reported.[27]

CONCLUSIONS

It seems that the removal of a small central segment of the rectus abdominis muscle with maximal preservation of the intercostal innervation (MS-2 free TRAM) does not make a difference when comparing outcomes observed with the DIEP flap, especially for the unilateral reconstruction. There does seem to be a trend for improved abdominal strength and contour after bilateral DIEP flap reconstruction. Although there may ultimately be a statistically significant improvement in abdominal contour after the bilateral DIEP flap when compared with the bilateral MS-2 free TRAM flap, it was not demonstrated in this series of women. On the basis of these results, the DIEP flap can be successfully performed in the majority of women without an increase in fat necrosis, venous congestion, or flap failure when compared with the MS-2 free TRAM flap. Prospective women should be aware that removal of a small segment of the rectus abdominis muscle (MS-2 free TRAM) is not likely to result in additional abdominal morbidity such as weakness or bulge.

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