SCOPING REVIEW

Robotic-assisted free flap harvesting for diverse soft tissue reconstruction: a PRISMA scoping review of clinical outcomes over the last decade

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Abstract

Introduction: The aim of our study was to assess the advantages and limitations of robotic technology in diverse reconstructive procedures.

Methods: A scoping review was conducted in Oct'23, on published studies from 2013 to 2023, focussing on robotic-assisted free flap harvesting. Three databases Ovid-MEDLINE, Scopus, and PubMed were searched. Original research studies reporting robotic-assisted free flap harvest were included. Studies on lesion excision, microvascular anastomosis, local flap harvest, robotic-assisted flap inset, review articles, abstract-only studies, non-English documents, and animal studies were excluded from this review.

Results: Sixteen studies met the inclusion criteria out of a total of 318, searched initially. These studies included a total of 128 patients, who underwent robotic-assisted free flap harvest for the reconstruction of various defects, with 140 free flaps harvested. The most common flaps harvested by robotic technique were deep inferior epigastric artery perforator (DIEP) flap 120 (85.7%), radial forearm free (RFF) flap 11 (7.9%), latissimus dorsii flap 4 (2.9%), rectus abdominus flap 4 (2.9%), and omental flap 1 (0.7%). Breast reconstruction was the major procedure done i.e. 120 (85.7%) followed by head and neck 11 (7.9%) and limb defects 9 (6.4%) reconstruction procedures. The reported clinical outcomes were acceptable in all the studies with a 99% flap success rate and minimal complications. Variability in operating time was observed depending upon surgical steps undertaken with robotic systems.

Conclusion: This scoping review highlights the role of robotic-assisted free flap harvesting in plastic surgery and its potential benefits on clinical outcomes, due to its high precision and minimal invasiveness. However, challenges like cost effectiveness, resource distribution and learning curve are there.

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Introduction

Minimally invasive surgical techniques are being acquired by most of the surgical specialties around the globe as it offers small incision, less complication, and enhanced post operative recovery.[1] Over the past two decades, Robotic surgery emerged as an addition to the surgical toolbox and is being adopted by a number of surgical specialties including urology, orthopaedics, gynaecology, otorhinolaryngology and plastic surgery.[2,3] Its role in plastic surgery is still evolving, but overall plastic and reconstructive surgery has been reluctant in adopting minimally invasive and robotic surgery in routine practice.[4]

Numerous studies have highlighted the application of robotic systems in reconstructive surgeries for intricate tasks like microscopic anastomoses and flap in setting, for both oncological and non-oncological cases. In 2005, the first robotic assisted free flap was done in a Minipig model by using the da Vinci system.[5] Ryan d. Katz et al [6] again demonstrated six successful microvascular anastomoses in dog's limbs using Da Vinci Surgical System. Later more studies were done and demonstrated that robots have more accurate control than freehand.[4] In 2013, dissection of radial and ulnar arteries followed by division and repair in cadaveric limbs was done by Robert et al and all the anastomoses had no leaks.[7] More complex robotic microsurgery procedures were attempted later i.e. supraclavicular brachial plexus exploration with interposition nerve grafting.[8]

Robot assisted flap reconstruction for head and neck tumour resection is being adopted widely.[2] Successful robot assisted flap procedure like facial artery myomucosal flap for soft palate reconstruction[9] and precise in setting of free flaps without mandible division.[10] Robot assisted flap harvesting is reported to have acceptable harvest time, reduced donor site morbidity and enhanced postoperative recovery.[11] Successful series of robot assisted latissimus dorsi (LD) flaps harvest for breast reconstruction was done with access to the LD pedicle and minimal donor scar.[12] Perforator flap harvest for free tissue transfer had also been attempted with significantly acceptable results including transabdominal harvest of rectus abdominus muscle [13] and deep inferior epigastric artery flap (DIEP).[14]

Despite advancements in robotic microsurgery, literature on free flap harvest is limited and heterogeneous. In this era of rapidly innovative technology that offers preoperative planning, intraoperative precision and enhanced postoperative recovery in microsurgery and reconstructive surgeries, the assessment of advantages of robotic surgery and its limitation is very crucial. Thus, the aim of this study is to review the use of robotic technology in free flap harvesting for the reconstruction of various defects and its outcomes.

Methods

The present review was carried out by searching of scientific articles, published over the last 10 years from 1st January 2013 till 8th Oct 2023, , in three databases PubMed, SCOPUS and OVID Medline. The review was conducted in Oct'2023 and search terms used were as follows: "robotic", "flap harvest" and "free flap". The "and" filler was included during the keywords search.

The number of studies screened, assessed for eligibility, and included in this review, with reasons for exclusion are presented in the PRISMA flow diagram (Fig. 1). Our initial literature search resulted in a total of 318 results. Two reviewers independently screened these results, by title and abstract that presented 37 studies. After removal of duplicate articles, full text review was done, of total 22 articles, out of which 16 articles fulfilled the inclusion criteria and were finally selected for systemic review.

Inclusion and exclusion criteria

Articles published over the period of 1st January 2013 till 8th Oct 2023, in English language, were reviewed in Oct'23. All original studies, including randomised control trials, cohort studies (prospective/ retrospective), case studies, and case series that reported free flap harvesting with robotic technique were included. Exclusion criteria included focussing on

1. excision of lesion/ resection using robot,
2. for microvascular anastomosis,
3. harvest of local flap
4. robotic-assisted flap inset,
5. review articles,
6. abstracts only,
7. manuscripts not written in English,
8. cadaveric or animal-based studies.

Data was extracted encompassing details related to the population, intervention, comparison, and outcomes following the PICO approach. The population composed of individuals undergoing robotic assisted soft tissue defect reconstruction. The intervention involved the assistance of robotic surgery in harvesting free flaps. The primary outcome was the flap's success rate, while secondary outcomes included the overall number of complications, total operative time, and the robotic time. Flap success was defined as those not requiring any further surgery and did not suffer from any total/partial failure. (Figure 1)

Results

The characteristics of all the included 16 studies can be seen in Table 1. There were 5 retrospective cohort studies, 4 case reports, 6 case series, and 1 case control study. The following number of studies were published in respective years: 2 (12.5%) in 2023, 6 (37.5%) in 2022, 4 (25%) in 2021, 1 (6.3%) in 2020,2019, 2018 and 2014, each. The highest number of studies reporting use of robotic system for harvest of free flaps were published in 2022. (Table 1)

Patient characteristics

Sixteen studies included a total of 128 patients undergoing reconstruction by free flaps for various defects and total 140 free flaps were harvested.

The mean age of patients was 49.84 ± 6.63 years with a male-to-female ratio of 8:113. The gender of 7 patients were not specified in two studies. Among the patients of included studies, 40(31.3%) had significant past medical or surgical history. 4(3.12%) were hypertensive, 1(0.8%) had Diabetes Mellitus, 1(0.8%) thyroid disorder, 1(0.8%) history of coronary artery bypass graft for ischaemic heart disease, 1(0.8%) BRCA1 gene mutation, 3(2.3%) BRCA2 gene mutation, 17(13.3%) history of abdominal surgery, and 12(9.4 %) had history of either neo-adjuvant chemotherapy or radiation or both.

Pathologies requiring reconstruction in patients, were as follows: 35(27.3 %) patients had breast cancer, 1(0.8 %) had osteomyelitis of right distal tibia, 1(0.8 %) had knee joint hardware related infection post resection of reticular cell sarcoma of right thigh, and 91(71.1 %) had unspecified pathology.

Reconstruction methods

The types of free flaps (n=140) harvested were: 120 (85.7%) deep inferior epigastric perforator (DIEP) flap,

Table-1: Summary of extracted data from all included studies.

Authors, (year), study design	No. of flaps	Age (years)	Gender (n)	Co-morbids	Mean robotic time(min)	Mean total operative time(min)	Type of Flap	Anatomic Region
Tsai et al .[15](2023) Retrospective Cohort Study	13	46 ± 10.96	F (12)	HTN (2)s/p abdominal surgery (2)	53.2 ± 13.4	NR	DIEP	Breast
Shin et al [16](2023) Case Control Study	11	47.2±7.2	M (7)F (4)	NR	107.2±21.8	NR	RFF	Tongue (6)Floor of mouth (1)Palate (2)RMT (2)
Dayaratna et al. [17](2022) Case report	2	46	F (1)	BRCA 1 gene mutation (1)	NR	680	DIEP	Breast
*Lee et al. [14](2022) Retrospective Cohort Study	21	48.5 +/- 6.6	F (21)	HTN (2)	68.8	509+/-71	DIEP	Breast
Wittesaele et al.[18] (2022) Case Series	10	53.1	F (10)	s/p RT (7)S/p abdominal surgery (4)	86	479	DIEP	Breast
Jung et al. [19](2022) Case report	1	58	F (1)	None	NR	NR	DIEP	Breast
Bishop et al.[20](2022) Case series	21	54.6 ± 7.6	F (21)	s/p abdominal surgery (10)	44.8	425.3	DIEP	Breast
Daar et al.[21](2022) Retrospective Cohort Study	7	52 +/- 6.9	F (4)	s/pNACT (1)NACRT (2)	NR	717.6	DIEP	Breast
Kurlander et al. [22] (2021) Case series	13	50 ± 9.9	F (13)	NR	NR	NR	DIEP	Breast
Choi et al. [23](2021) Case series	17	NR	F (17)	NR	65 ± 33	487 ± 93	DIEP	Breast
Shakir et al.[24](2021) Retrospective Cohort Study	6	53.2 ± 8.5	F (3)	DM (1)Thyroidopathy (1)s/p abdominal surgery (1)	40	535.3 ± 67.0	DIEP	Breast
Piper et al. [25](2021) Case series	8	50.25 ± 8.2	F (4)	BRCA 2 gene mutation (3)	45	NR	DIEP	Breast
Fouarge et al. [26](2020) Retrospective Cohort Study	4	NR	NR (4)	NR	NR	NR	LD	Upper and lower limb defects
Özkan et al. [27](2019) Case report	1	58	M (1)	s/p CABG (1)	60	150	Omental flap +STSG	Distal tibia
Gundlapalli et al. [28] (2018) Case report	1	51	F (1)	s/p MRM and CRT (1)	40	531	DIEP	Breast
Pedersen et al. [29] (2014) Case series	4	30	F (1)NR (3)	s/p Reticular cell sarcoma of right thighresection followed by CRT (1)	45	NR	RAM +STSG	All for lower limb defects

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Laterality / Side of flap (n)	Flap success (%)	Complications (n)	Pathology	Length of hospitalstay (days)	Method of anastomosis	Follow up (month)	Type of Robot
Unilateral (11)Bilateral (1)	13 (100%)	Donor site morbidity (wound healing/abdominal hernia) (1)	NR	NR	NR	15.0 ± 9.3	Da Vinci ^
NR	11 (100%)	NR	NR	NR	Veins: Suture (3)Coupler (8)	3	Da Vinci Si
Bilateral (1)	2 (100%)	None	Breast cancer	NR	NR	3	Da Vinci Xi
Unilateral (21)	20 (95.2%)	Flap loss (1)Fat necrosis (2)Conversion to open (1)	Breast cancer	7.92 +/- 1.2	NR	NR	Da Vinci SP
Unilateral (10)	10 (100%)	Recipient site haematoma (1)	NR	5	NR	6 weeks	Da Vinci MP
Unilateral (Right) (1)	1 (100%)	None	Breast cancer	7	Manual	7	Da Vinci SP
Unilateral (21)	21 (100%)	Surgical site occurrence (5)Delayed wound healing (1)	NR	3.8 ± 0.9	NR	5	NR
Unilateral (Right) (1)Bilateral (3)	7 (100%)	Donor site wound dehiscence (2)1 underwent scar revision	Breast cancer	3.7	NR	6.31	Da Vinci Xi
NR	NR	NR	NR	NR	NR	NR	NR
NR	NR	NR	NR	NR	NR	NR	Da Vinci SP
Bilateral (3)	6 (100%)	Donor site delayed healing (1)	Breast cancer	4.7 ± 4.6	NR	3	Da Vinci Xi
Bilateral (4)	8 (100%)	None	Breast Cancer	NR	NR	NR	Da Vinci Xi
NR	4 (100%)	None	NR	5	NR	2 weeks	Da Vinci Si (2) and Xi (2)
Right (1)	1 (100%)	None	Osteomyelitis	12	Manual	12	Da Vinci Xi
Unilateral (Right) (1)	1 (100%)	None	Breast cancer	NR	Manual	9	Da Vinci ^
Right (1)	4 (100%)	None	Implant related infection (1)NR (3)	NR	NR	NR	Da Vinci ^

NR=Not Reported. Gender: F=female, M=male. NACT= neoadjuvant chemotherapy. NACRT= neoadjuvant chemoradiotherapy. RT= radiotherapy. RMT= retromolar trigone. CABG= coronary artery bypass grafting. MRM=modified radical mastectomy. CRT= chemoradiotherapy. RAM=Rectus abdominis muscle flap. STSG=split thickness skin grafting. DIEP =Deep inferior epigastric artery flap. DM =Diabetes Mellitus. HTN=Hypertension. RFFF= radial forearm flap. LD =Latissimus Dorsi flap. s/p= status post*Results after applying Inverse Probability of Treatment Weighting (IPTW). + Surgical site occurrence= (breast wound dehiscence, infection, skin flap necrosis, fat necrosis, hematoma, seroma). ^ = Intuitive Surgical, Sunnyvale. MP=Multiport

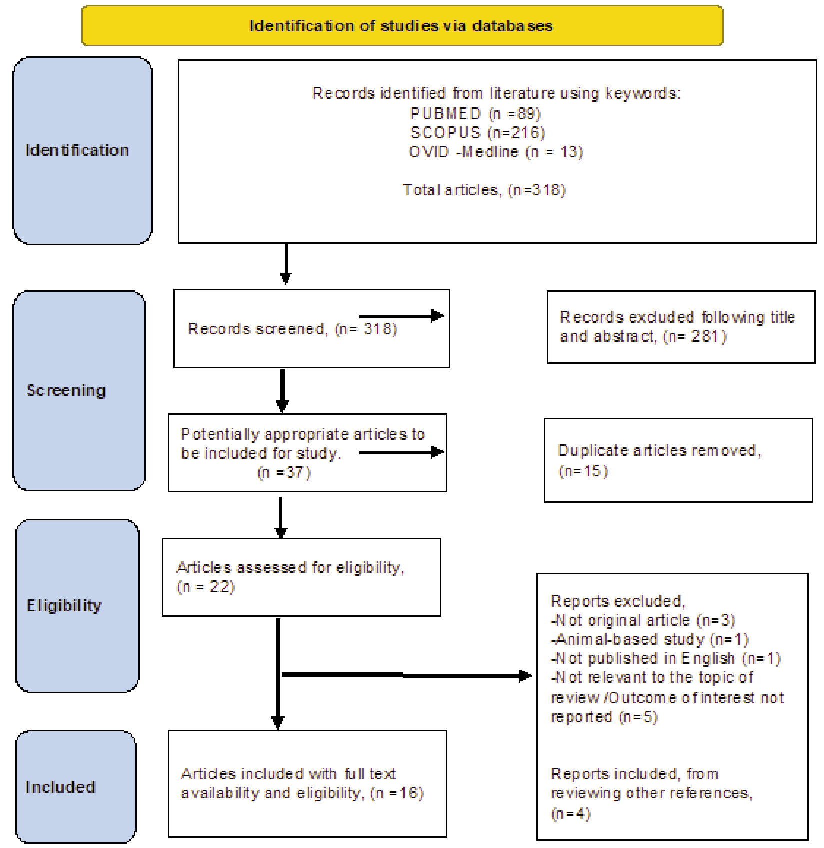

Figure-1: PRISMA flow diagram of the study selection process.

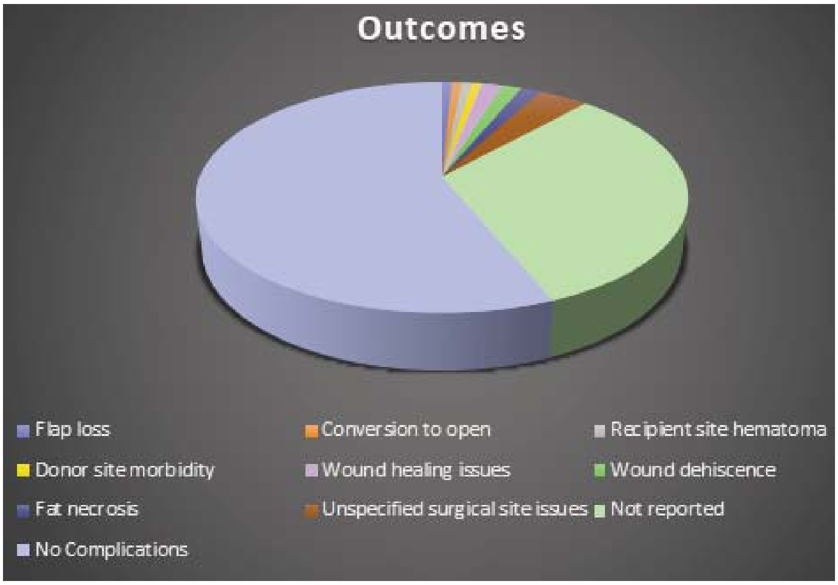

Figure-2: Complications reported in robotic-assisted free flap harvest.

11(7.9%) radial forearm flap, 4(2.9%) latissimus dorsi flap, 4 (2.9%) rectus abdominis muscle flap and 1(0.7 %) omental flap. Skin graft was used for skin coverage of 2(1.4%) flaps after setting in 2 patients, ,i.e omental flap (n=1) and rectus abdominis flap (n=1).

Most common anatomical regions, requiring flaps, included: 120(85.7%) flaps for breast reconstruction, 11(7.9%) for head and neck defects, and 9(6.4%) flaps for upper and lower limb defects. For breast reconstruction, 24 (20 %) flaps were harvested for bilateral breast reconstruction and 66(55 %) cases underwent unilateral breast reconstruction. Two studies did not specify the details of 30(25%) DIEP flaps harvested for breast reconstruction.

Laterality or side of flap was not mentioned for 45 (32.1%) flaps.
Method of anastomosis was not reported in 12 studies and in 4 studies anastomosis was done manually. Conventional venous anastomoses with sutures were performed in 5(3.6 %) flaps and in 8(5.7 %) flaps, venous anastomoses were done with coupler.

The following types of robotic platform were used for harvesting: the Da Vinci Intuitive Surgical, Sunnyvale 18 (12.9 %), the Da Vinci SP 39 (27.9 %), the Da Vinci Xi 26 (18.6 %), the Da Vinci MP 10 (7.1 %) and the Da Vinci Si 13 (9.3 %) and types of robotic devices were not specified for 34 (24.3%) flaps.

Outcomes for robotic-assisted flap harvest

The flap success rate was 99% in the 14 studies, reporting robotic-assisted free flaps, and no instances were reported in which flap re-exploration, salvage procedure or secondary flap harvest was needed, whereas Choi JH[23] and Kurlander [22] did not report the outcome of 17 and 13 harvested DIEP flaps, respectively.

Outcomes were reported for 87 patients (Fig. 2), among which one(1.1 %)[14] had intraoperative complication needing conversion to open and [14](16.1%) experienced postoperative complications: flap failure[14] 1(1.1 %), wound healing issues[15,20] 2(2.3 %), wound dehiscence21 2 (2.3 %), fat necrosis14 2 (2.3 %), recipient site haematoma[18] 1 (1.1 %), donor site morbidity i.e abdominal hernias or wound healing[15] in 1(1.1 %) and unspecified surgical site occurrences (including breast wound dehiscence, infection, skin flap necrosis, fat necrosis, haematoma and seroma)20 5(5.8%), moreover, complication status was not reported for 41 patients.[16,22,23] Analysis of complications by flap type showed that all these patients had DIEP flap reconstruction, therefore, complication rate in DIEP flap, with denominator 120, was 15(12.5%).

Secondary surgical procedures were reported in 2(1.6%) patients: for drainage of haematoma[18] (n=1) and abdominal scar revision[21] (n=1).

Length of hospital stay ranged from 3–12 Days. Follow up period was from 2 weeks to 15 months. The mean robotic harvest time of flap/pedicle as reported in 11 studies, was 59.5±21.29 min and mean operative time as reported in 9 studies was 8.36±2.7 hours (501.5 ± 162.29 min). Five studies did not comment on duration of flap harvest and 7 studies did not mention duration of total surgery. (Figure 2)

Discussion

The thought of incorporation of robots in plastic surgery has gained interest ever since the inception of robotic-assisted surgery (RAS)This study comprehensively reviews literature from the past decade, examining the various types of free flaps harvested with the assistance of robotic technology. Robotic surgery exhibits superior attributes compared to human surgeons, by providing more precision with wrist like movement, tremor elimination, motion scaling, tireless repeated movements and high-resolution 3D vision, reducing the risk of vascular injury/ pedicle injury [5,24]. All these features are present in the Da Vinci robotic system, making it a very suitable and attractive option for microsurgery.

In the past decade, robots have been used to harvest only five types of free flaps for covering soft tissue defects. This underscores the vast array of flaps that remain to be explored for integration with robotic harvesting techniques.

Conventionally, deep inferior epigastric artery perforator flap is approached anteriorly with long fascial incision. A robotic approach makes this flap harvest from the posterior surface with small fascial incision. Gundlapalli in 2018, for the first time described the use of Da Vinci robot to harvest DIEP flap for breast reconstruction.[28]

In DIEP flap procedures, determining the appropriate incision length presents a challenge as longer incisions allow for easier access but come with a higher risk of complications like muscle and nerve damage. In contrast, shorter incisions create spatial limitations and increase the risk of complications if the pedicle is dislodged.[19] Robotic devices, particularly the Da Vinci SP model, offer a potential solution as the "totally extraperitoneal" (TEP) approach, often used with robotic systems, minimizes incisions and risk of nerve and muscle injury leading to less donor site morbidity.[23].

In a study, comparing robotic assisted deep inferior epigastric artery perforator (RA-DIEP) surgery to conventional methods, RA-DIEP showed this advantage of short rectus sheath incision length in Robotic-Assisted Deep Inferior Epigastric Perforator (RA-DIEP) surgery (2.67 cm in RA-DIEP versus 8.14 cm in conventional DIEP flaps), and similar flap success rates, and other outcomes like wound healing, post operative pain levels,[15,29] reduced morbidity and shorter hospital stays when compared to conventional methods.[15] However, some authors are of the view that the currently existing robotic tools are not proficient in perforator dissection.[22]

A study that compared the radial forearm free flap harvest by robot group and conventional group reported similar flap surface areas. Both groups had harvested flaps which included vena comitans. When comparing the success rates, the robot group had a 100% radial forearm free flap survival rate, while the conventional group had a 90.9% survival rate, which was statistically not significant. In postoperative follow-up, the robot cases had better and superior aesthetic outcomes due to reduced linear scarring. However, the robot-assisted harvesting took significantly longer time than the conventional group[16].

Patel in 2012 presented a case in which robotic system was used to harvest pedicled myocutaneous LD flap [30] and Selber in 2012 reported robotic harvest of free latissimus dorsi flap.[31] For latissimus dorsi flap, robotic technology allows intricate dissections around the thoracic curvature, even in areas not directly aligned with the instrument's straight shafts. Also, it has been reported to reduce back scar length from up to 40 cm to a 5-cm scar hidden high in the axilla, which is expected to further reduce to introduction of newer robotic devices, Additional port scars of robots resemble those related to drains in open techniques.[26]

One of the few limitations in robotically assisted latissimus dorsi myocutaneous flap (LDMF) harvest is restriction in the dissection of the pedicle, particularly when directed cranially toward the axilla, with certain robotic models.[26] The primary drawback of robotic latissimus dorsi flap harvest is the limited operative field visibility that increases as dissection progresses in the subcutaneous space.[27]

The initial documentation of robotic harvesting for the rectus abdominis muscle in humans' dates back to 2010.[13] Traditionally for harvesting the rectus muscle, incisions used are midline, paramedian, and Pfannenstiel. The main concern with these approaches is aesthetically unpleasing incision on the abdomen, and disrupts the anterior rectus sheath, increasing morbidity risk.

The robotic harvest offers an intraperitoneal approach and is advantageous as it entirely relies on the ports placed on the contralateral abdominal wall, avoiding any violation of the anterior rectus sheath. It allows for muscle harvesting from the inside, using access through the posterior sheath, leaving the anterior sheath covering the empty rectus sheath intact. The "port-only" technique minimizes incision length to approximately 2 inches, eliminating, incisional morbidity with minimal risk of hernia or bulge, and the operation is well-tolerated by the patient, although longer follow-up is required for conclusive results.[29]

Omental flap use is limited in reconstructive surgery as most plastic and reconstructive surgeries take place in the subcutaneous space, and omental flap harvesting requires laparotomy that can result in devastating complications. Ozkan reported the harvest of omental free flap for the first time in 2019.[27] Using robotic techniques, pedicle dissection for omental flap is as easy as the open technique and nearly with same operative time. Microvascular transfer of the flap is reliable, and the flap can be used more radically due to its tissue bulk and vascularity [27]. Use of robotic technique will be a great adjunct to harvest intraperitoneal omental flap.

There were variations observed in both robotic harvesting time and operating time. This discrepancy could be attributed to the diverse utilization of robots for various surgical steps by certain authors, while those steps were conventionally executed in other studies, and vice versa. For instance, some studies employed robots for the complete harvesting of flaps, whereas others utilized robotic systems solely for dissecting the pedicle of the flaps. Additionally, this variability might be influenced by the learning curve in some cases, as experienced surgeons might perform procedures in shorter times. Interestingly, it is worth noting that only two studies were published in the current year reporting utilisation of robotics for free flap harvest, with one of them being the first study to report radial forearm flap harvest using this technique. In this era of modernisation, the expectation is to harness the potential of robots for harvesting newer and different types of free flaps for reconstruction. However, the limited number of publications this year is not encouraging, and this decline may be indicative of a waning popularity for this application, possibly due to increased operative time and costs as certain comparative studies have reported that robotic reconstruction is associated with a longer operative time.[14]

It is crucial to acknowledge the resource-intensive nature of robotic surgery, its impact on room availability for other specialties, longer learning curve, time-consuming option,[27] and use of disposable equipment's, instruments and drapes.[24]. The costs need to be weighed against the cosmetic benefits minimal scarring, however few studies have reported that patient charges were comparable to traditional flap harvesting surgeries.[28] These considerations are significant due to its potential impact on the adoption of this cutting-edge technology in developing countries. The approach is not free of complications, like peritoneal perforation, uncontrolled bleeding, and pedicle Damage, need of CO^2 gas for insufflation related subcutaneous emphysema, pneumothorax, and gas emboli.[27]

Nevertheless, this technology is still in its infancy within the realm of plastic surgery, lacking formal training for plastic surgeons in minimally invasive techniques or robotics. Absence of specialty-specific training should not deprive our patients of the potential benefits offered by these approaches, especially in complex surgeries of thorax, abdomen and pelvis.[29]

Limitations

The primary limitation of this review is the significant heterogeneity among the included studies. Different types of studies often focused on different aims, leading to variations in reporting and outcomes. This diversity made it challenging to draw direct comparisons between the studies and reach unified conclusions. Secondly, some of the included papers lacked comprehensive reporting of critical variables, such as defect size, robotic flap harvest time, and mean operative time. This limited our ability to assess whether outcomes varied based on defect size and whether robotic techniques are more time-efficient compared to traditional methods.

Conclusion

In conclusion, robotic technology has shown promise in enhancing precision and reducing invasiveness in plastic surgery. Despite resource-intensive requirements, its potential benefits in flap harvest, reconstructions, and microsurgery are evident. Further research and standardisation are needed, but the future of robotics in plastic surgery looks promising.

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Conflict of Interest: None.

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