

Deep Inferior Epigastric Perforator Flaps & Preoperative CT Angiographic Evaluation for Robotic-Assisted Harvest: Current Literature & Artificial Intelligence Applications

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ABSTRACT

Breast reconstruction techniques continue to evolve to best suit the patient and provide the most efficient operative planning and execution for the surgeon. It is a common practice for plastic surgeons to utilize CT angiography for surgical planning in autologous reconstruction and has demonstrated improved operative times and perforator choice. The application of artificial intelligence (AI) in the planning, informed consent, patient and surgeon decision making allows the delivery of the optimal outcome for patient care, education and the surgeon. Leveraging current and future modalities of mixed realities (MR) will be essential to the innovation and evolution of breast reconstruction.

Keywords: Artificial Intelligence; Robotic Plastic Surgery; DIEP, Perforator Flap; CT Angiogram; Decision Making; Augmented Reality; Virtual Reality; Mixed Reality

Abbreviations: AI: Artificial Intelligence; MR: Mixed Realities; CTA: CT Angiography; RCT: Recent Randomized Controlled Trial; MRI: Magnetic Resonance Imaging; AR: Augmented Reality; VR: Virtual Reality; MR: Mixed Reality

Introduction

While artificial intelligence (AI) is a familiar concept with origins dating back several decades, in recent years, it has rapidly evolved into a pivotal force poised to transform many aspects of everyday life. Most broadly, AI is characterized by the development of software and algorithms that allow machines to approximate some facets of human intelligence such that they are able to “learn,” correct mistakes based on data inputs, and independently reason within certain constraints [1,2]. As such, the potential applications of this nascent technology

are self-evidently far-reaching, though it does appear that the domain of healthcare may face particularly profound transformations in light of these developments. First, medical imaging is one area that lends itself particularly well to enhancement by way of AI. Here, much development has been pursued in an area of AI known as deep learning. Using advanced algorithms and convolutional networks, deep learning machines are capable of advanced computer vision that has already allowed clinicians improve diagnostic performance and reduce subjectivity and errors [3]. Surgeons similarly stand to benefit

from practice-enhancing AI tools such as advanced robotics, and the burgeoning use of robotic assistance in many surgical procedures has already transformed the landscape of the practice in the past few decades [4].

Lastly, artificial intelligence has begun to offer significant utility with regard to predictive analytics, and in the context of surgery, such models may assist in supporting decisions to operate, identifying risk factors that influence outcomes, and pinpointing unique patient characteristics that may favor one surgical technique over another [5]. Along these lines, AI will allow for further personalization of health-care delivery to better suit individual patient needs.

Potential for AI in Plastic Surgery

As the utilization of AI continues to spread across medical specialties, the number of applications in which this technology can be utilized similarly increases. Regarding plastic surgery, AI has proven useful in clinical scenarios including initial consultations for aesthetic surgeries, diagnosis of conditions like craniosynostosis, and prediction of free flap survival in microsurgery procedures [6]. Data collected from patient-physician interactions and surgical outcomes will continue to improve overall success in operations and patient satisfaction; however, there remains a deficit in the literature relating to how to use AI to maximize efficiency intraoperatively [7]. Like surgical navigation systems used by ear, nose, and throat surgeons, AI has the potential to be incorporated into surgical planning and aiding surgeons in maximizing efficiency while simultaneously providing improved outcomes in operative interventions. If AI could be applied to the planning of microsurgical procedures such as free flap breast reconstruction, not only may patient satisfaction with the aesthetic results of breast reconstruction be improved, but morbidity related to the dissection of tissues and duration of time under anesthesia be decreased. By providing AI with data in the form of medical imaging, this technology could drastically change the way microsurgeons plan their dissections for free flap harvest.

Robotic DIEP Procedure & Variable Techniques

Although the DIEP free flap has proven to be a reliable source of tissue for breast reconstruction, the procedure itself can be morbid as the rectus abdominus and its fascia are dissected, leading to denervation of the rectus muscle, bulges, and hernias in some patients. The recent introduction of the robotic DIEP procedure allows for greatly reduced dissection and postoperative complications when perforators with short intramuscular courses are available. In a robotic DIEP procedure, the abdominal tissue is first raised in the standard fashion. Perforators are dissected down to the posterior rectus fascia, followed by insufflation and port placement in the contralateral abdomen [8]. The robot is docked, and the pedicle is dissected to its perforator which is then clipped and severed at its origin before completing the harvest of the DIEP flap. A similar extraperitoneal approach has been

described by Choi, et al. [9] which utilizes only a single port site [9]. This technique again begins with the dissection of a perforator down to the posterior rectus sheath, after which a single fascial incision is made along the linea semilunaris ipsilateral to the pedicle. Blunt dissection is utilized to create a space for insufflator placement below the arcuate line and insufflation is achieved to develop a preperitoneal space. The pedicle is then dissected via the undersurface of the rectus muscle and vasculature is transected near its origin at the external iliac arteries. The robot is undocked, the remaining fascial attachments are dissected, and the pedicle is freed and ready for inset in the chest.

CT Angiography & Current Literature

It is well-documented in the literature that, with regard to measures of patient satisfaction following surgery, autologous reconstructive methods are generally superior to implant-based techniques [10]. According to more recent studies, it appears that autologous, abdominal-based reconstructions (i.e., DIEP and TRAM flaps) lead to overall similar levels of general and aesthetic satisfaction following surgery [11]. Nevertheless, these procedures can lead to significant morbidity with potential problems occurring at donor sites, most commonly abdominal hernias, though complication rates can be reduced by minimizing the extent of harvested fascia and preserving a maximal amount of muscle [12]. CT angiography (CTA) has emerged as the most useful preoperative imaging study (in lieu of alternatives like Doppler ultrasonographic techniques, magnetic resonance angiography (MRA), etc.) and has been pivotal in helping surgeons to reduce complications and choose optimal surgical techniques based on unique patient anatomy [13]. Evidence for the utility of preoperative CTA is robust. Colakoglu, et al. [14]. report findings in their recent randomized controlled trial (RCT) that patients undergoing preoperative CTA experienced shorter times for flap harvest as well as overall operating room time when compared to patients who did not undergo preoperative imaging. A systematic review and meta-analysis further advances these findings by demonstrating that, in the aggregate, preoperative CTA leads to lower rates of partial necrosis and decreased flap loss [15].

Preoperative CTA even helps surgeons to reduce the number of perforators included in harvested flaps [16]. Most importantly, this imaging study has recently been shown to be useful in selecting candidates for robotic DIEP harvest. Kurlander, et al. [17]. report their groups practice of offering robotic DIEP flap harvest in any patient whose CTA reveals large-caliber perforators with short intramuscular courses. With a rigorous and standardized review of imaging, clinicians are able to predict the length of the robotic fascial incision and its position relative to the arcuate line. This may lead to reduction in donor site morbidity by way of carefully planned fascial incisions that avoid dipping below the arcuate line, which is typically considered to be a cause of such morbidity.

Expansion to Mixed Reality in Plastic Surgery

As discussed, AI applications have enhanced productivity while delivering high quality interpretations and has been used for decision making and diagnosis in areas such as dermatologic conditions, interpreting electrocardiograms, radiograph interpretation ranging from plain radiographs to CT scans and magnetic resonance imaging (MRI) [18]. When considering the application of AI designed for radiologists, other stakeholders, such as plastic and reconstructive surgeons have looked for opportunities to capitalize on this innovation to improve delivery of care for patients. It has been demonstrated that CT angiography can significantly shorten operative time [19] and reliably predict which perforator will be used in DIEP breast reconstruction [20]. Information from 3D photographs and CT angiography will predict needed flap volume for unilateral and bilateral breast reconstruction, flap type, perforator choice and breast mound shaping to meet patients' needs, minimizing fascial incisions, assisting both experienced and less experienced surgeons [21]. AI has been described and utilized in plastic surgery, seemingly at the highest level in cranio-maxillofacial and facial plastic surgery [22]. Augmented reality (AR) technology is game-changer in the field of surgical navigation, and revolutionized the way complex procedures are performed. This has the potential to significantly improving patient outcomes. When evaluating the use of AI in DIEP planning and execution, there are multiple areas to apply the modalities.

Augmented Reality (AR) and Virtual Reality (VR) combined as Mixed Reality (MR) will be the application of the future for breast reconstruction with DIEP or other flaps [23]. As we examine the AR of the vascularity and perforators in an autologous tissue donor site, the mapping of the 3-D model allows for accurate visualization of the perforators in the tissue deemed to be transferred. Our AI modeling concept involves review of the CT angiography or MR angiography obtained from patients and the AI predicted perforator and flap of choice. This is based on the concept of adequate perfusion, tissue volume, aesthetic desires and decreased morbidity that improved pre-operative planning provides. If the patient has adequate abdominal adiposity for a unilateral or bilateral DIEP, the flap perforators of choice are chosen to meet the robotic dissection criteria, predicted volume and aesthetic outcomes, MR intraoperatively allow the surgeon and resident physicians the advantage to work efficiently to dissect the subcutaneous prefascial perforator so that flaps are prepared for the completion dissection with the robotic surgical platform. This approach will also be utilized for mastectomy, tumor resection and dissection of the internal mammary or other recipient vessels. As robotic microsurgery and supermicrosurgical techniques evolve, the combination with MR will produce enhanced precision and performance during autologous reconstruction, reducing complications and speeding patient recovery.

Once the procedure is complete, the combination of ambient listening AI monitoring will allow for real-time evaluation of flap viability,

intra-flap perfusion changes and improve clinical decision-making of nursing and resident physicians in urgent and emergent situations. Innovations in AI expanded greatly during the COVID-19 pandemic as physicians, providers and staff demonstrated agility in accommodating the needs of the patients while maintaining excellence in care delivery and safety of all involved. Many of these innovations have revolved around telemedicine and remote patient monitoring. This allows health care professionals to gather real-time physiologic information about the patient's condition [24]. Remote patient monitoring is considered a feasible application by many physicians and providers. As the applications continue to grow, plastic surgeons can utilize this in combination with AI to obtain relevant information on the vascular pedicle in the DIEP or other autologous reconstruction and the physiologic status of the patient and flap during hospitalization and once the patient is discharged. Utilizing this type of monitoring combination will allow patients to be safely discharged as same day or after observation status while freeing up needed inpatient beds for patients with greater medical needs. This will provide a positive overall effect on patient care and the health care system. Our use of ambient listening in the pre- and post-operative settings provides a meaningful experience for clinicians and patients reducing the administrative burden and allowing improved clinical care and informed consent. The previously mentioned monitoring capabilities can be utilized by the patient on discharge in the home setting which assists in good clinical outcomes by enabling the patient to participate in their own care and outcome. Successfully utilizing AI in predicting which patients are candidates for DIEP and robotic DIEP breast reconstruction, evaluating the potential for 3-D breast shaping and volumetric analysis and delivering high value care, relies on leveraging the complementary algorithms of the surgeon and the machine.

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