Sensory Recovery of the Breast following Innervated and Noninnervated DIEP Flap Breast Reconstruction

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Background: The sensory recovery of the breast remains an undervalued aspect of autologous breast reconstruction. The aim of this study was to evaluate the effect of nerve coaptation on the sensory recovery of the breast following DIEP flap breast reconstruction and to assess the associations of length of follow-up and timing of the reconstruction.

Methods: A prospective comparative study was conducted of all patients who underwent either innervated or noninnervated DIEP flap breast reconstruction and returned for follow-up between September of 2015 and July of 2017. Nerve coaptation was performed to the anterior cutaneous branch of the third intercostal nerve. Semmes-Weinstein monofilaments were used for sensory testing of the native skin and flap skin.

Results: A total of 48 innervated DIEP flaps in 36 patients and 61 noninnervated DIEP flaps in 45 patients were tested at different follow-up time points. Nerve coaptation was significantly associated with lower monofilament values in all areas of the reconstructed breast (adjusted difference, −1.2; $p < 0.001$), which indicated that sensory recovery of the breast was significantly better in innervated compared with noninnervated DIEP flaps. For every month of follow-up, the mean monofilament value decreased by 0.083 in innervated flaps ($p < 0.001$) and 0.012 in noninnervated flaps ($p < 0.001$). Nerve coaptation significantly improved sensation in both immediate and delayed reconstructions.

Conclusions: This study demonstrated that nerve coaptation in DIEP flap breast reconstruction is associated with a significantly better sensory recovery in all areas of the reconstructed breast compared with noninnervated flaps. The length of follow-up was significantly associated with the sensory recovery. (*Plast. Reconstr. Surg.* 144: 178e, 2019.)

The deep inferior epigastric artery perforator (DIEP) flap, being the first choice for autologous breast reconstruction in many centers, yields permanent and aesthetically pleasing results with high patient satisfaction and quality of life.[1,2] However, the sensory recovery of the breast remains an undervalued aspect of breast reconstruction, and surgical reinnervation is not regarded as a priority by most reconstructive surgeons.[3,4] This is surprising, considering the importance of the sensation of the breast to a woman, the positive effect sensory recovery of the breast has on quality of life after breast reconstruction,[5,6] and the function it has to protect the skin against injuries.[7,8] Nevertheless, the use of sensate flaps in breast reconstruction has been very limited despite the availability of appropriate donor and recipient nerves.[9]

Sensation of the normal breast is provided medially by the anterior cutaneous branches of

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the first to sixth intercostal nerves, laterally by the lateral cutaneous branches of the second to sixth intercostal nerves, and cranially by branches of the supraclavicular nerve.[10,11] The nipple-areola complex is mainly supplied by the lateral cutaneous branch of the fourth intercostal nerve. Therefore, this branch has routinely served as the recipient nerve for coaptation since Slezak et al. first described innervated transverse rectus abdominis myocutaneous flaps for autologous breast reconstruction in 1992.[12,13] The first case series of DIEP flaps for breast reconstruction, including an innervated flap using the fourth intercostal nerve, was published by Allen and Treece in 1994.[14] However, nerve coaptation to the lateral cutaneous branch of the fourth intercostal nerve may be difficult and time consuming because it is often injured during mastectomy. Therefore, Spiegel et al. presented a technique to use the anterior cutaneous branch of the third intercostal nerve for coaptation that is located in the same microsurgical field as the internal mammary vessels, adding minimal time to surgery.[3,15]

Previous studies have shown highly variable results in terms of sensory recovery of the breast following both nerve coaptation and spontaneous reinnervation, further questioning the necessity of nerve coaptation.[13,16–18] To the best of our knowledge, this is the largest comparative study to evaluate sensory recovery after nerve coaptation (innervated) and spontaneous reinnervation (noninnervated) of DIEP flap breast reconstruction.

The aim of this study was to evaluate the effect of nerve coaptation on the sensory recovery of the breast following DIEP flap breast reconstruction. Secondary study objectives were the associations of length of follow-up and timing of the reconstruction with the return of sensation.

PATIENTS AND METHODS

In this prospective cohort study, patients who underwent DIEP flap breast reconstruction between January of 2010 and July of 2016 at Maastricht University Medical Center in The Netherlands were recruited. Nonconsecutive patients who had a postoperative control visit at the outpatient clinic between September of 2015 and July of 2017 were included. Sensory testing of their breasts was performed during different visits. Inclusion criteria were women older than 18 years, unilateral or bilateral DIEP flap breast reconstruction, control visit during the study period, and informed consent. Patients with a bilateral breast reconstruction with one innervated and one noninnervated DIEP flap were excluded for statistical reasons. Flaps that required a take-back were also excluded because the coapted nerve is usually ruptured.

Breast reconstructions were performed after mastectomy for breast cancer or after prophylactic mastectomy. In immediate breast reconstruction, skin-sparing mastectomy was performed. The study population was divided into two groups: patients who underwent DIEP flap breast reconstruction either with or without sensory nerve repair. Only reconstructed breasts with nerve repair by direct coaptation were included, whereas cases with nerve repair using nerve conduits or grafts were excluded. The study was performed in accordance with the ethical standards of the Declaration of Helsinki and was approved by the institutional review board committee.

Surgical Technique

Before surgery, magnetic resonance angiography of the abdomen[19] is performed, and the perforators of the deep inferior epigastric artery are located with a hand-held Doppler device. The DIEP flap harvest is performed in standard fashion, carefully dissecting the abdominal flap from lateral to medial. The donor nerve used for nerve coaptation is a cutaneous branch running with the perforators in the subcutaneous tissue and originates from the tenth to twelfth intercostal nerve, depending on the selection of the perforators and nerve. The lower intercostal nerves pass between the internal oblique and transversus abdominis muscles and run from posterior to inferior in an inferomedial direction toward the lateral edge of the rectus sheath. The anterior branches pass through the posterior lamina of the rectus sheath and enter the rectus abdominis muscle at variable locations as a single trunk or as multiple branches. These mixed nerves then split into one or more motor branches, running medially and laterally in the rectus abdominis muscle, and also into one or more sensory branches. The sensory branches run together with the medial and lateral perforating vessels through the anterior lamina of the rectus sheath into the subcutaneous tissue to provide sensation to the anterior abdominal wall (Fig. 1).[20–23] The sensory nerve included in the flap is dissected through the fascia to the point where the motor branch splits off and is then cut.

Meanwhile, a second team dissects the internal mammary artery and vein, which are used as recipient vessels. A small window is created next to the sternum in usually the third intercostal space by resecting a small part of the pectoralis major muscle and intercostal muscles using a rib-sparing

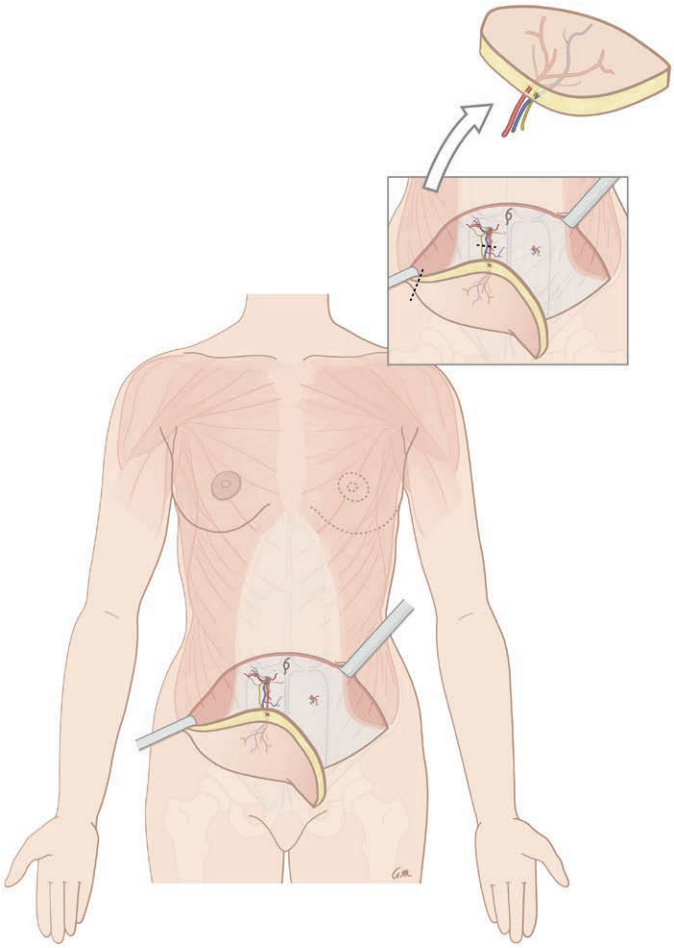

Fig. 1. The sensory branches originating from the intercostal nerves run together with the perforating vessels into the subcutaneous tissue and are included in the flap. (Copyright is held by Greet Mommen, scientific illustrator of this figure.)

approach. The technique to identify the recipient nerve and later coapt it to the donor nerve follows the method introduced by Spiegel et al.[3] The recipient nerve is the anterior cutaneous branch of the intercostal nerve that is usually identified at the inferior sternochondral junction. The anterior cutaneous branch is carefully dissected for a few centimeters to provide sufficient length for direct nerve coaptation. After shaping the flap, a direct end-to-end nerve coaptation is performed with two stitches using 9-0 nylon sutures (Fig. 2). Finally, a drop of tissue glue is applied.

Sensory Testing

The cutaneous pressure threshold (i.e., static one-point discrimination) was tested in nine areas of each breast using Semmes-Weinstein monofilaments (20-piece kit) with a calibrated application force ranging from 0.008 to 300 g. Figure 3 shows the nine areas corresponding to the normal breast and the reconstructed breast. In the reconstructed breast, areas 1 to 4 represent native breast skin, areas 5 to 8 represent flap skin, and area 9 represents the location of the nipple or where the nipple should be after reconstruction. However, in delayed reconstructions with large skin islands, areas 2 and 3 represent flap skin instead of native skin. The sensory recovery of the reconstructed breast was measured one or more times during follow-up.

The areas were tested in a random sequence by one examiner, who was blinded to the status of nerve repair. The examiner applied the filaments perpendicularly to the skin in ascending fashion, starting with the lightest filament, to determine the threshold level. The filaments were applied to the skin for 1.5 seconds in a uniform manner, bent in a C-shape. The index number of the lightest

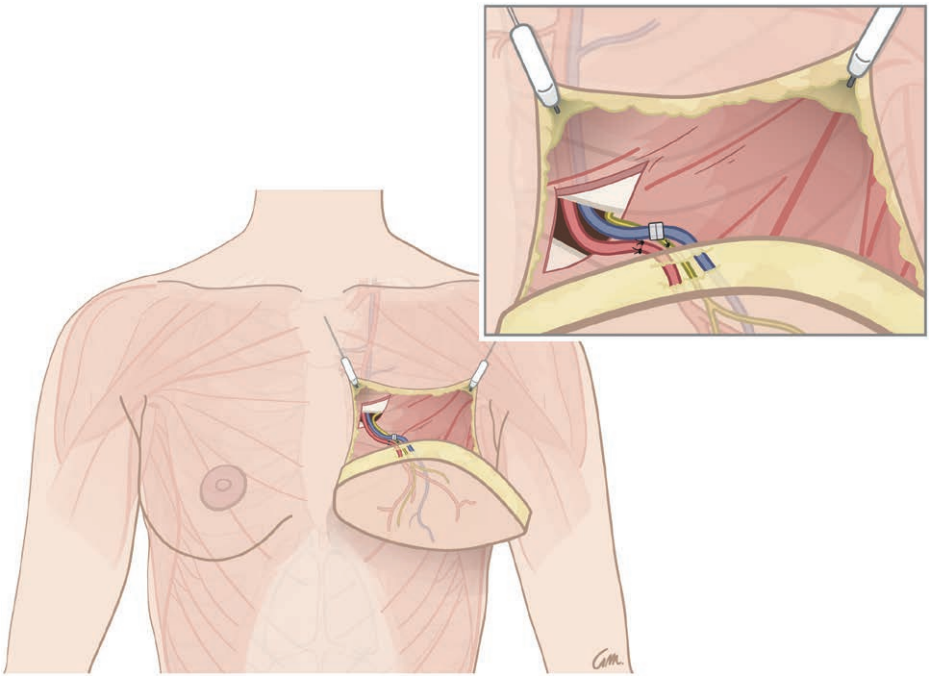

Fig. 2. Direct end-to-end nerve coaptation is performed to the anterior cutaneous branch of the intercostal nerve. (Copyright is held by Greet Mommen, scientific illustrator of this figure.)

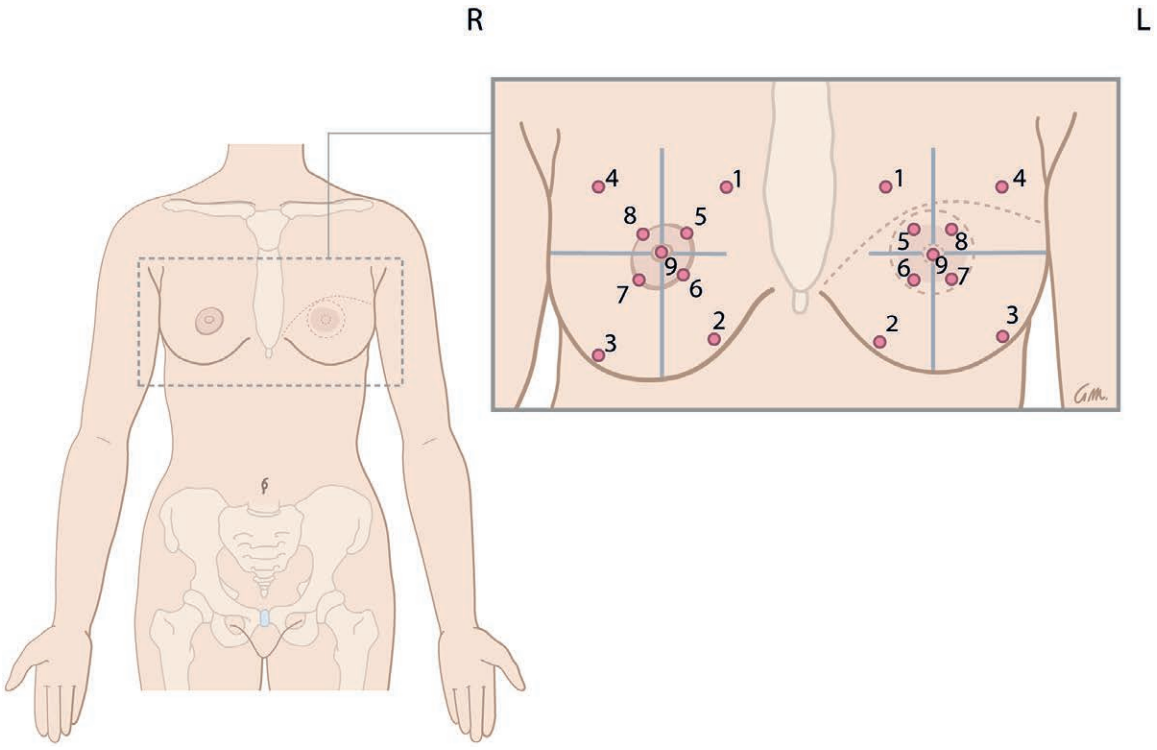

Fig. 3. The nine areas of the normal and reconstructed breast that were tested with Semmes-Weinstein monofilaments. Areas *1* to *4* represent native breast skin, and areas *5* to *9* represent flap skin. (Copyright is held by Greet Mommen, scientific illustrator of this figure.)

filament that the patient could detect during at least one of three applications was noted. Testing was performed while patients had their eyes closed, lying in supine position in a quiet, temperature-controlled room at the outpatient clinic.[24,25] The contralateral, nonoperated breast of patients with unilateral reconstruction served as reference for the sensibility of the "normal breast."

Patient Data

The patient demographics, risk factors, unilateral or bilateral reconstruction, timing of reconstruction (immediate or delayed), breast reconstruction history, reason for mastectomy, (neo)adjuvant therapy, follow-up length, and complications were recorded. Patients with major recipient-site complications (i.e., total flap loss, partial flap loss, or venous congestion) were excluded. Infection, hematoma, seroma, fat necrosis, and wound problems were registered as minor complications.

Statistical Analysis

Continuous variables are presented as mean and standard deviation or as median and interquartile range, depending on the distribution of data. Categorical variables are presented as absolute numbers and percentages. Continuous variables were compared with the independent samples *t* test or the Mann-Whitney *U* test as appropriate. Categorical data were tested with a chi-square or Fisher's exact test.

For sensory testing, the unit of analysis was the flap. Monofilament values were recorded as index values (markings on the rods ranging from 1.65 to 6.65) for all nine areas of both breasts. Each index value represents a common logarithm of 10 times the force in milligrams required to bend the filament. The actual force in grams is not equal to the originally calculated theoretical force in grams, but follows the calibrated forces.[26] A lower index value corresponds to better sensation. Mean monofilament values were calculated for native skin (areas 1 through 4), flap skin (areas 5 through 9), and total skin (areas 1 through 9). The monofilament values were used for the analysis, as these logarithmically transformed values provide normally distributed data, compared with using the values in grams.[25] Crude differences in mean monofilament values between innervated and noninnervated DIEP flaps were estimated using generalized estimating equations to correct for clustered data, as some patients underwent bilateral breast reconstruction and thus contributed two flaps to the analysis. Estimated differences were subsequently adjusted for clinically relevant confounders. Generalized estimating equations were also used to calculate the associations between sensory recovery of the reconstructed breast, follow-up in months, and timing (immediate or delayed) of the reconstruction. Furthermore, scatterplots using the Loess fit method for nonlinear lines were provided to illustrate these associations. Statistical significance was considered at $p < 0.05$. Data analysis was performed using IBM SPSS Version 23.0 for Windows (IBM Corp., Armonk, N.Y.).

RESULTS

Patient Characteristics

A total of 364 patients underwent DIEP flap breast reconstruction between January of 2010 and July of 2016 (Fig. 4). Ninety patients had a control visit in the study period between September of 2015 and July of 2017, of which 81 patients (36 patients with 48 innervated DIEP flap breast reconstructions and 45 patients with 61 noninnervated DIEP flaps) were included in this study. Nonoperated, contralateral breasts of 27 patients were used as reference. Median follow-up was 15 months (interquartile range, 11 to 17 months) and 17 months (interquartile range, 12 to 24 months) for innervated and noninnervated DIEP flaps, respectively. With the exception of the timing of reconstruction ($p = 0.013$), the patient characteristics were comparable for both groups (Table 1). No complications related to nerve coaptation were observed, and the surgical time was extended by approximately 15 minutes.

Sensory Recovery of the Reconstructed Breast

Mean monofilament values for each area of innervated and noninnervated DIEP flaps are summarized in Table 2. Reference values for nonoperated breasts were 2.66 ± 0.40 (areas 1 through 4), 2.75 ± 0.42 (areas 5 through 9), and 2.71 ± 0.40 for the total breast skin. The crude and adjusted regression coefficients of the association between nerve coaptation and mean monofilament values are reported in Table 3. Nerve coaptation was significantly associated with lower monofilament values in all areas of the reconstructed breasts (mean total skin difference, −1.1; $p < 0.001$). This indicates that the sensory recovery of the breast is significantly better in innervated compared with noninnervated DIEP flaps. Correction for the timing of reconstruction and length of follow-up

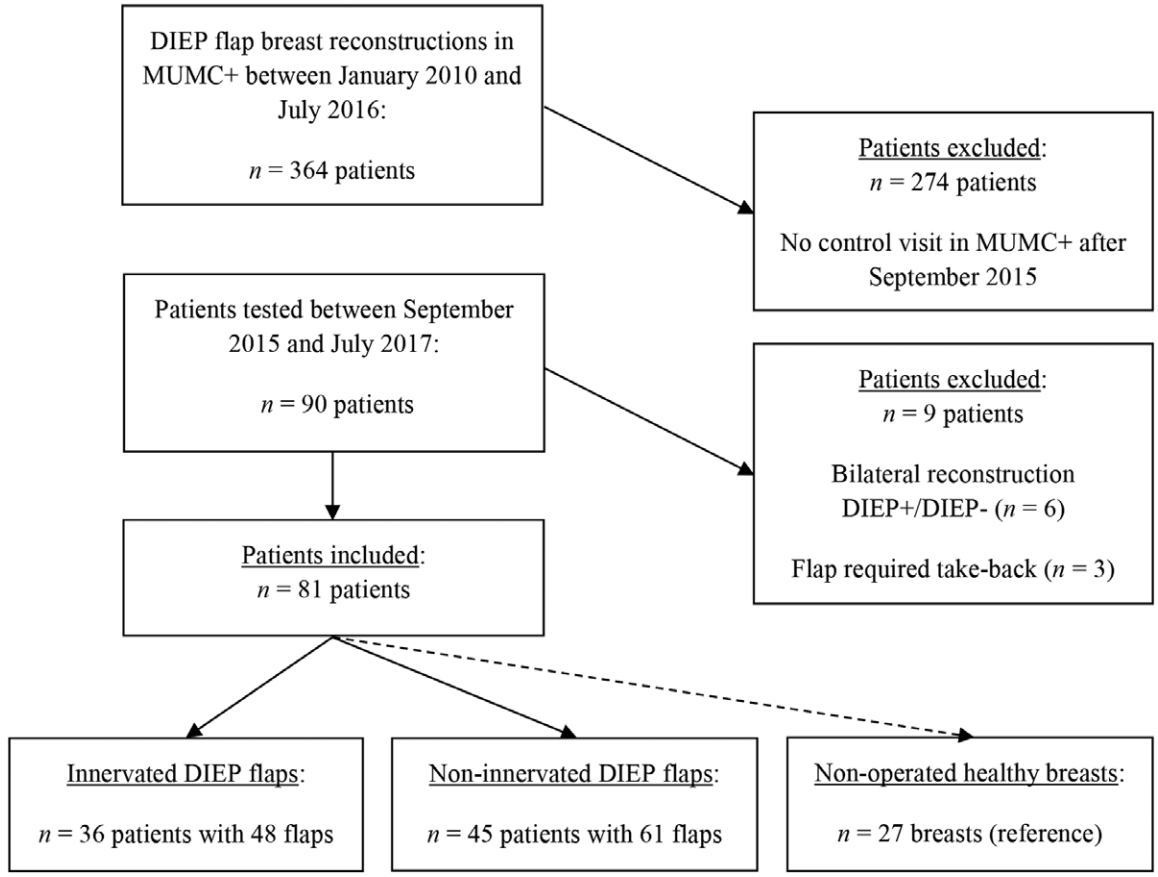

Fig. 4. Flow chart of patient inclusion. *MUMC+*, Maastricht University Medical Center.

showed increased differences between both groups (adjusted difference, −1.2; $p < 0.001$), further supporting the strong association between nerve coaptation and improved sensation. Larger differences in mean monofilament values were observed for flap skin compared to native skin (adjusted difference, −1.2 and −0.9 for flap skin and native skin, respectively). The lowest mean values were found in the superomedial quadrant of the breast.

Sensory Recovery and Length of Follow-Up

The sensory recovery of the reconstructed breast was significantly associated with length of follow-up in both innervated and noninnervated DIEP flaps (Tables 4 and 5). Adjusted for the timing of reconstruction, a significant recovery of sensation was observed in native skin and flap skin. For every additional month of follow-up, the mean monofilament value of the total skin decreased by 0.083 in innervated flaps ($p < 0.001$) and 0.012 in noninnervated flaps ($p < 0.001$). Figure 5 shows the scatterplots to illustrate the sensory recovery of innervated and noninnervated DIEP flaps over time. Compared to the reference value of normal breasts, sensation did not recover to normal thresholds in the majority of cases within the follow-up of this study.

Sensory Recovery and Timing of Reconstruction

Nerve coaptation was significantly associated with sensory recovery in immediate and delayed DIEP flap breast reconstruction (Tables 6 and 7), which indicates that nerve coaptation results in improved sensation of the reconstructed breast as illustrated in Figure 6. Regardless of the timing of reconstruction, both native skin and flap skin recovered significantly better in innervated flaps.

DISCUSSION

The aim of this study was to analyze the effect of nerve coaptation on the sensory recovery of the reconstructed breast by comparing the sensation of innervated to noninnervated DIEP flap breast reconstructions. Secondary objectives were to assess the sensory recovery over time and to study the association between the return of sensation and the timing of the reconstruction.

Table 1. Patient Characteristics*

Characteristic	Innervated DIEP flaps (%)	Noninnervated DIEP flaps (%)	*p*
Total no. of patients	36	45	
Total no. of DIEP flaps	48	61	
Mean age ± SD, yr	50.3 ± 8.9	50.0 ± 7.7	0.883
Mean BMI ± SD, kg/m^2	26.0 ± 3.2	26.7 ± 2.9	0.330
Active smoker	2 (5.6)	2 (4.4)	1.000
Diabetes mellitus	2 (5.6)	4 (8.9)	0.688
History of lumpectomy†	9 (18.8)	7 (11.5)	0.287
History of tissue expanders/implants†	11 (22.9)	17 (27.9)	0.557
Type of reconstruction			
Unilateral	24 (66.7)	29 (64.4)	0.834
Bilateral	12 (33.3)	16 (35.6)	
Timing of reconstruction†			
Immediate	28 (58.3)	21 (34.4)	0.013
Delayed	20 (41.7)	40 (65.6)	
Reason for mastectomy†			
Oncologic	30 (62.5)	40 (65.6)	0.740
Risk-reducing/prophylactic	18 (37.5)	21 (34.4)	
Mean flap weight ± SD, g†	591 ± 207	610 ± 184	0.634
Oncologic treatment			
History of radiation therapy†	17 (35.4)	17 (27.9)	0.398
Radiation therapy on DIEP flap†	1 (2.1)	1 (1.6)	1.000
History of chemotherapy	16 (44.4)	25 (55.6)	0.320
Neoadjuvant chemotherapy	7 (19.4)	5 (11.1)	0.294
Endocrine therapy	13 (36.1)	18 (40.0)	0.720
Immunotherapy	5 (13.9)	5 (11.1)	0.745
Minor breast complications†	7 (14.6)	11 (18.0)	0.630
Follow-up, mo			
Median	15	17	
IQR	11–17	12–24	0.086

BMI, body mass index; IQR, interquartile range.
*n = 81 patients.
†Total number of flaps as unit of analysis (innervated DIEP flap group, n = 48; noninnervated DIEP flap group, n = 61).

Table 2. Mean Semmes-Weinstein Monofilament Values per Area for Innervated and Noninnervated DIEP Flaps

Area No.	Area	Innervated DIEP Flaps	Noninnervated DIEP Flaps	*p*
1	Native skin upper-medial	3.59 ± 0.86	4.51 ± 0.94	<0.001
2	Native skin lower-medial	3.74 ± 0.96	4.98 ± 0.84	<0.001
3	Native skin lower-lateral	3.94 ± 0.93	5.12 ± 0.72	<0.001
4	Native skin upper-lateral	3.75 ± 0.90	4.56 ± 0.72	<0.001
1–4	Mean native skin	3.72 ± 0.81	4.64 ± 0.79	<0.001
5	Flap skin upper-medial	4.08 ± 0.70	5.41 ± 0.60	<0.001
6	Flap skin lower-medial	4.18 ± 0.72	5.52 ± 0.62	<0.001
7	Flap skin lower-lateral	4.24 ± 0.74	5.60 ± 0.61	<0.001
8	Flap skin upper-lateral	4.10 ± 0.72	5.47 ± 0.59	<0.001
9	Flap skin center	4.24 ± 0.77	5.67 ± 0.61	<0.001
5–9	Mean flap skin	4.17 ± 0.70	5.52 ± 0.55	<0.001
1–9	Mean total skin	3.99 ± 0.66	5.20 ± 0.56	<0.001

Our prospective study demonstrated that nerve coaptation was significantly associated with lower monofilament values in all areas of the reconstructed breast, suggesting that the sensory recovery of the breast is significantly better in innervated compared with noninnervated DIEP flaps. The scatterplots illustrate the pattern of sensory recovery of innervated and noninnervated flaps over time. Similar to what was previously found, the sensory recovery of innervated flaps was superior, started earlier postoperatively, and had a higher chance of approaching normal values.[13,21,27] However, in the majority of cases, normal sensation should not be expected. Even when the same force is applied alternately to the normal skin and the reconstructed breast, the patient often feels it differently. Therefore, asking patients how they feel a stimulus and not only whether they can feel it gives additional information about the quality of recovery.

Interpretation of test results showed that the sensory recovery of noninnervated flaps equalled

Table 3. Crude and Adjusted Regression Coefficients of the Association between Nerve Coaptation and Mean Monofilament Scores per Area

Area No.	Area	Crude* Coefficient	95% CI	*p*	Adjusted Coefficient†	95% CI	*p*
1	Native skin upper-medial	−0.8	−1.2 to −0.5	<0.001	−0.9	−1.3 to −0.5	<0.001
2	Native skin lower-medial	−1.1	−1.5 to −0.7	<0.001	−1.1	−1.5 to −0.7	<0.001
3	Native skin lower-lateral	−1.1	−1.4 to −0.7	<0.001	−1.2	−1.5 to −0.8	<0.001
4	Native skin upper-lateral	−0.8	−1.1 to −0.4	<0.001	−0.8	−1.1 to −0.5	<0.001
1–4	Mean native skin	−0.8	−1.2 to −0.5	<0.001	−0.9	−1.3 to −0.6	<0.001
5	Flap skin upper-medial	−1.3	−1.6 to −1.0	<0.001	−1.4	−1.7 to −1.1	<0.001
6	Flap skin lower-medial	−1.3	−1.6 to −1.0	<0.001	−1.4	−1.7 to −1.1	<0.001
7	Flap skin lower-lateral	−1.3	−1.6 to −1.0	<0.001	−1.4	−1.7 to −1.1	<0.001
8	Flap skin upper-lateral	−1.3	−1.6 to −1.1	<0.001	−1.5	−1.7 to −1.2	<0.001
9	Flap skin center	−1.4	−1.7 to −1.1	<0.001	−1.4	−1.8 to −1.1	<0.001
5–9	Mean flap skin	−1.3	−1.6 to −1.0	<0.001	−1.4	−1.7 to −1.1	<0.001
1–9	Mean total skin	−1.1	−1.4 to −0.9	<0.001	−1.2	−1.5 to −0.9	<0.001

*Note that the regression coefficients are not totally equal to the crude differences between the mean values reported in Table 2 because of correction for clustered data.
†Adjusted for timing of reconstruction (immediate vs. delayed) and follow-up (in months).

Table 4. Association between Sensory Recovery of the Reconstructed Breast and Follow-Up in Innervated DIEP Flap Breast Reconstructions

Area	Crude Coefficient	95% CI	*p*	Adjusted Coefficient*	95% CI	*p*
Mean native skin	−0.066	−0.096 to −0.037	<0.001	−0.067	−0.096 to −0.037	<0.001
Mean flap skin	−0.096	−0.123 to −0.068	<0.001	−0.096	−0.123 to −0.069	<0.001
Mean total skin	−0.083	−0.111 to −0.056	<0.001	−0.083	−0.111 to −0.056	<0.001

*Adjusted for timing of reconstruction (immediate vs. delayed).

Table 5. Association between Sensory Recovery of the Reconstructed Breast and Follow-Up in Noninnervated DIEP Flap Breast Reconstructions

Area	Crude Coefficient	95% CI	*p*	Adjusted Coefficient*	95% CI	*p*
Mean native skin	−0.019	−0.027 to −0.011	<0.001	−0.022	−0.030 to −0.014	<0.001
Mean flap skin	−0.010	−0.017 to −0.004	0.001	−0.011	−0.017 to −0.005	0.001
Mean total skin	−0.011	−0.016 to −0.006	<0.001	−0.012	−0.018 to −0.007	<0.001

*Adjusted for timing of reconstruction (immediate vs. delayed).

loss of protective sensation (monofilament values, 4.56 to 6.65), whereas the sensation of innervated flaps recovered to a level of diminished protective sensation (monofilament values, 3.84 to 4.31) and in some areas even to diminished light touch (monofilament values, 3.22 to 3.61).[16,24] Even though not assessed in this study, Bell-Krotoski et al. reported that patients with diminished protective sensation can still adequately respond to temperature and pain to prevent skin injury.[24] Moreover, sensory reeducation may further improve the sensory recovery of the reconstructed breast.[12,28] This emphasizes that nerve coaptation results in not only a statistically significant but also a clinically relevant difference in sensory recovery of the breast. Previous studies have already shown that improved sensation has a positive impact on the patient-rated quality of life.[5,6] Although it was not an outcome measured in this study, more patients with innervated flaps stated that their reconstructed breast felt like their own, and some even reported a return of erogenous sensation.

In contrast to most other studies, the anterior cutaneous branch of the third intercostal nerve was used as the recipient nerve for coaptation.[13] Choosing the anterior instead of the lateral cutaneous branch for nerve coaptation facilitates flap inset when using the internal mammary vessels as recipient vessels, limits traction on the nerve endings, and minimizes a possible nerve gap.[3,15] These factors influence nerve regeneration and may possibly explain the superior outcomes after nerve coaptation in this study.[13,29]

Furthermore, sensory recovery was significantly associated with length of follow-up in both innervated and noninnervated DIEP flaps. For

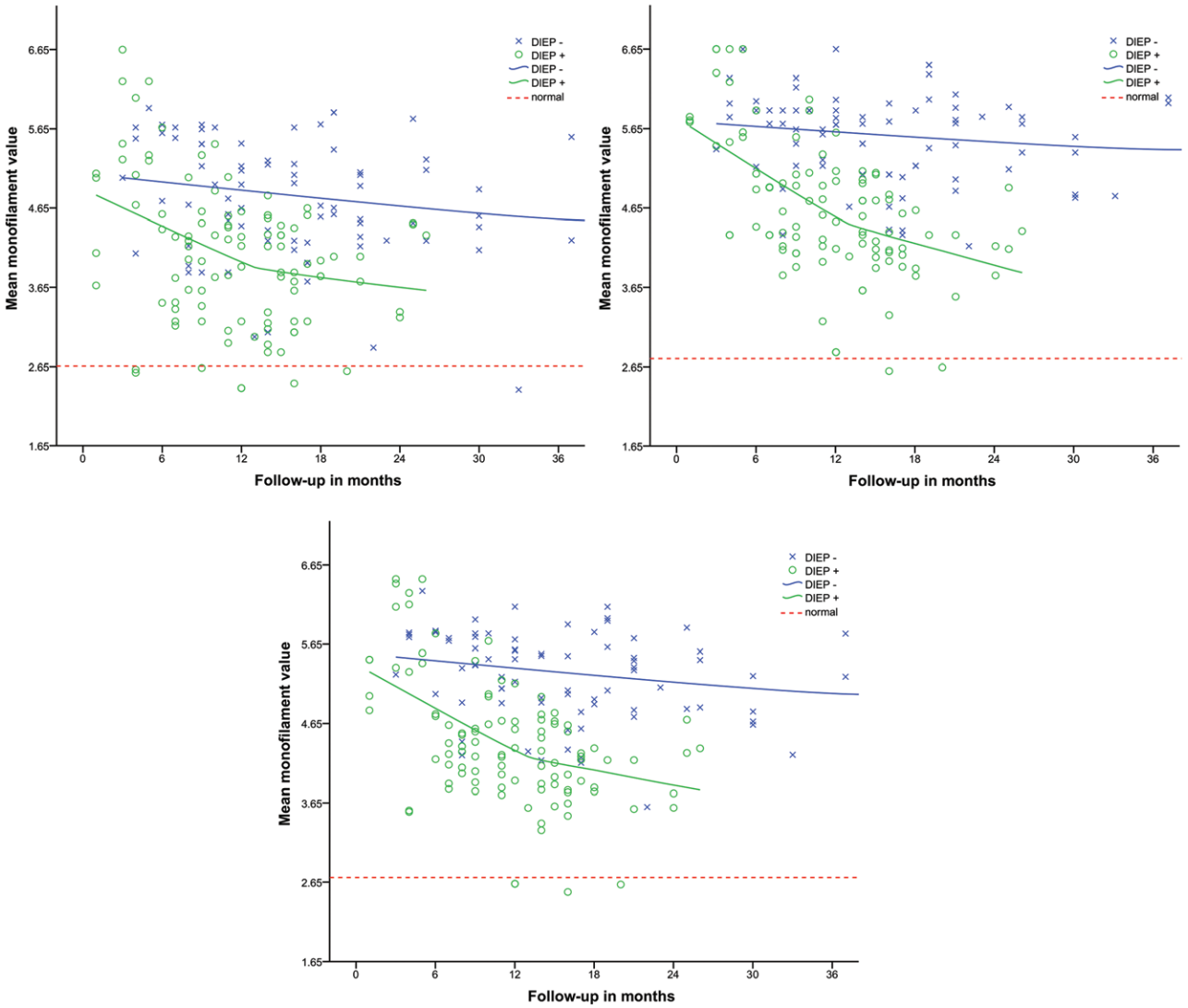

Fig. 5. Scatterplot of all measurements showing the sensory recovery of the reconstructed breast following innervated (*green circles*) and noninnervated (*blue crosses*) DIEP flap breast reconstructions. The *red line* represents the normal, nonoperated breast. (*Above*, *left*) Native skin. (*Above*, *right*) Flap skin. (*Below*) Total skin.

Table 6. Association between Sensory Recovery of the Reconstructed Breast and Nerve Coaptation in Immediate DIEP Flap Breast Reconstructions

Area	Crude Coefficient	95% CI	*p*	Adjusted Coefficient*	95% CI	*p*
Mean native skin	−0.78	−1.19 to −0.37	<0.001	−1.16	−1.55 to −0.76	<0.001
Mean flap skin	−0.83	−1.10 to −0.57	<0.001	−1.02	−1.31 to −0.73	<0.001
Mean total skin	−0.84	−1.13 to −0.56	<0.001	−1.09	−1.41 to −0.78	<0.001

*Adjusted for follow-up (mo).

Table 7. Association between Sensory Recovery of the Reconstructed Breast and Nerve Coaptation in Delayed DIEP Flap Breast Reconstructions

Area	Crude Coefficient	95% CI	*p*	Adjusted Coefficient*	9% CI	*p*
Mean native skin	−0.56	−0.89 to −0.23	0.001	−0.72	−1.06 to −0.39	<0.001
Mean flap skin	−1.00	−1.31 to −0.70	<0.001	−1.20	−1.49 to −0.92	<0.001
Mean total skin	−0.84	−1.14 to −0.55	<0.001	−1.02	−1.30 to −0.74	<0.001

*Adjusted for follow-up (mo).

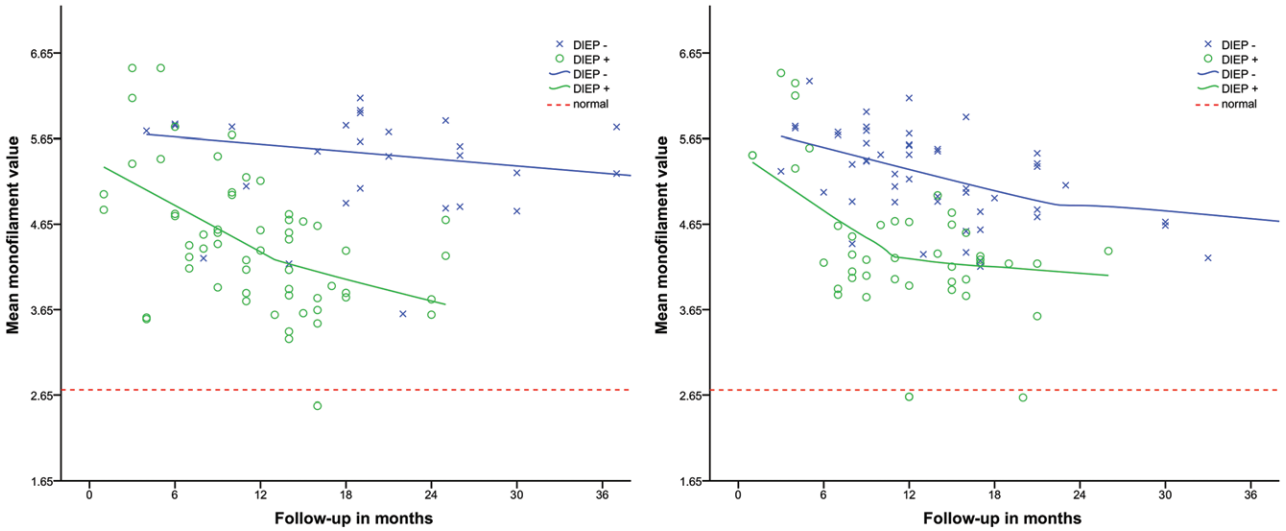

Fig. 6. Scatterplot of all measurements showing the sensory recovery of the reconstructed breast following innervated (*green circles*) and noninnervated (*blue crosses*) DIEP flap breast reconstructions. The *red line* represents the normal, nonoperated breast. (*Left*) Immediate breast reconstructions. (*Right*) Delayed breast reconstructions. Note that the trend line of innervated flaps (*green*) is affected by the relative lack of measurements after 18-month follow-up.

every month of follow-up, the sensation improved significantly, although in innervated flaps this occurred to a greater extent. It was found that nerve coaptation improved the sensory recovery of not only the flap skin but, surprisingly, also of the native skin. Even though the exact mechanism of reinnervation of flaps remains unknown, our results suggest that in innervated flaps sprouting nerve fibers from the underlying flap tissue may grow into the partially denervated native skin.[30]

Lastly, data analysis showed that nerve coaptation significantly improved the sensory recovery in both immediate and delayed DIEP flap breast reconstructions. This finding is in contrast to other studies suggesting that nerve coaptation might be indicated only in delayed reconstructions or following modified radical mastectomy.[16,17] Interestingly, a study by Santanelli et al. reported that immediate DIEP flaps undergo satisfactory spontaneous reinnervation.[17] However, only immediate noninnervated flaps after modified radical mastectomy were examined, without innervated flaps as a control group.

Limitations of this study include the absence of preoperative measurements and the inclusion of nonconsecutive patients, which may have introduced selection bias. Some patients were tested multiple times, whereas others were tested only once, depending on the patients' wishes and their treatment plans. Ideally, innervated and noninnervated flaps should be tested at the same intervals after surgery. In addition, more than merely the cutaneous thresholds to touch should be tested to assess the sensory recovery. Semmes-Weinstein monofilaments and not the pressure-specified sensory device were used because the latest version of this device was not available in Europe at the time of this study. The Semmes-Weinstein monofilaments are easy to use and are reliable for assessing sensory recovery, provided that they are applied in a uniform manner.[24,26]

The strengths of this study, in contrast, include the large sample size, the comprehensive data analysis, and the scatterplots to illustrate the sensory recovery. Both groups were similar in terms of patient characteristics, except for the timing of reconstruction, for which the results were adjusted. Moreover, the sensory recovery of reconstructed breasts could be compared to normal values because of the use of nonoperated breasts as a reference group.

CONCLUSIONS

This study demonstrated that nerve coaptation in DIEP flap breast reconstruction resulted in a significantly better sensory recovery in all areas of the reconstructed breast compared with noninnervated flaps. The sensory recovery of innervated flaps was superior, started earlier postoperatively, and had a higher chance of approaching normal values. Length of follow-up was significantly associated with the extent of sensory recovery in innervated and noninnervated flaps. Nerve coaptation significantly improved the sensation of the breast in both immediate and delayed breast

reconstructions. Therefore, we believe that nerve coaptation is a worthwhile addition to DIEP flap breast reconstruction.

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