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REVIEW

Advancing Breast Reconstruction: Next-Generation Robotic-Assisted Deep Inferior Epigastric Perforator Flap Techniques

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ABSTRACT

Robotic-assisted surgery has revolutionized the surgical world, introducing innovative methods to reduce invasiveness across a variety of procedures. Despite its promise, the adoption of robotic-assisted techniques in microsurgery has been gradual. Many microsurgical procedures traditionally rely on open approaches and demand a level of technical skill that exceeds the current capabilities of robotic systems. The robotic-assisted deep inferior epigastric perforator (DIEP) flap for breast reconstruction exemplifies a pioneering application of robotic technology that enhances the "gold standard" for flap-based breast reconstruction. This technique enables microsurgeons to harvest the pedicle of the abdominal flap with a significantly shorter fascial incision. It is hypothesized that minimizing the fascial incision length could mitigate donor site morbidity and related complications, such as core weakening, pain, and the risk of fascial bulge or hernia. This manuscript delves into the robotic-assisted DIEP flap, elaborating on the operative technique and sharing critical surgical insights necessary for successful implementation. Furthermore, it reviews the pertinent literature, underscoring both the successes and potential areas for enhancement of the robotic-assisted DIEP flap. This comprehensive examination showcases the current advancements and sets the stage for future innovations in the field of robotic-assisted microsurgery.

ROBOTIC-ASSISTED SURGERY OVERVIEW

Robotic-assisted surgery (RAS) was first conceptualized in the 1980s by Scott Fisher at the National Aeronautics and Space Administration (NASA) and Joseph Rosen, a plastic surgeon at Stanford University [1]. Originating as a derivative of laparoscopic surgery, RAS aims to improve surgical outcomes through minimally invasive approaches, thereby reducing human error [2]. Since the introduction of early robotic equipment such as the Programmable Universal Machine for Assembly (PUMA) Arm and RoboDoc, designed for neurologic and orthopedic surgery respectively, to the advent of the da Vinci® System, the field of RAS has experienced exponential growth over the past decades [1,2].

The da Vinci® System, which consists of a surgeon's console equipped with cameras for each eye, a patient trolley with four articulated arms, and an advanced imaging system, was the first surgical robot to receive FDA approval in 2000 [2,3]. It has been widely adopted across various medical subspecialties, including urology, gynecology, otolaryngology, cardiothoracic, and abdominal surgery [4–6]. Research on outcomes in these fields has underscored the significant benefits of RAS for both patients and providers.

BENEFITS AND ADVANCEMENTS IN RAS

RAS has been shown to minimize morbidity and mortality by reducing risks associated with surgical tremor and fatigue, providing seven degrees of motion, and offering three-dimensional vision, thereby enhancing the surgeon's dexterity and the visualization of the surgical field [6]. Given that the initial surgical robot was developed with clinical input from Joseph Rosen, a plastic surgeon, specifically to enhance neurovascular anastomoses in hand surgery, RAS has consistently demonstrated significant potential within the field of plastic surgery [1]. Its swift adoption in otolaryngology, particularly through transoral robotic surgery, exemplifies one way RAS has penetrated plastic surgery [7]. Research on transoral robotic surgery has shown it facilitates easier dissection, reduces damage to adjacent anatomy, and improves both visualization and ergonomics for surgeons [7–9].

RAS IN PLASTIC SURGERY

Similarly, the success of RAS in oncology has spurred the development of robotic techniques for nipple sparing mastectomy [9–13]. Studies have revealed that when RAS is applied to the harvesting of flaps, particularly the latissimus dorsi and deep inferior epigastric perforator (DIEP) flaps, it enhances visualization and reduces surgical complications and scarring [13–16]. Additionally, RAS has highlighted the benefits of tremor filtration and motion scaling in creating effective and successful anastomoses [13,17]. Head and neck and breast reconstructions are two areas where RAS can greatly improve both the surgical experience and outcomes, offering substantial advancements in plastic surgery.

CASE PRESENTATION

The authors report on a 63-year-old postmenopausal female patient with a documented history of moderately differentiated invasive ductal carci-

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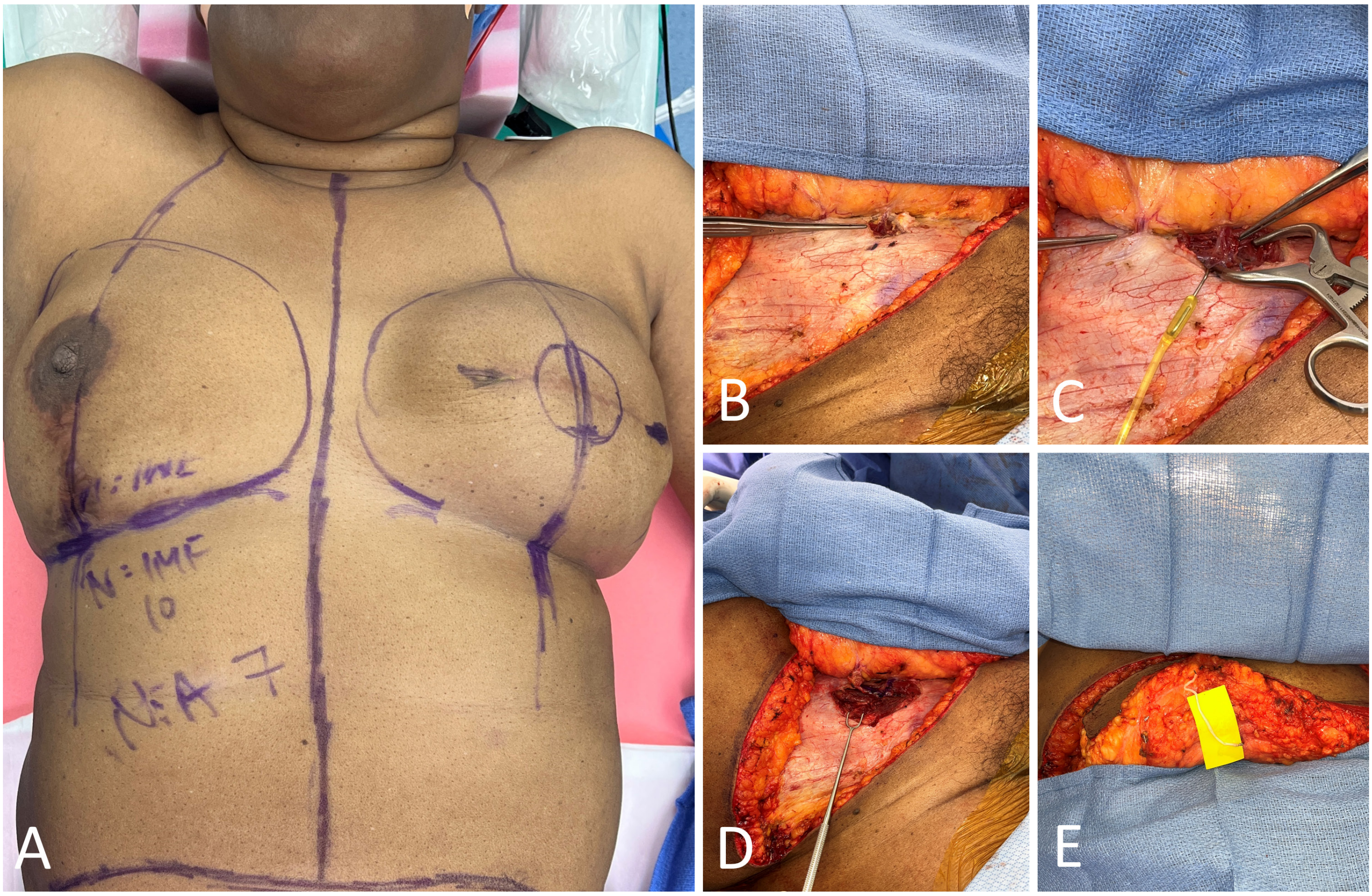

Figure 1. Preoperative marking and initial dissection. (A) Preoperative markings for a 63-year-old female with a history of left breast cancer, scheduled for delayed left breast microsurgical reconstruction utilizing a robotic-assisted right deep inferior epigastric artery perforator (DIEP) flap. (B) The targeted perforator is successfully identified and exposed, facilitated by preoperative magnetic resonance angiography. (C) The procedure identifies a single dominant perforator, optimal for the robotic-assisted DIEP flap harvest approach. Notably, an additional perforator is observed in proximity to the primary target along the same medial row. (D) A minimal extension of the fascial incision is performed to expose both perforators. Despite this extension, the incision's length remains conducive to the robotic-assisted approach. Once exposed, meticulous dissection is conducted following the pedicle to the submuscular plane. (E) A nerve graft is executed for coaptation following the harvesting of the DIEP flap.

noma in the left breast. The tumor tested positive for estrogen and progesterone receptors (ER+/PR+), and negative for the human epidermal growth factor receptor 2 (HER2-). It was staged as pT2N0 under the tumor, node, metastasis (TNM) classification system and classified as Stage 1B according to the American Joint Committee on Cancer (AJCC) standards.

She underwent a skin-sparing mastectomy of the left breast and prepectoral tissue expander reconstruction with an acellular dermal matrix. Neoadjuvant anastrozole was required, but adjuvant radiation therapy was not administered. Following the completion of her oncologic care, she expressed concerns about deformity, asymmetry, and mastodynia in her reconstructed breast.

Consequently, she showed interest in autologous breast reconstruction and decided to undergo a delayed microsurgical reconstruction of the left breast using a robotic-assisted right DIEP flap. This decision was informed by a detailed discussion of her options and preferences, taking into account her surgical history and insights from magnetic resonance angiogram scans.

For the robotic-assisted DIEP approach, preoperative imaging is essential for perforator mapping, selection, and assessment of the intramuscular course of the pedicle. The ideal candidate typically displays a single perforator or two grouped perforators in close proximity with a short intramuscular course. Analysis of the length of the intramuscular course is crucial for determining candidacy, as the fascial incision must extend the entire length of the pedicle's intramuscular course at a minimum. For this patient, the magnetic resonance angiogram revealed two notably large perforators, making her a suitable candidate for this advanced surgical technique.

OPERATIVE TECHNIQUE

Preoperative Marking and Initial Dissection

The donor and recipient sites were marked preoperatively while the patient was in the upright position (Figure 1A). The robotic-assisted DIEP flap technique began with the elevation of the abdominal flap, with dissection performed down to the anterior rectus fascia, similarly to the conventional open approach. The right abdominal donor site flap was elevated centrally from lateral to medial, with direct undermining based on the selected perforators identified by preoperative imaging (Figure 1B). Lateral perforators were clipped and ligated until two large medial row perforators were identified.

Once the pre-selected perforators were exposed, the anterior rectus fascia was minimally incised. The pedicle was then traced to the retromuscular position, and at this point, the remainder of the dissection was performed submuscularly (Figure 1C). The vertical length of the fascial incision was limited to the region through which the pedicle runs intramuscularly.

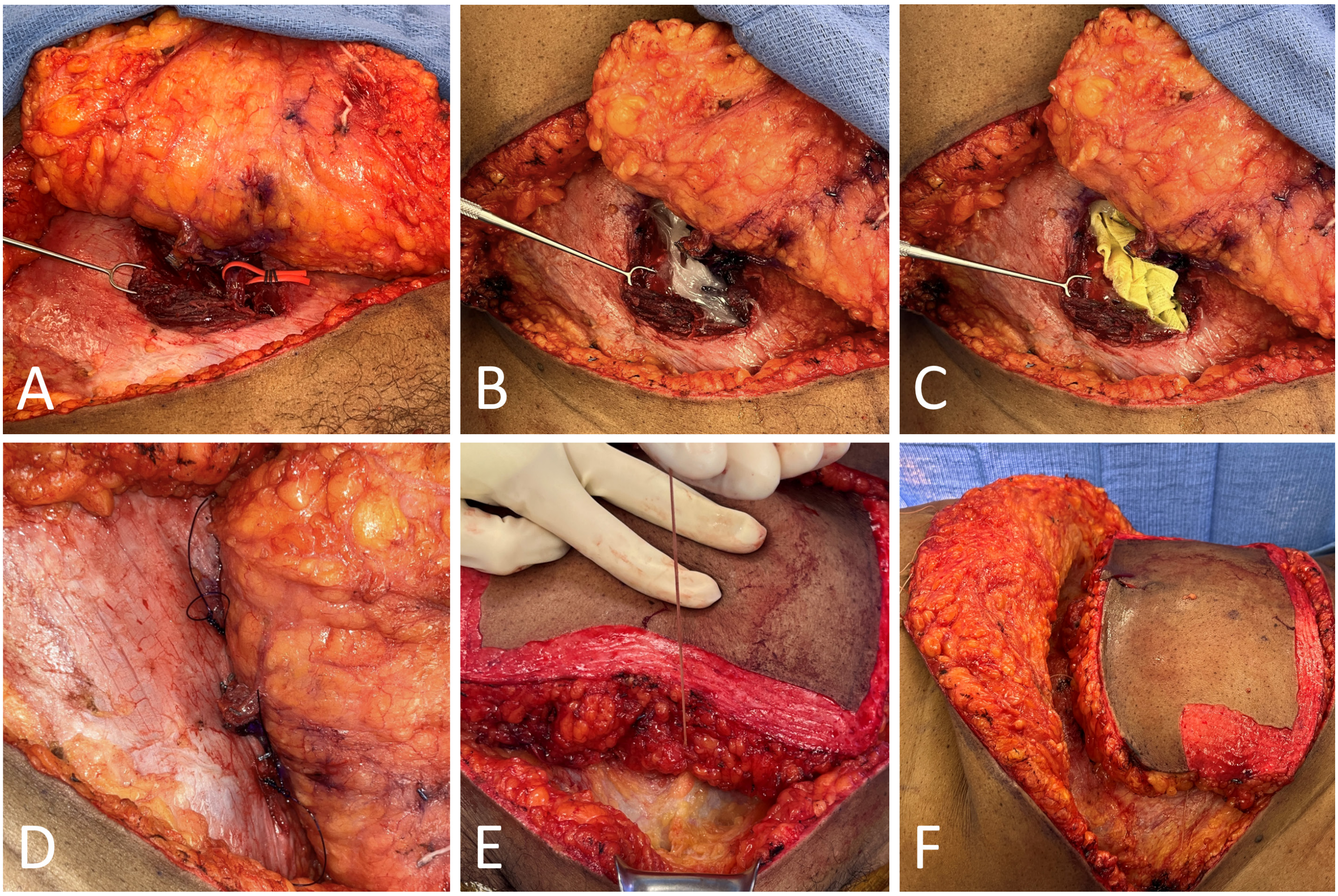

Figure 2. Securing and preparing the deep inferior epigastric perforator (DIEP) flap. (A) A red vessel loop is circumferentially secured around the pedicle and gently tunneled into the submuscular plane. Intra-abdominally, the vessel loop aids in pedicle retrieval and minimizes the risk of pedicle injury during robotic-assisted dissection. To mitigate gas leakage from the external defect during insufflation, Bacitracin ointment (B), Xeroform gauze dressing (C), and two size 0 polydioxanone (PDS) sutures (D) are applied sequentially. The sutures are strategically placed above and below the perforator. (E) Size 0 Vicryl sutures are employed to secure the DIEP flap during insufflation. (F) Size 0 Vicryl sutures are also utilized to reflect the superior flap, allowing for optimal robotic docking.

In this case, a separate perforator was in close proximity to the perforator of interest along the same medial row, and therefore the fascial incision was extended to expose both perforators (Figure 1D). Despite this extension, the overall length of the incision did not preclude the robotic-assisted approach. Notably, a nerve graft may be performed for coaptation after the DIEP flap is harvested (Figure 1E).

Securing and Preparing the DIEP Flap

Once the pedicle was dissected posterior to the rectus muscle, a vessel loop was loosely secured around the pedicle from the open, anterior exposure (Figure 2A). The loop was then channeled and nestled in the submuscular plane to facilitate robotic-assisted retrieval of the vessel loop intraperitoneally. To allow insufflation of the abdomen, Bacitracin ointment covered with Xeroform gauze was used as a temporary seal to minimize the escape of gas from the fascial defect. This seal was also temporarily reinforced with sutures (Figures 2B–D).

To ensure that the pedicle was not compromised after establishing a seal, the skin paddle of the abdominal flap was checked for adequate perfusion through assessment of color, capillary refill, and audible Doppler signal. The entire left hemi-abdominal flap was elevated prior to robotic-assisted dissection so that the flap was solely reliant on its right two perforators. After an adequate seal was established and the left hemi-abdominal flap was elevated, Size 0 Vicryl sutures were used to secure the DIEP flap and robotic-assisted access into the peritoneal cavity was performed (Figures 2E–F).

Bilateral DIEP Flap Considerations

In bilateral DIEP flap procedures, it is crucial to preserve the superior continuation of the perforator in the hemi-abdominal flap that is scheduled for secondary recipient site microsurgery. Alternatively, a separate perforator from the second transposed hemi-abdominal flap can be exposed, preserved, and maintained in situ based on the opposite row to ensure adequate perfusion of the flap. This is done after the pedicle of the primary perforator of interest has been clipped and ligated with robotic assistance intra-abdominally. The second perforator or the superior continuation of the perforator in the second hemi-abdominal flap is ligated once the second flap is prepared for microsurgical anastomosis. This careful preservation and management of perforators are essential to ensure the viability and successful integration of both flaps during the bilateral DIEP flap procedure.

Robotic DIEP Flap Procedure

At our institution, at this point in the procedure, a general surgeon with advanced skills in robotic techniques assumes the lead. The interdisciplinary nature of our team, which includes general surgeons, enables us to safely dissect the vascular pedicle robotically.

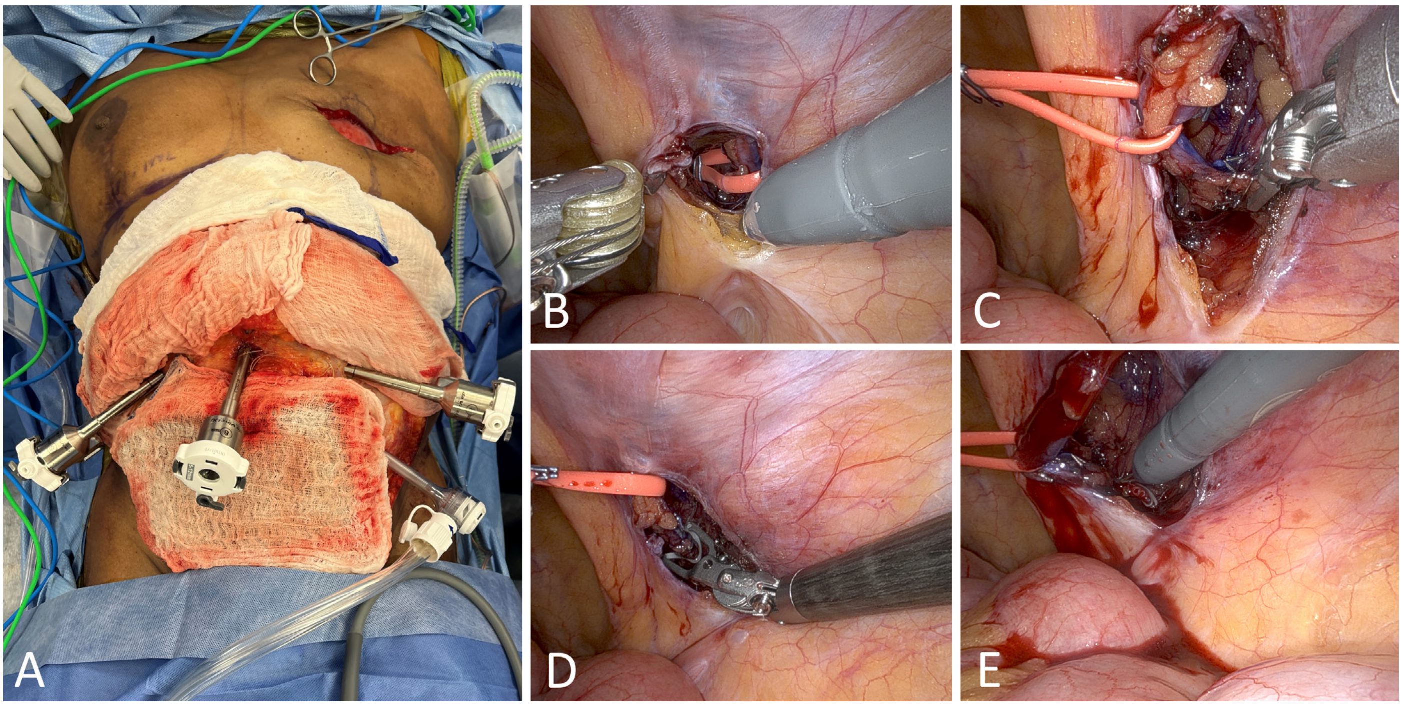

Figure 3. Robotic-assisted deep inferior epigastric perforator (DIEP) flap procedure. (A) Port placement mimics the approach used in robotic transabdominal preperitoneal (rTAPP) repair for inguinal hernia, with pneumoperitoneum established at a pressure of 10–15 mmHg. (B) Monopolar scissors and a fenestrated bipolar grasper are utilized to incise the peritoneum. The red vessel loop is retrieved intra-abdominally to facilitate optimal pedicle dissection. (C) All contributing side branches are either clipped using microclips or ligated with the bipolar device to ensure clear pedicle dissection. (D) Microclips are applied to the pedicle near its proximal origin at the level of the external iliac vessels. (E) After clipping, monopolar scissors are used to cut the pedicle at its base.

An open Hasson entry technique was utilized to access the peritoneal cavity, though a Veress needle could alternatively be used. After inserting an AirSeal port (CONMED, Utica, NY, USA), pneumoperitoneum was established at a pressure of 10–15 mmHg. A camera was then placed through the insufflation port to assist in the insertion of three additional 8-mm robotic ports. These ports were inserted above the umbilicus through the fascia at the level of the epigastrium, in a manner similar to the robotic transabdominal preperitoneal (rTAPP) repair for inguinal hernias (Figure 3A).

Alternatively, the contralateral ports relative to the targeted DIEP flap may be placed lateral to the semilunar line and along an imaginary line connecting the anterior superior iliac spine and the anterior axillary line, with the middle port positioned between the anterior superior iliac spine and the anterior axillary line. This approach necessitates undocking of the robot when switching to the contralateral side during a bilateral DIEP procedure, which reduces overall efficiency compared to the previously described approach that allows for single docking when harvesting both pedicles.

Monopolar scissors and fenestrated bipolar graspers initiated the intraperitoneal dissection of the pedicle (Figure 3B). The peritoneum was incised lateral to the lateral umbilical fold until the previously positioned vessel loop was visualized and retrieved. This vessel loop was then manipulated to aid in the dissection of the pedicle up to its proximal origin at the level of the external iliac vessels. Microclips and bipolar graspers were employed to sever all contributing side branches until the pedicle was substantially freed (Figure 3C).

Following thorough dissection, the pedicle was clipped, cut, and detached from the external iliac vessels (Figures 3D–E). The pedicle was then divided distally and completely removed through the external fascial opening. A detailed video supplement demonstrating the robotic-assisted extraction of the vascular pedicle in a DIEP flap procedure is available at https://doi.org/10.24983/scitemed.imj.2024.00185. This video clearly illustrates the removal process from the intra-abdominal cavity.

Closure and Final Steps

Robotic-assisted closure of the posterior rectus sheath was carried out, followed by the undocking of the robotic arms from the patient (Figure 4A). The pneumoperitoneum was then decompressed, and the port sites were closed using figure-of-eight sutures. The operation proceeded as a traditional DIEP procedure with the closure of the small external fascial defect after the flap had been removed and readied for microsurgical anastomosis (Figures 4B–D).

ROBOTIC DIEP RECONSTRUCTION EVOLUTION

To fully appreciate the current applicability and future potential of robotic-assisted DIEP flap breast reconstruction, it is crucial to understand its historical context. Autologous breast reconstruction has gained popularity, as numerous studies have shown it leads to higher patient satisfaction, fewer long-term complications, and superior aesthetic outcomes compared to implant-based reconstructions [18,19]. The DIEP flap has become the "gold standard" for breast reconstruction. While other flaps, such as thigh and trunk-based flaps, are also viable options, the DIEP flap is particularly advantageous due to the abundant availability of donor tissue in the abdominal area [20].

The main drawback of the DIEP flap is that the surgeon must create a lengthy fascial incision to harvest the pedicle. These fascial openings sometimes extend below the arcuate line, leaving patients more susceptible to significant postoperative pain, abdominal weakening, fascial bulge, or hernia [21,22]. Dr. Jesse Selber pioneered the robotic-assisted DIEP flap in the last decade to offer the benefits of autologous breast reconstruction with

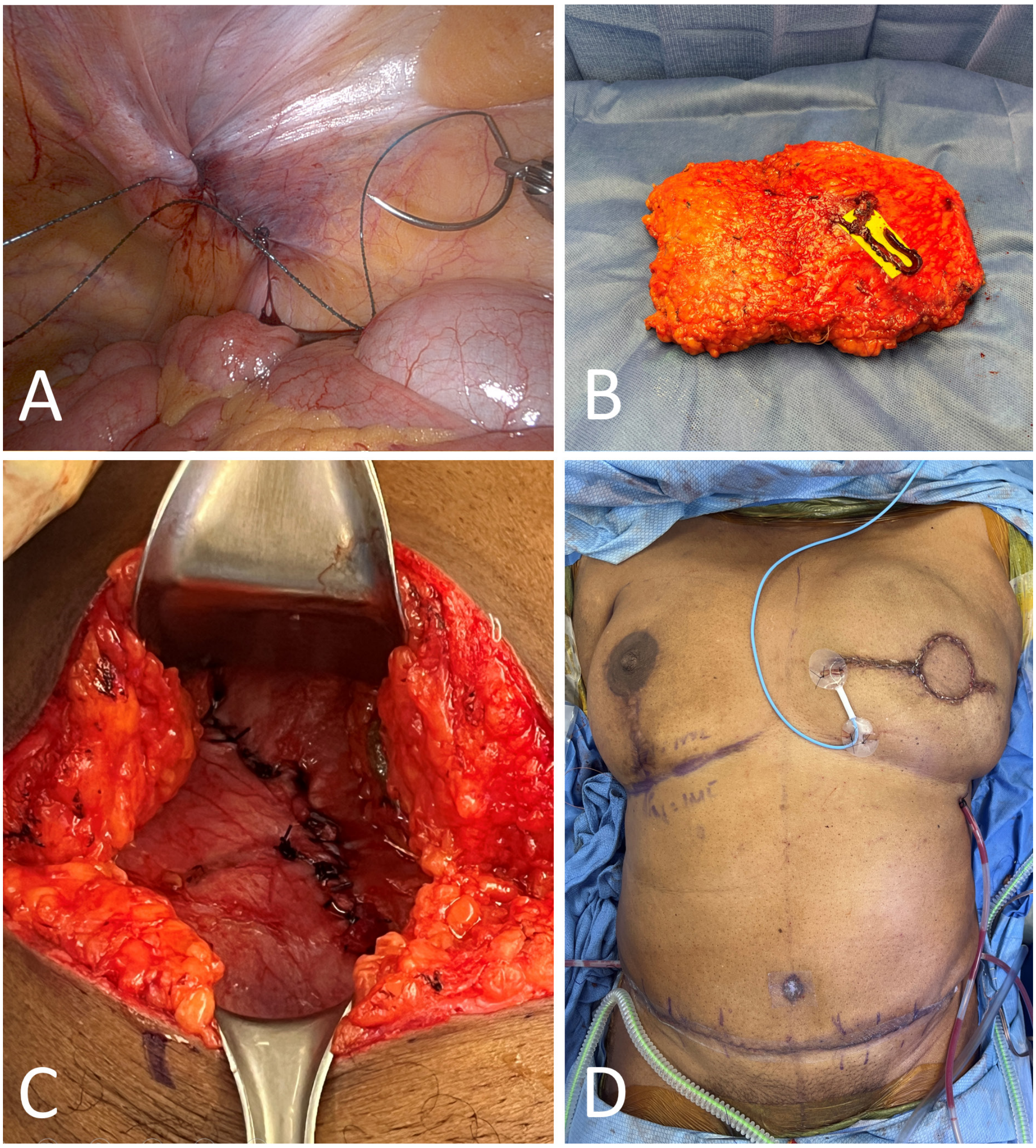

Figure 4. Closure and final steps. (A) A barbed suture is used to robotically close the posterior rectus sheath in a running fashion. (B) The isolated abdominal flap after the pedicle is completely ligated and removed through the external fascial defect. (C) Closure of the external fascial defect shows a defect length confined to less than 5 cm. (D) Immediate postoperative result.

the DIEP flap while minimizing invasiveness [14]. With the robotic-assisted DIEP flap technique, the fascial incision only needs to extend as long as the pedicle's intramuscular course. The remainder of the pedicle is harvested intra-abdominally using robotic assistance. This approach significantly reduces the length of the fascial incision, theoretically lowering the risk for significant pain and the aforementioned donor site complications.

PROMISING ROBOTIC DIEP OUTCOMES

While the robotic-assisted DIEP flap represents a relatively new advancement in microsurgical breast reconstruction, it has already shown promising clinical outcomes. In 2022, Selber and colleagues published a preliminary case series involving 21 patients who underwent robotic-assisted DIEP flap breast reconstruction [12]. This cohort had a mean fascial incision length of 3.6 ± 1.6 cm, significantly shorter than the traditional 13 cm incision associated with the standard DIEP technique. The mean pedicle length for this group was 13.3 ± 1 cm, and none of the patients developed bulges or hernias. Although the study's small sample size precludes definitive conclusions about complication rates, the reduction in fascial incision length without compromising pedicle length is notable.

Other institutions have also documented early success with the robotic-assisted DIEP flap technique. Lee et al. published an article reporting significantly lower levels of postoperative pain in patients who underwent robotic-assisted DIEP flap breast reconstruction compared to those who had traditional DIEP flap surgery [16]. Wittesale et al. conducted a retrospective review of outcomes at their institution and found no flap failures or intra-abdominal complications among 10 patients who received robotic-assisted DIEP flaps. They noted a steep learning curve associated with the robotic-assisted DIEP technique; although it did not impact the success of the surgeries, the operative time was significantly longer than that required for traditional DIEP flaps [23]. Furthermore, Daar et al. reported on a series involving four patients who underwent robotic-assisted DIEP flaps, with none experiencing flap loss or abdominal site complications [24]. While clinical outcome studies are still limited, initial reports consistently affirm the clinical viability and safety of the robotic-assisted DIEP flap technique, showing promising signs of improved postoperative outcomes.

CURRENT LIMITATIONS

Limitations in Patient Eligibility

The promising early success of robotic-assisted DIEP flap breast reconstruction is not without its limitations. A significant limitation of the current technique is that not all patients are ideal candidates. As previously discussed, if preoperative imaging shows a patient's vascular anatomy to have a long intramuscular course, a longer fascial incision is required, reducing the benefits of the robotic-assisted technique. Currently, there is no method to harvest the pedicle with an incision shorter than the length of the pedicle's intramuscular course [25]. This restricts the number of patients who can benefit from this advanced surgical method.

Technical Challenges and Port Setup

Additionally, the technology used in RAS involves a complex port setup. Multiple port sites are currently required, and for some bilateral procedures, the robotic system must be repositioned for each side [14]. Efficiency and invasiveness could be improved by reducing the number of necessary ports and eliminating the need for repositioning. The technical limitations of the robotic system can partially be attributed to its relatively new application in harvesting robotic-assisted DIEP flaps. Although it has been demonstrated that RAS can safely provide more minimally invasive breast reconstructions, the systems were not originally designed with this specific technique in mind. As the robotic-assisted DIEP flap, and more broadly, robotic microsurgical procedures, continue to be recognized for their superior outcomes, it is likely that robotic surgical systems will evolve to allow more seamless technical integration.

TAPP Versus TEP Approaches

There are two techniques that can be used for the robotic-assisted DIEP flap: the transabdominal preperitoneal (TAPP) approach and the totally extraperitoneal (TEP) approach. This paper focuses on the TAPP approach, with which we have experienced significant initial success at our institution. The TAPP approach offers several advantages over the TEP approach, including shorter operative times and a simpler learning curve. However, it is crucial to discuss the drawbacks of the TAPP approach, notably its more invasive nature due to the need to enter the intraabdominal cavity. Additionally, this technique presents a higher barrier to entry, particularly for plastic surgeons who are not proficient in intraabdominal procedures.

Conversely, the TEP approach provides completely extraperitoneal access to the vascular pedicle. Although the advantages of the TEP approach are well-documented, its steep learning curve and longer operative times have limited its widespread adoption for robotic-assisted DIEP flap harvest [26]. Manrique et al. conducted a cadaveric study comparing the TAPP and TEP approaches, validating the feasibility of both methods and confirming their theoretical advantages and limitations [27]. Further studies are essential to determine the most advantageous approach, enabling surgeons to refine and master a preferred technique.

Cost and Operative Time Considerations

The most significant drawback of the robotic-assisted DIEP flap technique is the increased cost and operative time. Firstly, the upfront cost of a robotic surgical system is substantial, and for institutions that do not already own one, this can be a considerable barrier [28,29]. Even if an institution already has a robotic surgical system or the upfront cost is not an issue, the robotic-assisted DIEP flap requires significantly longer operative times compared to the traditional DIEP flap. This increase in operative time results in higher hospital and anesthesia fees; however, reimbursement rates for robotic-assisted and traditional DIEP flaps are the same [30].

While studies are being conducted to analyze the overall cost-effectiveness of the robotic-assisted DIEP flap technique, there remains uncertainty as to whether the initial investment in operative time and cost is justified in the long term [31,32]. However, analysis of cost-effectiveness in other specialties suggests promising results. For example, Leow et al. reported that robotic-assisted prostatectomies could reduce overall hospital expenses compared to traditional radical open prostatectomies by decreasing time spent in the intensive care unit and shortening hospital stays [33]. Furthermore, Rodrigues Martins et al. showed that experience plays a significant role in improving cost-effectiveness, providing further incentive to develop effective multidisciplinary training protocols [34].

FUTURE DIRECTIONS FOR ROBOTIC DIEP FLAP

Advancing Robotic DIEP Flap Efficiency

For the robotic-assisted DIEP flap technique to continue gaining popularity and acceptance, refining the technique and preparing the next generation of surgeons are crucial. Enhancing the port setup required for robotically harvesting the pedicle of the DIEP flap could significantly improve the efficiency of the procedure. Currently, the technique requires multiple robotic port sites and frequent repositioning of the surgical robot in bilateral cases.

Further research and validation of single-port techniques are essential. Advancements in robotic technology that enable bilateral pedicle harvesting without repositioning could make surgeries less invasive. These innovations would also significantly reduce operative times, improving overall surgical efficiency and patient outcomes. While there are promising studies indicating major improvements in robotic surgical systems [6,35], these advancements have yet to be applied and validated for the robotic-assisted DIEP flap technique. Moreover, robotic surgical systems designed for microsurgery are rapidly evolving. As these systems with enhanced technical capabilities become more widely available, it is conceivable that procedures currently unsuitable for RAS, such as vascular anastomosis and nerve reinnervation, could also be performed robotically.

To address the issues of increased operative time and costs associated with the robotic-assisted DIEP flap technique, enhancing the operative efficiency of surgeons is key. Research indicates that even minor improvements to the operating room setup and coordination can significantly boost surgical efficiency [36,37]. Additionally, the noted steep learning curve associated with this technique underscores the importance of surgeons gaining proficiency and comfort with the necessary robotic technology and procedures [12,23]. Dr. Selber has advocated for the expansion of plastic surgery residency curriculums to include training in RAS [38], highlighting the critical need for hands-on experience.

Interdisciplinary Programs for Training

The development of interdisciplinary programs is vital. These initiatives should enable general surgeons with advanced robotic training to instruct residents, fellows, and practicing plastic surgeons. Such programs could drastically accelerate the learning process, enabling surgeons to achieve peak operational efficiency more swiftly. Furthermore, by educating and training the next generation of surgeons in robotic techniques, institutions may be more inclined to invest in robotic surgical technology, thereby enhancing the accessibility of advanced methods like the robotic-assisted DIEP flap.

CONCLUSIONS

The introduction of the DIEP flap has significantly transformed the options available for women considering breast reconstruction. Although it is considered the "gold standard" for autologous breast reconstruction, the traditional DIEP flap is invasive and may result in lengthy abdominal fascial incisions, which can lead to increased pain, bulging, and hernias. The robotic-assisted DIEP flap marks the next advancement in this field, providing all the advantages of traditional DIEP flap reconstruction while reducing morbidity at the donor site. While the robotic-assisted approach currently involves longer operative times and higher costs, there are numerous potential improvements that could alleviate these disadvantages. The robotic-assisted DIEP flap is a crucial development in enhancing the surgical experience for women undergoing breast reconstruction.

ARTICLE INFORMATION

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