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Robotic approaches to breast reconstruction

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Abstract
The purpose of this manuscript is to fully characterize modern approaches to robotic breast reconstruction. The authors review and describe preoperative planning, operative anatomy & techniques, and clinical outcomes regarding robotic breast reconstruction. In the modern era of robotic surgery, many of the beneficial outcomes in other surgical specialties also apply to breast reconstruction. When comparing outcomes between traditional and robotic latissimus flap reconstruction, a robotic approach is associated with a shorter hospital length of stay, lower postoperative opioid requirements, and higher patient satisfaction. For robotic DIEP flap reconstruction, outcomes from several studies also report favorable results with no flap losses, intraabdominal complications, or postoperative hernia/bulge. Although barriers exist regarding this technology, robotic latissimus and DIEP flap reconstruction can be safely learned and applied with thoughtful patient selection and preoperative planning. Robotic breast reconstruction facilitates a minimally invasive approach that decreases donor-site morbidity, length of stay, and opioid requirements, and even improves patient satisfaction.

Keywords: Robotic surgical procedures, breast reconstruction, microsurgery

INTRODUCTION

Originally funded by NASA and the United States military for the application of remote operations, robotic surgery was first brought to the forefront of modern healthcare by urologists for use in prostate surgery[1].

Subsequent adoption of this technology within other surgical specialties such as general surgery, thoracic surgery, gynecologic surgery, and otolaryngologic surgery illustrates that robotic surgery enhances operative ergonomics by providing three-dimensional optics at 10× magnification, increasing precision with 5:1 motion scaling, and eliminating tremor[2]. A robotic approach to breast reconstruction was first described in 2006 by Boyd *et al* for the harvest of intermammary recipient vessels among 20 patients undergoing autologous tissue transfer[3].

Arising from the premise of a robotic approach to recipient vessel dissection, literature describing a full robotic approach to workhorse flaps first appeared in 2011 with the harvest of 10 robotic latissimus dorsi muscle flaps in a cadaveric model[4]. These techniques were subsequently applied clinically to harvest pedicled latissimus muscle flaps for breast reconstruction[5]. Robotic latissimus muscle flap harvest affords distinct advantages to a traditional open approach, notably an 80-88% reduction of the donor site incision and better circumnavigation of the back with high-resolution optics and superior ergonomics. To further maximize the precision of autologous breast reconstruction while minimizing donor-site morbidity, a robotic approach to the deep inferior epigastric perforator (DIEP) flap was also developed[6,7]. Traditional DIEP flap harvest requires significant disruption of the abdominal wall to effectively isolate necessary perforators and obtain the pedicle length necessary for microsurgery. While dissection utilizing lateral row perforators results in less intramuscular dissection, this approach puts motor nerves at higher risk of violation, leading to abdominal wall weakness, bulging, or hernia[8]. Robotic DIEP flap harvest utilizes a submuscular approach for pedicle dissection, sparing motor nerves with a much smaller fascial incision, minimizing the risk for donor-site morbidity.

In this chapter, we will fully characterize the preoperative planning, operative anatomy & techniques, and clinical outcomes regarding the robotic harvest of two workhorse flaps in autologous breast reconstruction, the latissimus muscle flap and DIEP flap. All aspects of this chapter were conducted and are presented in ethical accordance with the Declaration of Helsinki, with the approved secondary use of de-identified figures and photographs obtained through patient written-informed consent; these methods meet Institutional Review Board rules and standards of approval for exemption.

CLINICAL CONSIDERATIONS

While full clinical adoption of robotic latissimus and DIEP flap harvest is steadily gaining traction in current literature, it is still only practiced in notable volumes at a small number of centers. The absence of an FDA-approved clinical indication in plastic surgery renders any use of the robot in breast reconstruction off-label. Only recently has a prospective study been performed under an investigational device exemption through the FDA for obtaining 510(k) approval, demonstrating the safety of the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA) for robotic latissimus dorsi harvest; this remains to be performed for robotic DIEP flap harvest[9]. Despite being off-label, robotic breast reconstruction allows for minimal incisions and decreased donor site morbidity when performed in select patients.

Robotic latissimus muscle flap harvest is clinically indicated for patients with thin mastectomy flaps and increased risk of implant exposure, or capsular contracture requiring capsulectomy after adjuvant radiation therapy who may otherwise not be candidates for free tissue transfer. These are reconstructive scenarios whereby latissimus muscle flap coverage may be beneficial to protect an implant[10]. Robotic DIEP flap harvest is ideal in scenarios whereby the surgeon seeks to minimize violation of the anterior rectus sheath, abdominal wall nerves, and rectus musculature.

PREOPERATIVE PLANNING

Adding robotics as an additional factor in the surgical equation necessitates a team approach in the care of the breast reconstruction patient. Surgical outcomes are the direct result of the intraoperative team, including the operating surgeons, scrub nurses and techs, anesthesia team, and circulating staff. Increasing familiarity with robotic approaches among operating room staff through didactics, skills training, case observation, bedside assisting, and mentorship optimizes the potential to successfully implement robotic breast reconstruction for patient care[11,12].

Robotic latissimus muscle flap and DIEP flap harvest can both be safely performed with careful preoperative planning. While preoperative imaging may not be necessary for robotic latissimus muscle flap, a preoperative computed tomographic angiography or magnetic resonance angiography is paramount in planning a robotic DIEP flap[11-13]. Preoperative imaging allows for perforator selection and preoperative decision making based on perforator anatomy, allowing for patient selection and reducing operative times[13].

RELEVANT VASCULAR ANATOMY

Traditional latissimus muscle flap harvest requires a 15-45 cm longitudinal incision to facilitate exposure of the thoracodorsal pedicle within the axilla and the thoracolumbar fascia. Utilizing a robotic approach, only a short 5cm axillary incision is necessary for thoracodorsal pedicle identification and dissection. No preoperative imaging is required for primary reconstruction, though imaging may be necessary in cases of reoperation to confirm the presence of intact thoracodorsal vessels on a case-by-case basis.

Traditional DIEP flap harvest relies on an entirely anterior approach. Isolation of the DIEP pedicle down to its origin requires a large fascial incision, with dissection of the vessel free from surrounding nerves and musculature. This leads to significant abdominal wall disruption, especially below the arcuate line. For robotic DIEP flap harvest, preoperative computed tomography angiography (CTA) is necessary to determine if a patient's perforator anatomy is conducive to a robotic approach. Ideal candidates for robotic DIEP flap harvest have one-to-two dominant, closely-grouped DIEP perforators taking a short intramuscular course [Figure 1][11,12]. In circumstances whereby preoperative imaging reveals that anterior perforator dissection below the arcuate line can be avoided, up to 70% of DIEP flap patients may be eligible and benefit from a robotic approach[13]. Utilizing a robotic approach, a posterior intraperitoneal perforator dissection facilitates preservation of the abdominal wall by limiting the anterior fascial incision to the tissues surrounding the pedicle. The fascial incision may be limited to only the length of the perforator's intramuscular course, which in some cases could be as small as 2 cm [Figure 2].

OPERATIVE TECHNIQUE

Robotic pedicled latissimus muscle flap

The borders of the latissimus dorsi muscle are marked preoperatively [Figure 3]. An axillary incision is marked parallel to the thoracodorsal pedicle, and two port sites are marked; the first port site is marked four finger breadths (8 cm) anterior to the anterior border of the muscle and four finger breadths inferior to the axillary incision, while the second port site is marked four finger breadths (8 cm) distal to the second port and anterior to the muscle. The patient is positioned in the lateral decubitus position with the ipsilateral arm prepped and placed on a sterile Mayo stand. An axillary roll is placed below the contralateral arm to prevent brachial plexopathy. In the setting of breast surgery, whereby a sentinel node or axillary lymphadenectomy incision is already present, this incision may be used for thoracodorsal pedicle isolation and no additional axillary incision is necessary. The thoracodorsal pedicle is isolated and marked with a vessel loop to facilitate easy identification during robotic dissection. The subcutaneous space along the anterior border of the

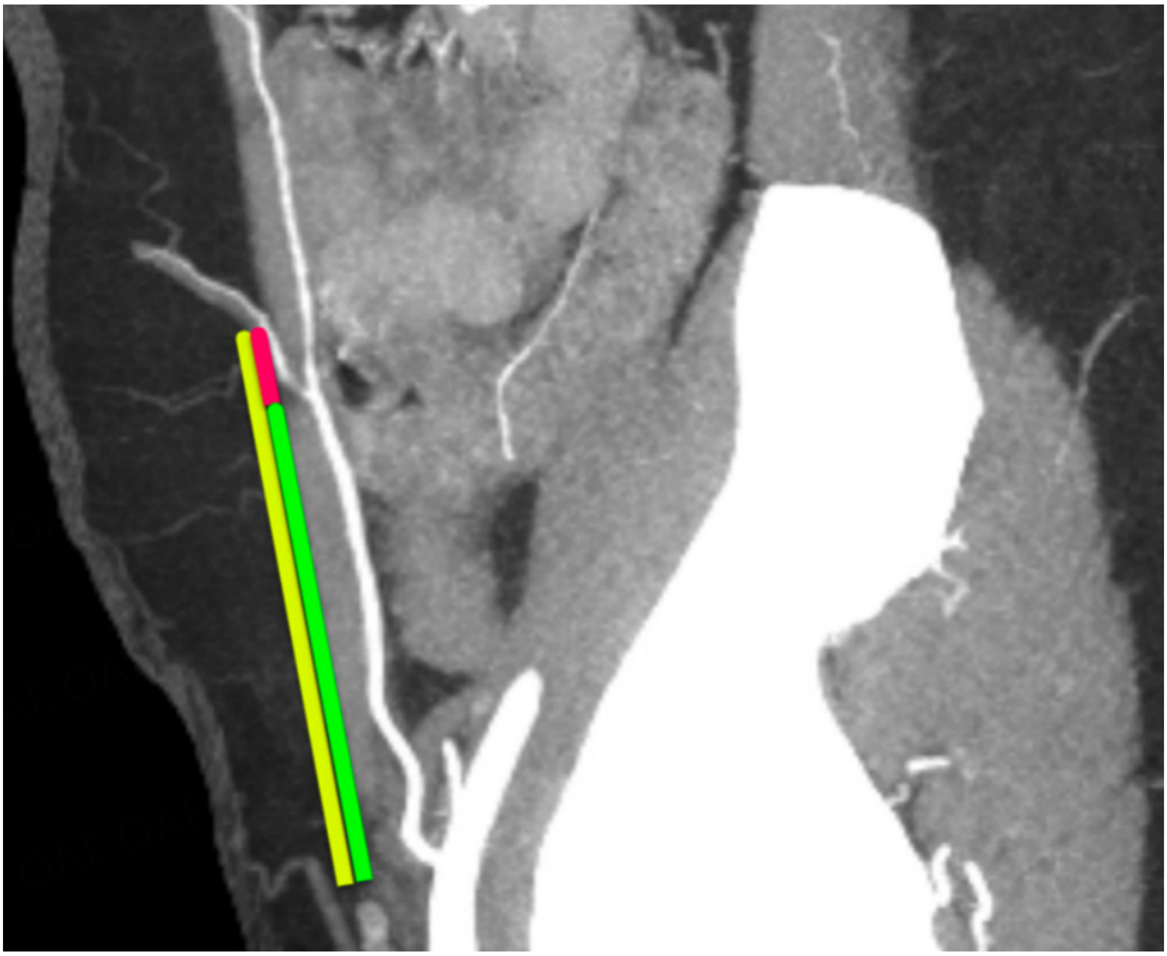

Figure 1. Preoperative CT Angiography showing the course of a deep inferior epigastric perforator (DIEP) pedicle. The total length of the pedicle (yellow) and its intramuscular course (red) are used to illustrate the calculated benefit of reduced intramuscular dissection needed for pedicle dissection (green).

latissimus is then dissected using Bovie electrocautery and a lighted retractor to facilitate adequate working space, and appropriate port placement of both the endoscopic and working robotic arms in the same subcutaneous plane. Port placement is performed under direct visualization and finger palpation through the axillary incision. With the working ports placed in the appropriate subcutaneous space, a zero-degree endoscope is introduced, and the axillary incision is temporarily closed around an 8-12 mm port to maintain adequate insufflation at 10mmHg. A second working arm is introduced through this port.

After port placement, the robotic side cart (da Vinci, Intuitive Surgical, Sunnyvale, Calif.) is positioned posterior to the patient with the two robotic arms and the endoscope extending over the patient [Figure 4]. The robotic working arms are then aligned along the plane of the latissimus muscle. Once the robotic arms are docked to the ports, insufflation is achieved, and dissection begins along the undersurface of the muscle. Encountered vessels are clipped with a laparoscopic clip applier. After adequate dissection of the undersurface of the latissimus muscle, dissection is performed between the superficial aspect of the muscle and the subcutaneous plane. Once both the superficial and deep planes are dissected, the inferior-posterior border of the muscle is dissected free and released. Visualization and protection of the thoracodorsal pedicle are paramount as the dissection approaches the axilla.

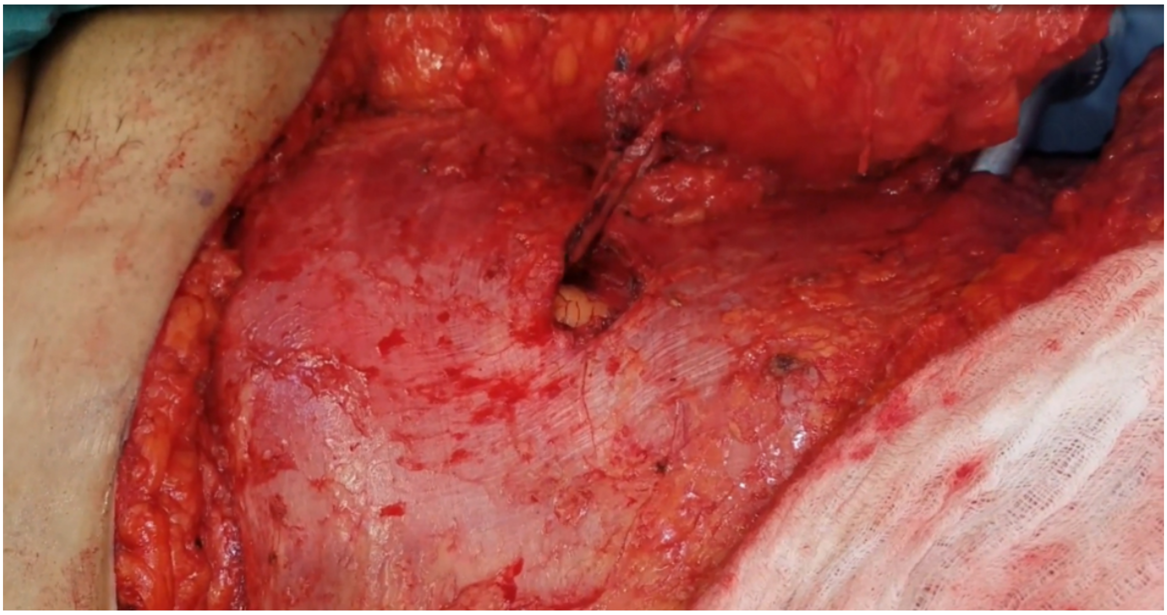

Figure 2. Limited anterior fascial incision with robotic DIEP flap harvest; DIEP= deep inferior epigastric perforator.

Figure 3. Preoperative marking for robotic latissimus muscle flap.

Once the latissimus muscle is free, it will be easily accessible through the axillary incision [Figure 5]. After endoscopic confirmation of hemostasis, the robot can be undocked, the axillary incision reopened, and the latissimus muscle delivered. Drains are placed through the two lower port sites.

Figure 4. Intraoperative patient and robotic arm positioning during robotic latissimus muscle flap harvest.

Robotic deep inferior epigastric perforator flap

Standard abdominal DIEP flap markings are used preoperatively, and the patient is positioned supine with bilateral arms abducted on arm boards. The operation begins as a standard DIEP flap harvest until perforators are isolated and chosen. Anterior dissection of the perforator under loupe magnification is limited to only where the perforator exits the inner surface of the rectus muscle. Pneumoperitoneum is then obtained to 15 mmHg utilizing Varess needle insufflation. Three robot ports are then placed through the fascia on the contralateral side of the flap along the anterior axillary line. The robot is positioned at bedside to the ipsilateral flap, and the robotic arms are docked to the ports. A bipolar grasper and monopolar scissors are then introduced under endoscopic visualization.

The course of the inferior epigastric vessels is traced under endoscopic vision, and the posterior sheath is opened to facilitate circumferential dissection of the pedicle free from surrounding tissues [Figure 6]. The pedicle is then clipped, divided, and pulled gently through the small anterior facial defect. A barbed suture is then introduced into the abdomen and used to close the posterior sheath [Figure 7]. If a bilateral DIEP flap is planned, the robot can be rotated for harvest on the contralateral side. After flap harvest and extraction, the ports are removed, and port sites are closed. DIEP flap inset and microsurgical anastomosis are then performed in a traditional fashion.

POSTOPERATIVE CONSIDERATIONS

The postoperative approaches for robotic latissimus muscle flap and DIEP flap patients can vary and should

Figure 5. Delivery of the latissimus muscle flap through the axillary incision following robotic latissimus muscle flap harvest.

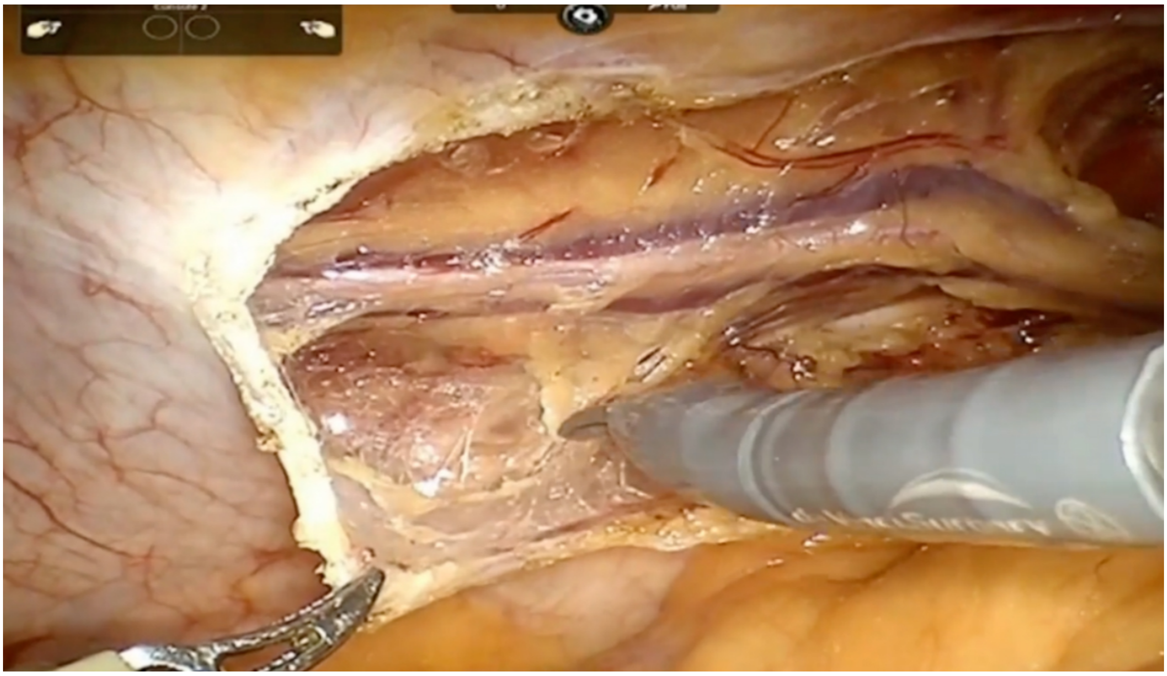

Figure 6. Robotic intraabdominal dissection of the DIEP flap perforator through the posterior sheath; DIEP= deep inferior epigastric perforator.

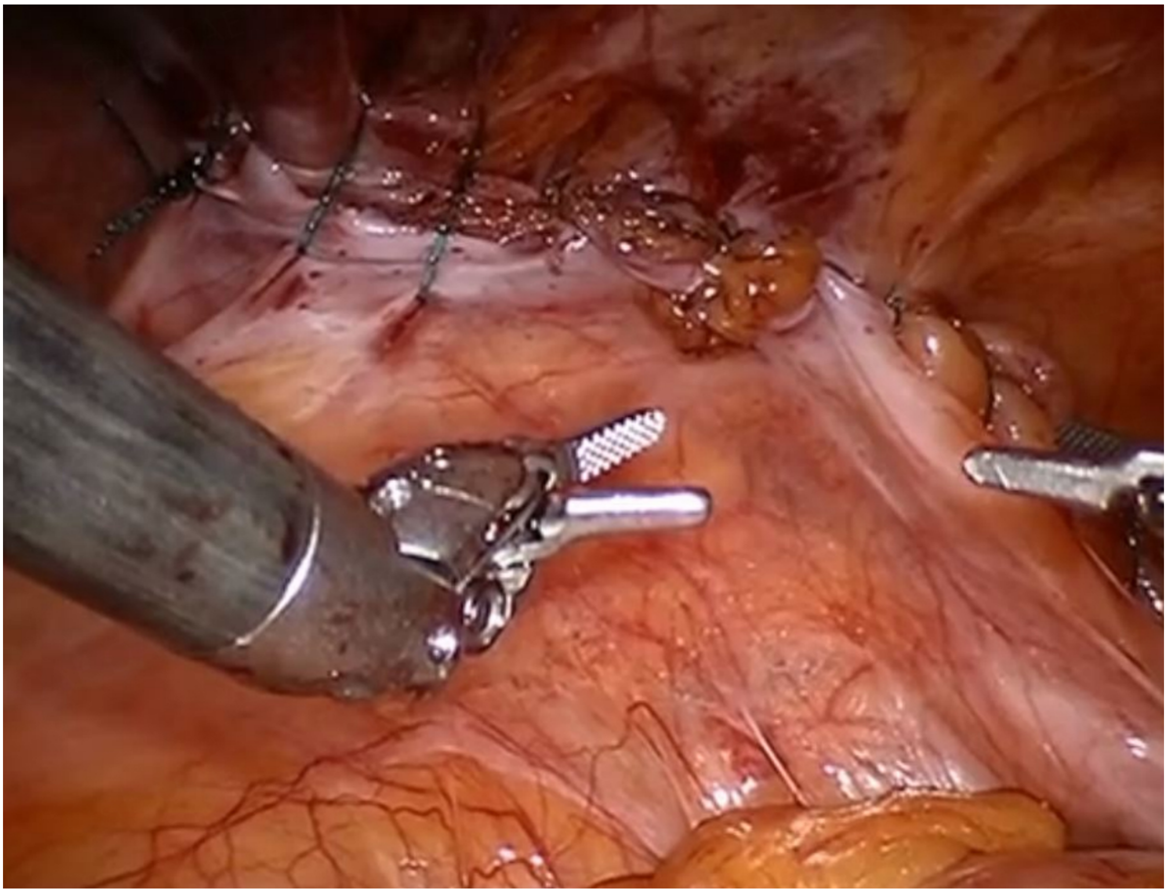

Figure 7. Robotic closure of the posterior sheath after DIEP flap harvest; DIEP= deep inferior epigastric perforator.

not significantly differ from a standard postoperative care pathway. In adopting a robotic approach to autologous breast reconstruction, the authors recommend maintaining the standard practice for enhanced recovery postoperative care tailored to individual patient needs, provider preferences, and institutional policies (i.e. flap assessment/monitoring, anticoagulation, use of surgical drains, etc.).

CLINICAL OUTCOMES AND COMPLICATIONS

In the modern era of robotic surgery, many of the beneficial outcomes in other surgical specialties also apply to breast reconstruction[14]. When comparing outcomes between traditional and robotic latissimus flap reconstruction, a robotic approach is associated with a shorter hospital length of- stay and lower postoperative opioid requirements; contemporary data even show higher patient satisfaction due to the smaller scars resulting from a robotic approach[10,15]. For robotic DIEP flap reconstruction, outcomes from several studies also report favorable results with no flap losses, intraabdominal complications, or postoperative hernia/bulge; Lee *et al.* even report significantly improved abdominal physical well-being with robotic DIEP harvest compared to a conventional approach[13,16-18]. Functional abdominal wall data comparing traditional and robotic DIEP flap harvest has not yet been published Table 1.

With the adoption of any new surgical technology, some notable limitations exist. As is the case for robotic breast reconstruction, these limitations include the costs of robotic surgery implementation and surgeon/operating team learning curves[19]. The institutional costs associated with acquiring and maintaining a surgical robot are considered cost-prohibitive by some medical centers[20]. Furthermore, at centers where a

Table 1. Current benefits and limitations of robotic-assisted reconstructive surgery

Benefits and Limitations of Robotic-Assisted Reconstructive Surgery	
Benefits	**Limitations**
Perforator Circumnavigation and Dissection with High-Resolution Optics and Superior Ergonomics. Shorter Hospital Length of Stay and Lower Postoperative Opioid Requirements Decreased Donor Site Morbidity and Smaller Scars lead to Improved Patient Satisfaction and Well-Being	Considered Off-Label by the U.S. Food and Drug Administration (F.D.A.) for Novel Reconstructive Applications. Institutional Costs of Surgical Robot Acquisition and Upkeep Learning Curve for the Surgeon and Operating Room Staff

robotic platform is established, it can present a significant learning curve for plastic surgeons and OR staff with limited exposure; robotic flap harvest is associated with longer operating time compared to an open approach during this learning period[10,17]. Even if a surgeon is adept at robotic techniques, training deficiencies among operating room staff could serve as an additional bottleneck in robotic surgery efficiency, leading to increasing operative time and costs[12]. Though progress is being made in current literature highlighting robotic plastic surgery, more barriers still need to be overcome before robotic approaches to breast reconstruction become universal, including FDA approval. The current benefits and limitations of robotic-assisted reconstructive surgery are outlined in Table 1.

SUMMARY

Robotic breast reconstruction facilitates a minimally invasive approach that decreases donor-site morbidity, length of stay, and opioid requirements, and even improves patient satisfaction. Although barriers exist regarding this technology, robotic latissimus and DIEP flap reconstruction can be safely learned and applied with thoughtful patient selection and preoperative planning.

DECLARATIONS

Authors' contributions

Made substantial contributions to the conception and design of the study and performed data analysis and interpretation: Hammond JB, Egan KG, Selber JC

Performed data acquisition, as well as providing administrative, technical, and material support: Hammond JB, Egan KG, Selber JC

Availability of data and materials

Not applicable.

Financial support and sponsorship

None.

Ethical approval and consent to participate

This manuscript was ethically composed from currently published literature outlining surgical techniques involving human subjects; referenced studies were performed in accordance with the Declaration of Helsinki, and these methods meet Institutional Review Board approval for exemption. Consent to participate has been obtained from patients.

Consent for publication

All figures within the manuscript are original works and sourced from the senior author with permission for publication.

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