Computed Tomographic Angiography with VirSSPA Three-Dimensional Software for Perforator Navigation Improves Perioperative Outcomes in DIEP Flap Breast Reconstruction

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Background: Vascular anatomy of the abdominal wall varies greatly, especially in the case of the perforator branches of the deep inferior epigastric artery. Preoperative three-dimensional reconstructions with VirSSPA software have been used in the authors' center since the year 2007 for the planning of perforator flaps in breast reconstruction. The main objectives were to reduce surgery time and the number of complications.
Methods: A comparative study was conducted in 70 patients subjected to delayed breast reconstruction based on unilateral deep inferior epigastric perforator (DIEP) flaps. Half of the patient group underwent preoperative imaging with computed tomographic angiography–guided VirSSPA reconstruction, whereas the other half was subjected to preoperative Doppler ultrasound for perforator mapping. Operation time ranges, lengths of stay, and operative complications were assessed.
Results: The use of VirSSPA preoperative planning correlated with operative times reduced by a mean of 2 hours 8 minutes. In addition, a statistically significant reduction (>45 percent) in the incidence of any flap-related complications was observed in patients undergoing preoperative computed tomographic angiography–guided VirSSPA reconstruction and a decrease above 50 percent in overall donor-site morbidity. The use of computed tomographic angiography–guided VirSSPA three-dimensional reconstruction was found to be a protective factor against developing any kind of complication after DIEP flap surgery (odds ratio, 0.03; 95 percent confidence interval, 0.006 to 0.15).
Conclusions: Computed tomographic angiography–guided VirSSPA three-dimensional reconstruction in the assessment of perforator flaps was proved to be safe and reliable. The main benefits of this technique were the reduction of surgical time and reduction of the number of complications. (*Plast. Reconstr. Surg.* 125: 24, 2010.)

Currently, the first option in breast reconstruction with autologous tissue is the abdominal perforator flap, because of the similarity of this tissue to that of the breast.[1] Vascular anatomy of the abdominal wall varies greatly, especially in the case of the perforator branches of the deep inferior epigastric artery (DIEA). For this reason, a presurgically established vascular map can facilitate surgical planning in each patient.[2–4]

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Computed tomographic angiography–guided VirSSPA three-dimensional software for virtual reality navigation in DIEP flap surgery has been de-

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veloped in our hospital by a multidisciplinary team composed by both specialists in simulation and virtual reality applications and medical doctors. Although it can be used for a wide range of reconstructive procedures,[5] VirSSPA software has been shown to be highly accurate in demonstrating the intramuscular, subfascial, and subcutaneous segments of individual DIEA perforators, with a reported average error rate of 0.23 cm from the real distances measured intraoperatively.[6] Despite the accuracy and potential benefits of VirSSPA software, improvements in operative outcomes have not been formally demonstrated.

VirSSPA has been used in our center for the planning of perforator flaps in breast reconstructions since the end of 2007. The aim to introduce this technique was to better map the perforators to reduce the dissection time of the flap and the number of complications. The current study examines the potential for preoperative computed tomographic angiography–guided VirSSPA reconstruction to improve perioperative outcomes in autologous breast reconstruction. Prospective data from patients undergoing preoperative imaging with computed tomographic angiography–VirSSPA are compared with results from patients undergoing equivalent surgery with the same surgeons but without the use of computed tomographic angiography–guided VirSSPA. The outcomes attributable to computed tomographic angiography–guided VirSSPA reconstructions, including benefits to flap survival, donor site morbidity, length of operation, and overall length of hospital stay, are assessed.

PATIENTS AND METHODS

A prospective study of patients undergoing preoperative imaging with computed tomographic angiography and a VirSSPA three-dimensional virtual reality model for breast reconstruction was undertaken. Between January of 2008 and February of 2009, 35 consecutive patients were included in the study and referred for computed tomographic angiography scanning at a single institution. An approval from the ethical committee of the hospital was obtained to carry out this study, and all patients gave verbal and written informed consent. A comparative group was formulated by performing a retrospective review of patients operated on by the same primary and assisting surgeons at the same institution. Thirty-five such patients underwent autologous breast reconstruction with a DIEP free flap between May of 2004 and December of 2007, all of them with a Doppler ultrasound performed preoperatively.

The radiologic techniques were performed by the same radiology team. Twelve patients were excluded from the study under exclusion criteria that included previous abdominal donor-site free flaps or other extensive surgery to the anterior abdominal wall, active smoking at the time of surgery, refusal of voluntary informed consent to participate, and bilateral and immediate reconstruction. This selection was made to prevent a mismatch in surgery time because of different types of reconstruction.

A minimum of 3 months' follow-up was required and achieved for all patients. Comprehensive data sheets were compiled, with the corresponding data collected from patient medical records by the primary investigator. Details on patient demographics, comorbidities, neoadjuvant treatments, surgical data, extent of hospital stay, complications, and length of intravenous analgesia were collected. Because of the great variability in analgesic prescription patterns, we decided to take into account the duration in days rather than doses or type of analgesic drug used.

Specific parameters that might potentially contribute to surgical complications were examined. These included patient age at operation, obesity (body mass index >30), number of perforators to supply the flap above two, patient comorbidities (diabetes and hypertension), use of chemotherapy, flap harvesting time (average time from the first skin incision to the autonomization of the flap) exceeding 150 minutes, ischemia times longer than 60 minutes, and operative times (defined as the time between the first incision and wound closure) going beyond 500 minutes, and the use of VirSSPA software for surgical planning.

The Microsurgery Section at Virgen del Rocío University Hospitals, Sevilla, Spain, consists of three plastic surgeons and one resident on surgical rotation. The number of DIEP flaps performed since the beginning of 2003 is approximately 35 to 40 per year.

Computed Tomographic Scanning Technique

Computed tomographic angiography studies were obtained by means of a 16-detector-row computed tomography scanner (General Electric LightSpeed 16; General Electric Company, Fairfield, Conn.). Computed tomographic scans were performed using the following parameters: 0.37-second gantry rotation speed, 0.63-mm collimator width slice thickness, and 1.37 helical detector pitch. X-ray tube voltage was 120 kV and tube current was 250 to 300 mA. All scanning took place after intravenous

administration of 100 ml of nonionic iodinated contrast medium at a concentration of 350 mg/ml (Omnipaque 350; GE Healthcare, Barcelona, Spain). The contrast material was injected mechanically (Stellant Medrad, Indianola, Pa.) at a rate of 4 ml/second through an 18-gauge intravenous catheter inserted into an antecubital vein. The scanning delay was approximately 30 seconds. Bolus tracking was performed with the region of interest on the aorta, just above the aortic bifurcation. Scanning was initiated approximately 10 seconds after the region of interest reached 100 HU.

Sections were obtained from 4 cm above the umbilicus to the lesser trochanter of the hip in a single breath hold. The approximate time of acquisition was 10 to 12 seconds. The entire procedure took less than 10 minutes and was, therefore, very well tolerated by the patient. The volumetric data acquired were then used to reconstruct images with a slice width of 0.63 mm and a reconstruction interval of 0.8 mm. The resulting complete set of reconstructed images was automatically transferred to a computer workstation, which generated multiplanar reformatted images and three-dimensional volume-rendered images. Data were stored as a digital imaging and communications in medicine–compatible file onto a CD-ROM to be loaded into a personal computer with VirSSPA software.

The three-dimensional reconstruction of the abdominal wall was carried out by the primary investigator. The suitability of each perforator was then analyzed. Their caliber, course, and anatomical relationships were evaluated, locating the exact point of emergence through the aponeurosis of the abdominal rectus (Fig. 1). Using these three-dimensional images, perforators were marked on a grid centered on the umbilicus and printed on a transparent template scale (1:1) to allow their transposition onto the abdominal skin of the patient.

Statistical Analysis

Data are represented as mean values ± SD. A Kolmogorov-Smirnov test was undertaken to determine that all data were normally distributed. Two-sample t and chi-square tests were used to compare the groups. Fisher's exact test was applied when expected values were less than 5. Adjusted odds ratios, 95 percent confidence intervals, and p values were calculated by using multiple logistic regression analyses. Statistical significance was considered to be $\alpha \leq 0.05$. Analysis of data was performed using the SPSS version 15.0 (SPSS, Inc., Chicago, Ill.).

RESULTS

Demographics

Patients undergoing computed tomographic angiography with VirSSPA three-dimensional reconstruction for the imaging of DIEA perforators were compared with those not subjected to this imaging. The demographics of the two groups are shown in Table 1, which points to the absence of statistically significant differences between the groups in demographic factors. In the computed tomographic angiography–guided VirSSPA group, all reconstructions were performed after mastectomy resulting from breast cancer. In 94.28 percent of the cases in the control group, reconstructions were carried out because of breast cancer, whereas two patients had reconstructions on account of extreme deformities after removal of an infected prosthesis. All patients in both groups underwent delayed breast reconstruction.

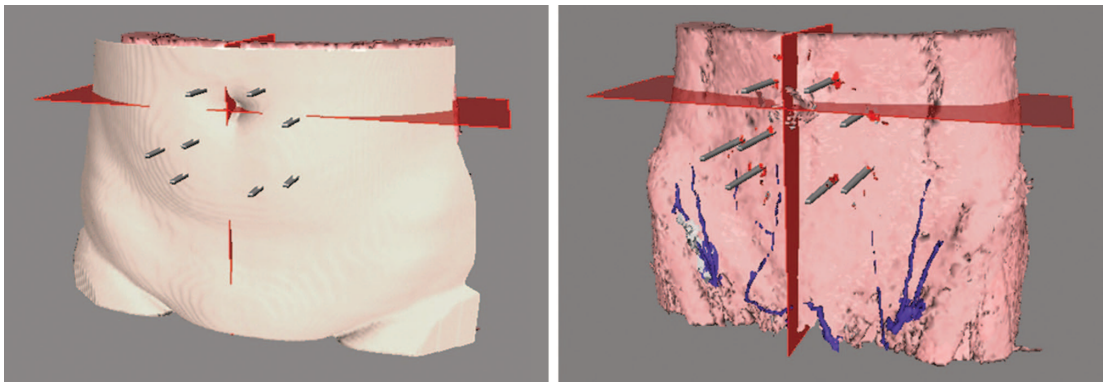

Fig. 1. Three-dimensional abdominal wall reconstruction with VirSSPA software from computed tomographic angiography images. (*Left*) Emergence of multiple perforators from the anterior rectus sheath and through the abdominal skin located with *gray posts*. (*Right*) Perforators and their course through the muscle without the skin envelope. The superficial inferior epigastric system is marked in *blue*.

Table 1. Demographics of Patients Undergoing Preoperative Computed Tomography Angiography with or without VirSSPA Three-Dimensional Reconstruction*

Patient Demographics	Control Group (Doppler Ultrasound) (%)	Experimental Group (VirSSPA) (%)	*p*
General			
Age (yr)	47.09 ± 7.05	48.89 ± 7.52	0.305
Body mass index	25.86 ± 2.86	27.17 ± 3.66	0.100
Neoadjuvant therapies			
None	5 (14.28)	5 (14.28)	1.000
Radiotherapy	10 (28.57)	10 (28.57)	1.000
Chemotherapy	2 (5.71)	2 (5.71)	1.000
Hormonal	11 (31.42)	11 (31.42)	1.000
Combination	7 (20)	7 (20)	1.000
Hypertension	6 (17.14)	8 (22.85)	0.766
Diabetes	3 (8.57)	2 (5.71)	1.000

*The total sample size was 70 patients, 35 patients in the control group (Doppler ultrasound) and 35 patients in the experimental group (VirSSPA).

Surgery

The internal mammary vessels were used as receptor site in all cases. Anastomoses were always end-to-end and sutured by hand.

In the computed tomographic angiography–guided VirSSPA group mean, ischemia time was 70 ± 15.71 minutes and flap harvesting time 130 ± 41.49 minutes. In the control group, the mean ischemia time was 97.71 ± 26.01 minutes and flap harvesting time was 217.86 ± 60.10 minutes (Table 2).

The mean total operative time in the computed tomographic angiography–guided VirSSPA group was 478 ± 56.94 minutes as compared with a mean value of 606.29 ± 81.94 minutes in the control group. Thus, operative times were reduced by a mean of 2 hours 8 minutes when DIEP flaps were performed after computed tomographic angiography–guided VirSSPA perforator mapping ($p < 0.001$). This value accounts for a reduction of almost 25 percent as a result of preoperative perforator mapping (Fig. 2).

Length of Hospital Stay

The total length of hospital stay for each patient, from admission until discharge, was reviewed for all patients in both groups. The mean length of hospital stay for computed tomographic angiography–gided VirSSPA patients was 9.4 days, whereas that for thecontrol group was 9.8 days. Although a trend was observed among patients undergoing preoperative computed tomographic angiography–guided VirSSPA to shorten their extent of hospital stay by approximately half a day, this finding did not reach statistical significance (Table 2).

The mean length of intravenous analgesia for computed tomographic angiography–guided VirSSPA patients was 3.34 days, and this parameter was 4.86 days for the control group. Therefore, the length of intravenous analgesia in the computed tomographic angiography–guided VirSSPA group was significantly lower and the decrease accounted for a mean of 1½ days when comparing DIEP flaps performed after computed tomographic angiography–guided VirSSPA perforator mapping was introduced ($p < 0.001$). Also, the number of red cell concentrates transfused was reduced by 64 percent as a result of preoperative perforator mapping with computed tomographic angiography–guided VirSSPA ($p = 0.005$) (Table 2).

Table 2. Mean Operative Data of Patients Undergoing Preoperative Computed Tomography Angiography with or without VirSSPA Three-Dimensional Reconstruction

	Control Group (Doppler Ultrasound)	Experimental Group (VirSSPA)	*p*
Surgery data			
No. of perforators in the flap	2.34 ± 0.76	2.26 ± 0.70	0.626
Flap harvesting time (min)	217.86 ± 60.10	130.00 ± 41.49	<0.001*
Ischemia time (min)	97.71 ± 26.01	70 ± 15.71	<0.001*
Total operative time (min)	606.29 ± 81.94	478 ± 56.94	<0.001*
Postoperative data			
Length of intravenous analgesia (days)	4.86 ± 1.97	3.34 ± 0.96	<0.001*
Length of hospital stay (days)	9.80 ± 1.81	9.40 ± 1.76	0.353
Red cell concentrates transfused	1.09 ± 1.14	0.40 ± 0.77	0.005*
Reexploration	6 (17.14%)	0 (0%)	0.025*

*Statistical significance.

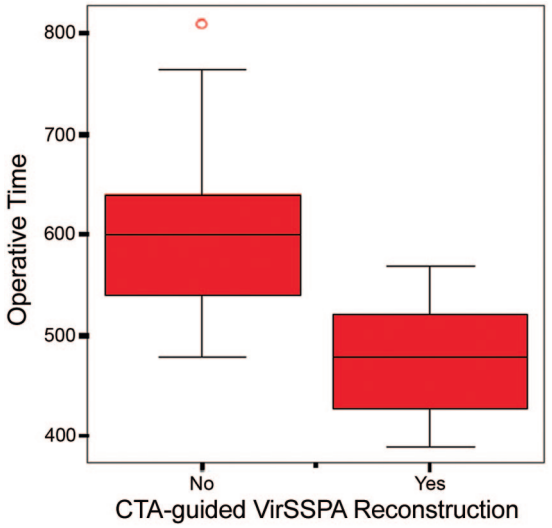

Fig. 2. Mean total surgery time (in minutes) with or without VirSSPA. Error bars represent the confidence interval of the mean (confidence interval, 95 percent). *CTA*, computed tomographic angiography.

Flap-Related Complications

Complications were classified as hematoma, infection, partial necrosis (<75 percent tissue loss), total necrosis or flap failure (>75 percent tissue loss), fat necrosis, seroma, arterial insufficiency, venous insufficiency, or a combination of the last two complications. Early fat necrosis was noted when lumps were palpable in the flap seen in the clinic at 2 weeks postoperatively or when there was a fluid discharge consistent with fat necrosis. Delays in wound healing, whether attributable to infection or otherwise, were also noted.

No complications occurred in the computed tomographic angiography–guided VirSSPA group when compared with the control group (0 percent versus 45.68 percent). In the control group, 14 patients presented flap-related complications. Fat necrosis was observed in three cases, and hematoma and seroma were observed twice each. Revision of the anastomoses was needed in three cases. All flaps were successful in the computed tomographic angiography–guided VirSSPA group. In contrast, two flaps failed, and partial necrosis occurred in four flaps in the control group. Flap venous congestion alone was not observed in any case. Differences between the two groups were not sufficiently large to reach statistical significance in terms of individual complications. However, a correlation was established to a statistically significant reduction (>45 percent) in the incidence of any flap-related complications in patients undergoing preoperative computed tomographic angiography–guided VirSSPA ($p < 0.001$) (Table 3).

Donor-Site Morbidity

Donor-site complications were assessed, comprising a review of abdominal bulge, hematoma, seroma, infection, abdominal herniation, abdominal flap necrosis, and wound dehiscence. No cases of abdominal bulge or herniation were detected in patients who underwent preoperative computed tomographic angiography–guided VirSSPA. In contrast, there were three cases of abdominal bulges in the control group. Seroma was present in four patients in the control group and in two patients in the computed tomographic angiography–guided VirSSPA group. A comparison between both groups revealed a statistically significant reduction (>50 percent) in overall donor-site morbidity in all patients undergoing computed tomographic angiography–guided VirSSPA ($p = 0.001$) (Table 3).

Systemic Complications

One patient developed a pleural effusion, another suffered an acute myocardial infarction, and three more patients presented a deep venous thrombosis. All these patients were included in the control group, which means that 14.28 percent of the 35 patients of the control group developed a systemic complication. However, this observation did not reach statistical significance when compared with the computed tomographic angiography–guided VirSSPA group ($p = 0.054$) (Table 3).

Analysis of Risk Factors and Complications

No significant relationships were found between obesity, diabetes, hypertension, chemother-

Table 3. Overall Complications after DIEP Flap Breast Surgery of Patients Undergoing Preoperative Computed Tomography Angiography with or without VirSSPA Three-Dimensional Reconstruction

	Control Group (Doppler Ultrasound)	Experimental Group (VirSSPA)	Total	*p*
DIEP complications	14	0	14	<0.001*
Donor-site complications	15	2	17	0.001*
Systemic complications	5	0	5	0.054

*Statistical significance.

apy, or more than two perforators recruited to supply the flap and complications after DIEP flap surgery. Patients showing ischemia times longer than 60 minutes and with total operative times longer than 500 minutes were significantly more prone to any kind of complications after DIEP flap surgery than those with minor times (odds ratio, 19.20; 95 percent confidence interval, 2.38 to 154.45; and odds ratio, 11; 95 percent confidence interval, 2.31 to 52.27, respectively). Subsequent analysis revealed that patients with flap harvesting times longer than 150 minutes were five times more likely to present complications after breast reconstruction surgery with DIEP flap (odds ratio, 5; 95 percent confidence interval, 1.59 to 15.67) (Table 4). However, the use of computed tomographic angiography–guided VirSSPA three-dimensional reconstruction was found to be a protective factor against the development of this type of complication after DIEP flap surgery (odds ratio, 0.03; 95 percent confidence interval, 0.006 to 0.15).

Odds ratios revealed that DIEP flap–related complications were strongly associated with patients having total operative times longer than 500 minutes and flap harvesting times longer than 150 minutes. A patient undergoing DIEP flap surgery was thus 9.06 times more likely (odds ratio, 9.06; 95 percent confidence interval, 1.10 to 74.17) and 13.96 times more likely (odds ratio, 13.96; 95 percent confidence interval, 1.70 to 114.07), respectively, to show a DIEP flap-related complication after breast reconstruction surgery when compared with a patient with shorter surgery times. However, the use of computed tomographic angiography–guided VirSSPA three-dimensional reconstruction was also found to be a protective factor against developing any type of DIEP flap-related complications after DIEP flap surgery (odds ratio, 0.002; 95 percent confidence interval, 0.001 to 0.25). No other statistically significant differences between risk factors and DIEP flap-related complications were found.

A bivariate logistic regression analysis was undertaken including as a dependent variable the risk of presenting any type of complication after DIEP flap surgery, and considering as independent variables the use of VirSSPA software for perforator mapping, operative times longer than 500 minutes, harvesting times over 150 minutes, and ischemia times longer than 60 minutes. Regression analysis revealed that the use of computed tomographic angiography–guided VirSSPA reconstructions was the only independent variable to maintain its statistical significance. Therefore, the probability of presenting any type of complication after DIEP flap breast reconstruction without using the computed tomographic angiography–guided VirSSPA three-dimensional reconstruction for perforator mapping is 31 times higher than when using the VirSSPA program (odds ratio, 31.62; 95 percent interval, 6.45 to 154.89).

DISCUSSION

The perforator characteristics identified on computed tomographic angiography–guided VirSSPA three-dimensional reconstructions have been directly translated into improved outcomes. Operating times and hospital stays are slightly longer than those in earlier reports.[7–9] In our experience, a unilateral DIEP flap breast reconstruction can be performed within 7 hours. In cases of difficult perforator harvest or insufficient venous outflow, a DIEP flap operation can take much longer. In the current series, unilateral DIEP flap reconstructions lasting more than 8 hours had significantly more flap complications. Operative times were increased because the unit is a major center for surgical training and part of the surgery was carried out by the resident in a high proportion of operations, inevitably increasing operative times.

The most threatening complications in this series were systemic complications, particularly thromboembolism, which was recorded in three of 35 patients (8.57 percent). These figures are

Table 4. Analysis of Risk Factors and Any Type of Complication after DIEP Flap Breast Surgery

	Odds Ratio	95% Confidence Interval	*p*
VirSSPA	0.03	0.006–0.15	<0.001*
Diabetes mellitus	2.93	0.45–1886	0.257
Hypertension	0.66	0.18–2.39	0.535
Chemotherapy	1.87	0.24–14.15	0.545
Body mass index (>30)	1.52	0.36–6.28	0.560
No. of perforators >2	0.64	0.23–1.75	0.389
Ischemia time >60 min	19.20	2.38–154.45	0.005*
Flap harvesting time >150 min	5.00	1.59–15.67	0.006*
Operative time >500 min	11.00	2.31–52.27	0.003*

*Statistical significance.

higher than those found in the literature for abdominoplasty combined with other procedures[10] but are difficult to interpret because of the small size of the series.

Today, health care faces new challenges such as increased costs and the need to raise efficiency.[11] The cost of one preoperative computed tomographic angiography mapping is approximately €300 (U.S. $390) in our hospital but may vary depending on the institution concerned. Computed tomographic mapping can therefore be carefully coordinated with the oncology team so that it might form part of the routine oncology staging investigations that the patient may undergo in any case.[12] This possibility eliminates such issues as the x-ray dosage and the extra costs of computed tomographic angiography mapping.

We observed that preoperative VirSSPA three-dimensional reconstruction for mapping of the donor site in microvascular perforator flap reconstruction diminishes surgery time and complications. Because the cost of time in the operating room in our hospital has been calculated approximately as €460 (U.S. $600) per hour, savings in operative time pays significant dividends in reducing the use of resources. The total cost of DIEP breast reconstruction could be decreased by reducing surgery time. Although the cost of one computed tomographic angiography scan was approximately €300 (U.S. $390), the reduction in surgery time led to an average saving of approximately €1000 (U.S. $1300) per patient.

VirSSPA software three-dimensional reconstructions are easy to interpret. We consider that the learning of this technique is not difficult and can be readily mastered by any motivated surgeon. However, there is a short learning curve and it takes approximately 30 minutes to create the image. It seems important to note the fact that the interpretation of the computed tomographic angiography images is operator dependent, so that as the experience of the radiologist increases, more accurate mapping is performed. This may be reduced with VirSSPA reconstructions for perforator mapping because image interpretation can be accordingly performed by the surgeon in an intuitive and easy way. After VirSSPA reconstruction, the various data are stored on a CD ready to be used and easily managed with a standard computer and subsequently reviewed as often as necessary. Therefore, interpretation and display of the images by the radiologist becomes unnecessary.

This novel approach has enabled us to accurately delineate the course of the perforators across the entire abdomen in individual patients. The precision for locating the perforator emergence through the abdominal wall may be even superior to conventional computed tomographic angiography techniques.[6] This could permit making firm preoperative decisions as to which side the flap will be pedicled on, whether we should raise a muscle-sparing transverse rectus abdominis musculocutaneous flap in patients with small perforators, or when there is a long intramuscular course. Besides, it allows us to determine the exact location and caliber of the superficial epigastric system, which is important in planning a superficial inferior epigastric artery perforator flap or as an alternative venous drainage system to solve complications in a DIEP flap. Our virtual reality model changes the usual procedure for harvesting the flap because there is no need to assess the value of the perforators by careful dissection and intraoperative selection of the more suitable ones as performed previously. Therefore, one can go straight to the chosen perforators with confidence to ligate safely the other perforators without wasting time.

Although the current study has been comprehensive in inclusion and exclusion criteria, several limitations were unavoidable and warrant consideration. A retrospective comparison of non–computed tomographic angiography cases with prospective computed tomographic angiography cases was suboptimal. However, we considered that the more significant variables when analyzing operative outcomes were surgical factors, and thus the study was designed to control for the surgeon rather than for the nature of the trial. A minimum of 3 months' follow-up was given for all cases. Nevertheless, it was noticeable that the control group had a longer follow-up period, which may have resulted in the inclusion of later complications that were missed in the computed tomographic angiography–guided VirSSPA group. Revisions of the literature led to the fact that the only DIEP flap surgery–related complications classified as late complications (>6 weeks) were fat necrosis, bulging, and herniation.[8,13] In our series, those complications did not reach statistical significance when analyzed individually between both groups.

Another limitation of this study was the selection criteria; the complete computed tomographic angiography–guided VirSSPA group had surgery after the control group. Whether our results are attributable to the introduction of VirSSPA or other factors such as increased experience, improved theater set-up, and patient selection is unknown. Before the introduction of VirSSPA, approximately 100 DIEP breast recon-

structions had been performed in our unit. During this period, no significant decrease in surgery time or complications was observed. Taking this into account, it seems more likely that the current decrease in operating time can be attributed directly to the introduction of VirSSPA.

CONCLUSIONS

Computed tomographic angiography–guided VirSSPA three-dimensional reconstruction in the assessment of perforator flaps was proved to be safe and reliable. The key advantage of this technique is that it prevents the time lost by dissecting small perforators when larger ones exist elsewhere, thus helping in the reduction of surgery time. There are also indications that it positively influences the survival rate of flaps, but larger series are needed to confirm this outcome.

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