Accepted Manuscript

Submission Date: 2023-05-03
Accepted Date: 2023-09-20
Accepted Manuscript online: 2023-12-05

Journal of Reconstructive Microsurgery Open

Bridging the Gap: A Pilot Study on the Efficacy of Nerve Allografts in Autologous Breast Reconstruction

Marcos Lu Wang, Hao Huang, Ashley Zhang, Angela Ellison, Grant G Black, David M Otterburn.

Affiliations below.

DOI: 10.1055/a-2222-9031

Please cite this article as: Lu Wang M, Huang H, Zhang A et al. Bridging the Gap: A Pilot Study on the Efficacy of Nerve Allografts in Autologous Breast Reconstruction. Journal of Reconstructive Microsurgery Open 2023. doi: 10.1055/a-2222-9031

Conflict of Interest: The corresponding author, Dr. David Otterburn received research equipment and device support from AxoGen, Inc. for the pressure-specified sensory device used to measure sensation in this study

Abstract:
Background: Breast anesthesia is commonly reported after mastectomy and reconstruction. During deep inferior epigastric perforator (DIEP) flap reconstruction, we coapt at least one of the T10–12 thoracoabdominal nerves within the flap to the anterior cutaneous branch of the 3rd intercostal nerve using a nerve allograft. We aim to evaluate the efficacy of nerve grafting in improving sensory recovery following neurotized DIEP flap reconstruction.
Methods: Thirty patients (54 breasts) underwent immediate neurotized DIEP flap reconstruction using nerve grafts. Sensitivity evaluation was performed in nine breast regions. For each patient, sensation was compared between two time points: 3 to 6 months postoperatively versus 12 to 24 months postoperatively. The reconstructive BREAST-Q was used to survey patients' satisfaction of their breasts, physical wellbeing, psychosocial wellbeing, and sexual wellbeing.
Results: At 3 to 6 months postoperatively, patients had a mean sensitivity measurement of 52.1 g/mm2. At 12 to 24 months postoperatively, patients had a mean sensitivity measurement of 40.3 g/mm2. There was a significant decrease in the mean cutaneous threshold required for patients to perceive sensation between the two time points (–29.1 percent, p = 0.041). On the reconstructive BREAST-Q, patients scored significantly higher in breast satisfaction (56.7/100 versus 75.1/100, +32.5 percent, p = 0.032) and physical wellbeing (66.0/100 versus 85.5/100, +20.2 percent, p = 0.022) between the two time points.
Conclusions: Patients who undergo nerve graft-based DIEP flap reconstruction can expect significant improvements in sensation to pressure over time. This improvement found on sensory testing correlates with significant improvement in patients' BREAST-Q scores.

Corresponding Author:
Dr. David M Otterburn, Weill Cornell Medicine, Plastic Surgery, 525 E 68th St, 10065 New York, United States, dmo9004@med.cornell.edu

Affiliations:
Marcos Lu Wang, NewYork-Presbyterian Weill Cornell Medical Center, New York, United States
Hao Huang, NewYork-Presbyterian Hospital/Weill Cornell Medical Center, New York, United States
Ashley Zhang, Weill Cornell Medicine, New York, United States
[...]
David M Otterburn, Weill Cornell Medicine, Plastic Surgery, New York, United States

Bridging the Gap: A Pilot Study on the Efficacy of Nerve Allografts in Autologous Breast Reconstruction

Marcos Lu Wang MD[1], Hao Huang MD[1], Ashley Zhang BSE[2], Angela Ellison MS[2], Grant G. Black BA[2], David M. Otterburn MD[2]

[1]NewYork-Presbyterian Hospital—Cornell and Columbia, New York, NY, USA
[2]Division of Plastic and Reconstructive Surgery, Weill Cornell Medicine, New York, NY, USA

Corresponding Author:
David M. Otterburn MD
Weill Cornell Medicine
525 E 68th St, New York, NY 10065, USA
Email: dmo9004@med.cornell.edu

ABSTRACT

Background: Breast anesthesia is commonly reported after mastectomy and reconstruction. During deep inferior epigastric perforator (DIEP) flap reconstruction, we coapt at least one of the T10–12 thoracoabdominal nerves within the flap to the anterior cutaneous branch of the 3rd intercostal nerve using a nerve allograft. We aim to evaluate the efficacy of nerve grafting in improving sensory recovery following neurotized DIEP flap reconstruction.

Methods: Thirty patients (54 breasts) underwent immediate neurotized DIEP flap reconstruction using nerve grafts. Sensitivity evaluation was performed in nine breast regions. For each patient, sensation was compared between two time points: 3 to 6 months postoperatively versus 12 to 24 months postoperatively. The reconstructive BREAST-Q was used to survey patients' satisfaction of their breasts, physical wellbeing, psychosocial wellbeing, and sexual wellbeing.

Results: At 3 to 6 months postoperatively, patients had a mean sensitivity measurement of 52.1 g/mm^2. At 12 to 24 months postoperatively, patients had a mean sensitivity measurement of 40.3 g/mm^2. There was a significant decrease in the mean cutaneous threshold required for patients to

perceive sensation between the two time points (–29.1 percent, $p = 0.041$). On the reconstructive BREAST-Q, patients scored significantly higher in breast satisfaction (56.7/100 versus 75.1/100, +32.5 percent, $p = 0.032$) and physical wellbeing (66.0/100 versus 85.5/100, +20.2 percent, $p = 0.022$) between the two time points.

Conclusions: Patients who undergo nerve graft-based DIEP flap reconstruction can expect significant improvements in sensation to pressure over time. This improvement found on sensory testing correlates with significant improvement in patients' BREAST-Q scores.

INTRODUCTION

Many patients choose to undergo autologous breast reconstruction following mastectomy due to its low rates of reconstructive failure and improved quality of life from physical, psychosocial, and sexual perspectives.[1-3] Despite these improvements in postoperative outcomes, breast anesthesia and poor breast sensation are still commonly reported due to the necessary transection of sensory nerves during surgery. In a recent survey, Djohan et al. found that while patients are overall satisfied with nipple-sparing mastectomy and immediate reconstruction, a majority (67 percent) rated their sensation as fair or poor.[4] Anecdotally, in our clinical practice, poor breast sensation continues to be a common complaint, and some patients have presented with superficial burn wounds from activities of daily living as a result of the breast anesthesia.

Since its first description and utilization by Allen and Treece in 1994, the deep inferior epigastric perforator (DIEP) flap has become a workhorse flap for autologous reconstruction.[5] During DIEP flap harvest, sensory nerves from T10 to 12 thoracoabdominal nerves can be preserved to create a sensate flap.[6] Furthermore, Xia et al. has shown that neurotization does not significantly prolong operative times—an average increase of only 12 minutes.[7] Despite this potential and minimal increase in operative duration, the adoption of neurotized DIEP flaps is

still variable. In our prior study, we have shown that neurotized DIEP flaps yield superior sensory compared to implant-based reconstructions irregardless of the use of skin paddles. In our DIEP flap cohort, sensation to pressure returned to baseline in over 75 percent of the breasts by 24 months.[8] This correlates with our clinical experience in which our DIEP flap patients have consistently noted an improvement in sensory return, especially between the first-year and second-year follow up visits.

Current studies of sensory return in neurotized DIEP flaps have largely focused on creating the sensate flap through direct end-to-end nerve coaptation. For example, Beugels et al. in the Netherlands have demonstrated that innervated DIEP flaps resulted in significantly lower monofilament testing values to detect pressure than non-innervated flaps.[9,10] To date, there has been extremely limited studies on the use of nerve grafts in microsurgical breast reconstruction. Historically, nerve grafting resulted in poorer outcomes due to the confluence of one additional coaptation, poor vascularity of wound beds, and attempts at utilizing the shortest grafts possible, which resulted in additional tension across repair sites through positional maneuvers such as joint flexions and extensions.[11] Recent advances in nerve grafts have resulted in thinner grafts more apt at revascularization and have contributed to current success with nerve grafting.[11]

At our institution, we have largely transitioned from performing direct end-to-end coaptations to utilizing nerve autografts to assure minimal tension at the coaptation site.[12] To this end, the aim of this study is to evaluate changes in breast sensation following DIEP flap breast reconstruction with nerve allografting, with a special emphasis on two time-point temporal changes. We also aim to correlate measured changes in breast sensation with actual patient perceptions. We postulate that patients who underwent DIEP flap reconstruction with nerve grafting should experience significant improvements in sensory recovery over time.

METHODS

This study was approved by the Weill Cornell Medicine Institutional Review Board as a prospective study of patients undergoing mastectomy and immediate reconstruction using the neurotized DIEP flap between April 2019 and August 2021 at a single tertiary care institution. Inclusion criteria included women age 18 or older, unilateral or bilateral immediate DIEP flap reconstruction with nerve grafting, and two or more postoperative measurements at least 6 months apart. Exclusion criteria included patients with any neuropathy (including diabetes and chemotherapy-induced), patients who underwent postoperative radiation therapy, and patients with less than two postoperative measurements.

Surgical Technique

All patients underwent reconstruction using the DIEP flap in standard fashion as described by Allen and Treece.[5] Neurotization was performed using the donor and recipient nerves first introduced by Spiegal et al. for coaptation.[6,13] The donor nerve is a sensory branch of T10–12 thoracoabdominal nerves within the DIEP flap. The recipient nerve is the anterior cutaneous branch of the 3rd intercostal nerve near the internal mammary recipient vessels. Nerve coaptation was performed using the 70 x 1–2 mm Avance nerve graft (AxoGen, Alachua, FL). All patients underwent a second revision procedure at 2 weeks postoperatively to remove the excess skin paddle left in place in case of the need for additional skin coverage.

Sensory Testing Protocol

All patients were prospectively identified and consented at their initial preoperative consultation visit or at their first postoperative visit. For each patient, the first postoperative sensory testing occurred between 3 to 6 months postoperatively, and the second postoperative sensory testing occurred between 12 to 24 months postoperatively.

Sensory testing was conducted using the AcroVal pressure-specified sensory device (AxoGen, Aluchua, FL). Previous studies have shown that the pressure-specified sensory device is a reliable method for quantifying breast sensation.[14-16] Testing was performed by A.E., H.H., or M.L., all of whom were trained in this technique. During testing, patients were seated in a reclining chair in a quiet exam room with their eyes closed and blinded to all visual or auditory cues. Patients were instructed to press on a small transductor whenever pressure stimulus was perceived on the breast skin.

Sensitivity measurements were performed in 9 breast regions using 1-point static cutaneous thresholds (range, 0.1–100 g/mm^2). Higher measurements indicated worse sensitivity results. Testing was conducted in the following sequence: outer superior region, outer medial region, outer inferior region, outer lateral region, inner superior region, inner medial region, inner inferior region, inner lateral region, and the nipple areola complex (**Figure 1**).[17] In each region, 5 measurements were obtained, with the 2 outliers discarded and the remaining 3 measurements averaged. Because the thoracic skin is unable to discriminate distances shorter than 30 millimeters, 2-point discrimination was not tested.[18]

Patient-Reported Outcomes

All patients were asked to complete the reconstructive module of the BREAST questionnaire (Version 2.0) sent electronically after their clinic visit. The BREAST-Q is an assessment tool designed to gauge patient satisfaction and quality of life, with specific evaluations on patients' physical, psychosocial, and sexual well-being. All scores were converted to a scale of 0 to 100 according to the BREAST-Q reconstruction module manual, with higher scores indicating better patient outcomes.[19,20]

Statistical Analysis

For each patient, sensitivity data across the 9 breast regions were averaged. Sensitivity data was further pooled across patients at each time point: 3 to 6 months postoperatively or 12 to 24 months postoperatively. Two-sample unpaired *t*-test was used to compare sensitivity measurements between the two time points and assess differences in BREAST-Q scores. For all analyses, p-value < 0.05 was used as threshold for statistical significance. All statistical analyses were performed using GraphPad Prism 9 (Dotmatics, Bishops Stortford, United Kingdom) with figure graphics created with Excel version 16.56 (Microsoft Corp, Redmond, Wash).

RESULTS

Patient Characteristics

Between April 2019 and August 2021, thirty patients (54 breasts) who underwent mastectomy and immediate DIEP reconstruction with nerve grafting were enrolled in this study. Our cohort had an average age of 48.1 ± 9.4 years and an average body mass index of 26.6 ± 4.1 kg/m^2. All patients underwent nipple-sparing mastectomy as part of their oncologic care. The

average mastectomy weight was 564.00 ± 151.08 g and the average DIEP flap weight was 625.96 ± 198.31 g. DIEP flaps tended to weigh more than mastectomy specimens, as the excess DIEP flap skin is removed in a separate procedure. No patients underwent postoperative radiation therapy or reported chemotherapy-induced peripheral neuropathy.

Breast Sensory Measurements

In this cohort, 3 patients (6 breasts) underwent preoperative sensation testing, with an average preoperative baseline measurement of 14.0 ± 1.4 g/mm^2. During the first postoperative measurement at 3 to 6 months postoperatively, patients had a mean cutaneous threshold of 52.1 ± 20.8 g/mm^2, significantly higher than preoperative baseline measurements (p = 0.019). During the second postoperative measurement at 12 to 24 months postoperatively, patients had a mean cutaneous threshold of 40.3 ± 22.1 g/mm^2. There was a significant decrease in the mean cutaneous threshold required for patients to perceive sensation at their second postoperative measurement compared to their first (–11.8 ± 5.6 g/mm^2, –29.1 percent, p = 0.041, **Figure 2**). Within the 12- to 24-month time point, 4 patients (7 breasts) who were tested at exactly 24 months postoperatively had a mean cutaneous threshold of 31.4 ± 12.3 g/mm^2. This was comparable to preoperative baseline measurements, although a trend toward significance was noted (p = 0.083, **Figure 3**). This rather large difference in sensation between baseline and 24 months postoperatively without statistical significance may be due to small sample sizes.

BREAST-Q Responses

Four major areas were assessed through the reconstructive module of the BREAST-Q questionnaire: postoperative breast satisfaction, postoperative physical wellbeing, postoperative

psychosocial wellbeing, and postoperative sexual wellbeing. At 3 to 6 months postoperatively, patients scored on average 56.7/100 in breast satisfaction, 66.0/100 in physical wellbeing, 69/100 in psychosocial wellbeing, and 46.0/100 in sexual wellbeing. At 12 to 24 months postoperatively, patients scored on average 75.1/100 in breast satisfaction, 85.5/100 in physical wellbeing, 75.7/100 in psychosocial wellbeing, and 55.3/100 in sexual wellbeing. Between the two time points, there was a significant increase in both breast satisfaction (+32.5 percent, p = 0.032) and physical wellbeing scores (+20.2 percent, p = 0.022). There were no significant improvements in psychosocial wellbeing and sexual wellbeing scores between the two time points.

DISCUSSION

Advances in breast reconstruction have afforded patients a wide range of reconstructive options, from alloplastic devices to pedicled flaps to free flaps. Continued refinements in microsurgical techniques have allowed plastic surgeons to utilize perforator flaps, such as the DIEP flap, to perform breast reconstructions that closely resemble native breasts with minimal donor site morbidity.[21-23] Although patients commonly report high satisfaction with the aesthetic appearance of their reconstructed breasts, they continue to report poor breast sensation as a major dissatisfaction.[4,24]

Autologous breast reconstruction, such as using the DIEP flap, offers a promising method to improve breast anesthesia through the creation of a sensate flap. Spiegel et al. described utilizing the 10th, 11th, or 12th intercostal nerve within the DIEP flap and performing direct end-to-end coaptation to the anterior cutaneous branch of the 3rd intercostal nerve in the chest.[6,13] Recent studies have shown that direct end-to-end coaptation significantly improves breast

sensation. For example, Beugels et al. found that this method of innervation resulted in significantly lower values on the Semmes-Weinstein monofilament test over time compared to non-innervated DIEP flaps.[9,10] In addition, our last study demonstrated that for patients who underwent any type of neurotized DIEP flap breast reconstruction, they can expect sensation to return to baseline levels as early as 24 months postoperatively.[8] In this follow-up study, our aim is to specifically evaluate the utility of nerve allografts in DIEP flap breast reconstruction in improving sensory recovery.

As nerve allografts become increasingly utilized for neurotization of DIEP flaps, preliminary studies have demonstrated greater return of sensation—measured with Semmes-Weinstein monofilaments—in flaps neurotized with nerve allografts compared to non-neurotized reconstructed breasts.[25] Djohan et. al. showed similar results in a retrospective study of patients receiving neurotized reconstruction with a nerve allograft.[26] In this study, we utilize the AcroVal pressure-specified sensory device to generate precise, quantitative measurements of pressure threshold required for patients to detect pressure sensation on their breasts.[16] In contrast to the Semmes-Weinstein monofilaments, the pressure-specified sensory device generates multiple precise measurements rather than semi-quantitative results. In addition, the pressure-specified sensory device is largely user-independent given that all persons administering the test start at minimal pressures before slowly and gradually increasing the pressure threshold with time. Because our aim is to evaluate changes in absolute cutaneous thresholds for sensation, the pressure-specified sensory device would theoretically detect significant but minute changes that may otherwise be missed on monofilament testing.

In our cohort, all patients underwent nipple-sparing mastectomy followed by immediate reconstruction using the DIEP flap with nerve allografting. At our academic medical center, if

the breast surgeon deems the oncologic risk minimal, nipple-sparing mastectomy is usually performed. Although skin-sparing mastectomy was not an exclusion criterion, the inclusion of only nipple-sparing mastectomy patients is a strength of this study that allowed us to eliminate one potential confounder since the DIEP flap skin paddle is brought up to the surface in skin-sparing mastectomy reconstructions and would have been directly innervated following neurotization. Similarly, we specifically excluded patients who are undergoing or have undergone postoperative radiation therapy due to the varying levels of sensibility following radiation therapy. In our anecdotal experience, patients who are currently undergoing or have recently undergone radiation therapy can be more sensitive due to the radiation-induced burns and injuries to the breast skin. This concurs with a study by Magarakis et al. that found that radiated breast skin yielded better sensation in the short term but worse sensation in the long run.[14]

To our knowledge, our study is the first and only prospective study utilizing a pressure-specified sensory device to analyze the utility of nerve grafts in innervating the DIEP flap for breast reconstruction. In our analysis, we found a significant decrease in the cutaneous threshold required for patients to detect pressure sensation when measured between 3 to 6 months postoperatively and again at 12 to 24 months postoperatively. Our results show the potential of nerve allografts to be used to neurotize DIEP flaps in instances when direct end-to-end repair would instill too much tension and negatively affect nerve regeneration.[11,12,27] With the use of nerve grafts, the DIEP flap can be inset based on individual patient breast contours, sizes, and preferences to achieve the best aesthetic result without any potential constraints imposed by the need to perform direct end-to-end nerve coaptation.[24,28,29] Our results show that nerve grafts

provide plastic surgeons with another tool to perform a neurotized DIEP flap reconstruction without the need to sacrifice optimal flap inset or neurotization.

In our analysis of sensory return, patients' sensitivity measurements were worst at 3 to 6 months postoperatively before gradually improving with time. By 24 months postoperatively, patients' average sensitivity measurements were comparable to preoperative baseline levels (p = 0.083). In our previous study, we established that for patients with any type of neurotized DIEP flap reconstruction, breast sensation was worst at 3 months postoperatively before beginning to return to baseline at 24 months postoperatively.[8] Our results in this subset of nerve grafting patients highlight that sensory recovery follows a similar timeline as patients who underwent neurotization through direct end-to-end coaptation or using nerve conduits. Additionally, the trend toward significance indicates that 24 months postoperatively is likely the earliest time frame for returning to baseline sensation levels. For some patients, even at 24 months postoperatively, there is still lingering breast anesthesia. Recent studies have shown age, neoadjuvant chemotherapy, adjuvant chemotherapy, and radiation therapy as potential risk factors, but further higher-powered studies are needed to draw definitive conclusions.[10,30]

The sensory improvement, particularly between 3 to 6 months postoperatively and 12 to 24 months postoperatively, was not only shown on pressure-specified sensory testing, but also correlated with patient-reported perceptions. Using the reconstructive module of the BREAST-Q questionnaire, we focused on four sections: satisfaction with breasts, physical wellbeing, psychosocial wellbeing, and sexual wellbeing. Between the two administrations of the BREAST-Q, there were significant increases in breast satisfaction and physical wellbeing scores. Given the significant improvement in sensory findings, it can be reasonably inferred that improvement in sensation—and the associated satisfaction and physical benefits—likely contributed to higher

scores at the 12- to 24-month mark. These findings are in line with many previous studies which have found significant correlation between increased breast sensitivity and increased BREAST-Q scores and patient-reported quality of life.[31,32,33] Although not significant, psychosocial and sexual wellbeing scores also increased. There is a myriad of reasons for this, and many of which are patient-dependent, but it is likely that oncologic treatments likely played a not insignificant role in the lower absolute increases for these two categories. Furthermore, sexual wellbeing after breast surgery and reconstruction is still an area in need of study. Current literature shows varied results regarding patient-reported return of erogenous sensation in autologous reconstruction, suggesting multimodal contributors to sexual sensation beyond touch sensitivity.[14,34] Overall, in our study, the BREAST-Q captured an increase in patient satisfaction that occurred concurrently with sensory recovery.

This study has several limitations. First, the longitudinal nature of this study—spanning a minimum of 2 years—required sensory testing at set time points. In reality, patient follow-up appointment timelines rarely align exactly with sensory testing timelines. Therefore, sensory testing time points are defined by ranges rather than exact months—for example, 3 to 6 months postoperatively and 12 to 24 months postoperatively. Additionally, given that at our institution, we have largely transitioned to performing nerve grafting to innervate the DIEP flap, a direct comparison to other nerve coaptation techniques was not possible without introducing temporal biases. Finally, the BREAST-Q survey only contained two questions that directly addressed breast sensation, and we recognize that quality of life measurements are multifactorial. However, our goal for this study was to contribute our institutional experience with DIEP flap breast reconstruction using nerve allografts to the existing literature. Using this study as a starting point, we plan to conduct a comparative study in the future to assess the long-term sensation and

satisfaction outcomes in patients receiving neurotization with allograft, direct coaptation, and no neurotization. As more patients are enrolled in the study, we also plan to track postoperative sensory recovery at more granular timepoints. We hope these initial promising results inspire further studies in this new frontier for breast reconstruction.

CONCLUSIONS

This pilot study is the first prospective study utilizing a pressure-specified sensory device to evaluate the utility of nerve allografts in neurotized DIEP flap breast reconstruction in sensation recovery and patient satisfaction. Our results show that nerve grafting is a competitive alternative to direct end-to-end coaptation with significant improvements between 3 to 6 months postoperatively and 12 to 24 months postoperatively. Patients who undergoing DIEP flap breast reconstruction with nerve grafting can expect breast sensation to return as early as 24 months postoperatively.

Financial Disclosure Statement
Dr. David Otterburn receives research support from AxoGen Inc. (Alachua, FL) to evaluate return of sensation after autologous reconstruction. All other authors have no personal financial disclosures or commercial associations.

REFERENCES

1. Santosa KB, Qi J, Kim HM, Hamill JB, Wilkins EG, Pusic AL. Long-term Patient-Reported Outcomes in Postmastectomy Breast Reconstruction. *JAMA Surgery.* 2018;153(10):891-899.
2. Macadam SA, Zhong T, Weichman K, et al. Quality of Life and Patient-Reported Outcomes in Breast Cancer Survivors: A Multicenter Comparison of Four Abdominally Based Autologous Reconstruction Methods. *Plast Reconstr Surg.* 2016;137(3):758-771.

3. Bennett KG, Qi J, Kim HM, Hamill JB, Pusic AL, Wilkins EG. Comparison of 2-Year Complication Rates Among Common Techniques for Postmastectomy Breast Reconstruction. *JAMA Surgery.* 2018;153(10):901-908.

4. Djohan R, Gage E, Gatherwright J, et al. Patient satisfaction following nipple-sparing mastectomy and immediate breast reconstruction: an 8-year outcome study. *Plast Reconstr Surg.* 2010;125(3):818-829.

5. Allen RJ, Treece P. Deep inferior epigastric perforator flap for breast reconstruction. *Ann Plast Surg.* 1994;32(1):32-38.

6. Spiegel AJ, Menn ZK, Eldor L, Kaufman Y, Dellon AL. Breast Reinnervation: DIEP Neurotization Using the Third Anterior Intercostal Nerve. *Plastic and reconstructive surgery Global open.* 2013;1(8):e72-e72.

7. Xia TY, Scomacao I, Djohan R, Moreira A, Gurunian R, Schwarz GS. Neurotization Does not Prolong Operative Time in Free Flap Breast Reconstruction. *Aesthetic Plast Surg.* 2022.

8. Huang H, Wang ML, Ellison A, Otterburn DM. Comparing Autologous to Device-Based Breast Reconstruction: A Pilot Study of Return in Breast Sensation. *Ann Plast Surg.* 2022.

9. Beugels J, Cornelissen AJM, van Kuijk SMJ, et al. Sensory Recovery of the Breast following Innervated and Noninnervated DIEP Flap Breast Reconstruction. *Plastic and Reconstructive Surgery.* 2019;144(2).

10. Beugels J, Bijkerk E, Lataster A, Heuts EM, van der Hulst R, Tuinder SMH. Nerve Coaptation Improves the Sensory Recovery of the Breast in DIEP Flap Breast Reconstruction. *Plast Reconstr Surg.* 2021;148(2):273-284.

11. Dvali L, Mackinnon S. Nerve repair, grafting, and nerve transfers. *Clinics in Plastic Surgery.* 2003;30(2):203-221.

12. Beris A, Gkiatas I, Gelalis I, Papadopoulos D, Kostas-Agnantis I. Current concepts in peripheral nerve surgery. *Eur J Orthop Surg Traumatol.* 2019;29(2):263-269.

13. Spiegel AJ, Salazar-Reyes H, Izaddoost S, Khan FN. A novel method for neurotization of deep inferior epigastric perforator and superficial inferior epigastric artery flaps. *Plast Reconstr Surg.* 2009;123(1):29e-30e.

14. Magarakis M, Venkat R, Dellon AL, et al. Pilot study of breast sensation after breast reconstruction: evaluating the effects of radiation therapy and perforator flap neurotization on sensory recovery. *Microsurgery.* 2013;33(6):421-431.

15. Rodriguez-Unda NA, Bello RJ, Clarke-Pearson EM, et al. Nipple-Sparing Mastectomy Improves Long-Term Nipple But Not Skin Sensation After Breast Reconstruction: Quantification of Long-Term Sensation in Nipple Sparing Versus Non-nipple Sparing Mastectomy. *Ann Plast Surg.* 2017;78(6):697-703.

16. Dellon ES, Crone S, Mouery R, Dellon AL. Comparison of the Semmes-Weinstein monofilaments with the Pressure-Specifying Sensory Device. *Restor Neurol Neurosci.* 1993;5(5):323-326.

17. Santanelli F, Paolini G, Bittarelli D, Nofroni I. Computer-assisted evaluation of nipple-areola complex sensibility in macromastia and following superolateral pedicle reduction mammaplasty: a statistical analysis. *Plast Reconstr Surg.* 2007;119(6):1679-1683.

18. Slezak S, McGibbon B, Dellon AL. The sensational transverse rectus abdominis musculocutaneous (TRAM) flap: return of sensibility after TRAM breast reconstruction. *Ann Plast Surg.* 1992;28(3):210-217.

19. Cano SJ, Klassen AF, Scott AM, Cordeiro PG, Pusic AL. The BREAST-Q: further validation in independent clinical samples. *Plast Reconstr Surg.* 2012;129(2):293-302.

20. Portfolio Q. BREAST-Q Version 2.0. Published 2017. Accessed April 29, 2022.

21. Grünherz L, Keijzer W, Uyulmaz S, et al. Donor site aesthetics and morbidity after DIEP flap breast reconstruction-A retrospective multicenter study. *Breast J.* 2020;26(10):1980-1986.

22. Jeong W, Lee S, Kim J. Meta-analysis of flap perfusion and donor site complications for breast reconstruction using pedicled versus free TRAM and DIEP flaps. *Breast.* 2018;38:45-51.

23. Paik JM, Lee KT, Jeon BJ, et al. Donor site morbidity following DIEP flap for breast reconstruction in Asian patients: Is it different? *Microsurgery.* 2015;35(8):596-602.

24. Razzano S, Marongiu F, Wade R, Figus A. Optimizing DIEP Flap Insetting for Immediate Unilateral Breast Reconstruction: A Prospective Cohort Study of Patient-Reported Aesthetic Outcomes. *Plast Reconstr Surg.* 2019;143(2):261e-270e.

25. Momeni A, Meyer S, Shefren K, Januszyk M. Flap Neurotization in Breast Reconstruction with Nerve Allografts: 1-year Clinical Outcomes. *Plast Reconstr Surg Glob Open*. 2021;9(1):e3328.

26. Djohan R, Scomacao I, Duraes EFR, Knackstedt R, Mangan R, Schwarz G. Sensory Restoration in Abdominally Based Free Flaps for Breast Reconstruction Using Nerve Allograft. *Plast Reconstr Surg*. 2023;151(1):25-33.

27. Kornfeld T, Vogt PM, Radtke C. Nerve grafting for peripheral nerve injuries with extended defect sizes. *Wien Med Wochenschr*. 2019;169(9-10):240-251.

28. Gravvanis A, Kakagia D, Samouris G, Galani E, Tsoutsos D. Tips and Outcomes of a New DIEP Flap Inset in Delayed Breast Reconstruction: The Dual-Plane Technique. *J Reconstr Microsurg.* 2016;32(5):366-370.

29. Gravvanis A, Samouris G, Galani E, Tsoutsos D. Dual plane diep flap inset: Optimizing esthetic outcome in delayed autologous breast reconstruction. *Microsurgery.* 2015;35(6):432-440.

30. Bae JY, Shin HY, Song SY, Lee DW. Risk and protective factors affecting sensory recovery after breast reconstruction. *Arch Plast Surg.* 2021;48(1):26-32.

31. Cornelissen AJM, Beugels J, van Kuijk SMJ, et al. Sensation of the autologous reconstructed breast improves quality of life: a pilot study. *Breast Cancer Res Treat*. 2018;167(3):687-695.

32. Abbas F, Klomparens K, Simman R. Functional and Psychosocial Outcomes following Innervated Breast Reconstruction: A Systematic Review. *Plast Reconstr Surg Glob Open*. 2022;10(9):e4559. Published 2022 Sep 28.

33. Bijkerk E, Beugels J, van Kuijk SMJ, Lataster A, van der Hulst RRWJ, Tuinder SMH. Clinical Relevance of Sensory Nerve Coaptation in DIEP Flap Breast Reconstruction Evaluated Using the BREAST-Q. *Plast Reconstr Surg*. 2022;150(5):959e-969e.

34. Blondeel PN, Demuynck M, Mete D, et al. Sensory nerve repair in perforator flaps for autologous breast reconstruction: sensational or senseless?. *Br J Plast Surg*. 1999;52(1):37-44.

Figure 1. Nine breast regions used for sensory testing: outer superior (OS), outer medial (OM), outer inferior (OI), outer lateral (OL), inner superior (IS), inner medial (IM), inner inferior (II), inner lateral (IL), and nipple areola complex (NA).

Figure 2. Sensory testing results between 3 to 6 months postoperatively and 12 to 24 months postoperatively.

Figure 3. Sensory comparison at 24 months postoperatively.

Table 1. Reconstructive BREAST-Q Score (Scaled)

BREAST-Q Section	**3 to 6 Months Postop**	**12 to 24 Months Postop**	***p***
Breast Satisfaction	56.7 ± 9.1	75.1 ± 12.6	0.032*
Physical wellbeing	66.0 ± 14.0	85.5 ± 11.1	0.022*
Psychosocial wellbeing	69.0 ± 6.1	75.7 ± 14.3	0.474
Sexual wellbeing	46.0 ± 11.1	55.3 ± 13.1	0.273

*Statistically significant

Figure 1. Nine breast regions used for sensory testing: outer superior (OS), outer medial (OM), outer inferior (OI), outer lateral (OL), inner superior (IS), inner medial (IM), inner inferior (II), inner lateral (IL), and nipple areola complex (NA).

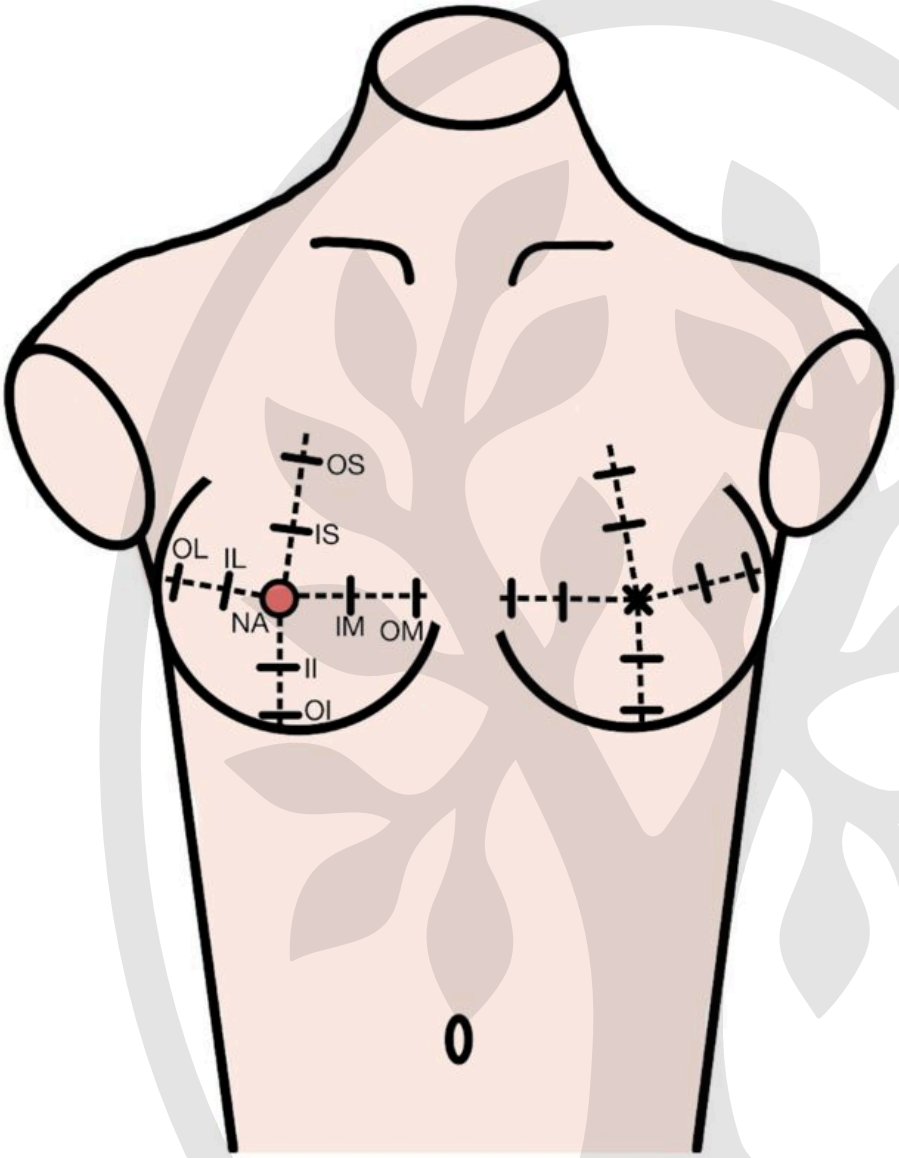

Figure 2. Sensory testing results between 3-6 months postoperatively and 12-24 months postoperatively.

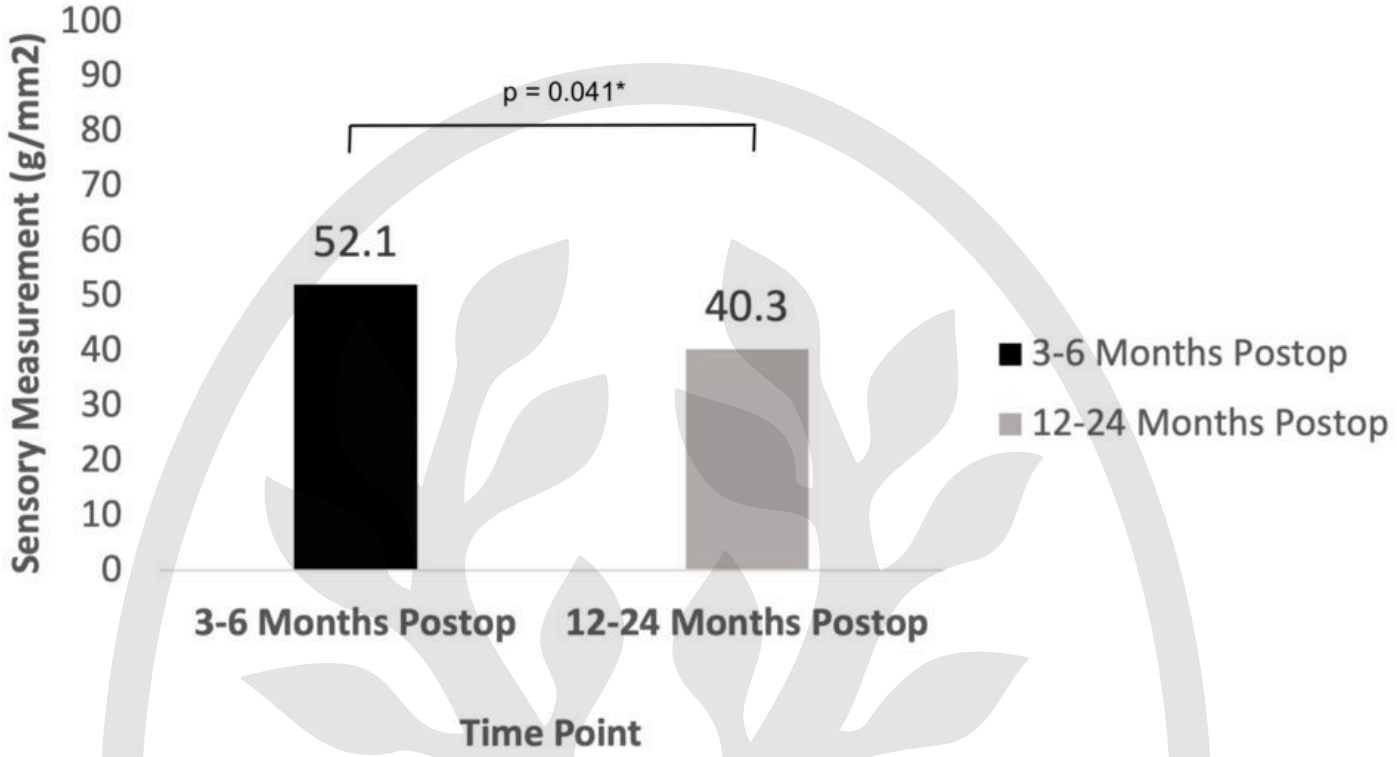

Figure 3. Sensory comparison at 24 months postoperatively.