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Systematic Review

Advances in the use of microvascular flaps for postoperative defect repair in complex abdominal surgery: innovative approaches to recovery and functionality

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ABSTRACT

Flap reconstruction technique was introduced by Sir Harold Gillies during WWI which is now evolved into microsurgical advancements in the 1970s enabling precise tissue transfer for complex reconstructions. By the 1980s, microvascular flaps matured period, offering durable solutions for extensive abdominal defects especially after oncological resections, infections, or previous surgeries. Our systematic strategy of papers selection focused on microvascular flap techniques in abdominal wall reconstruction. Studies that disuses latest advancements are extracted from papers published from 2020-2024. Proper inclusion and exclusion criteria is followed, papers are selected from peer-reviewed Journals, clinical trials, systematic reviews and meta-analysis and reviews. Results show that advancements in microvascular flap surgery have improved postoperative abdominal defect repairs. Innovations include precise microvascular techniques, perforator and free flaps, composite and propeller flaps, and the gracilis free muscle flap. Enhanced preoperative imaging, such as magnetic resonance angiography (MRA) and computed tomography angiography (CTA) and improved flap engineering techniques lead us to superior outcomes with less complications. Recent innovations in microvascular flap techniques have innovated abdominal defect reconstruction and suppressed traditional techniques. These advancements are offering enhanced precision, functionality, and aesthetic results. Advanced imaging and novel flap engineering methods along with technological advancements has optimized surgical outcomes.

Keywords: Microvascular flap surgery, Abdominal wall reconstruction, Advanced imaging, Perforator flaps, Flap engineering

INTRODUCTION

Flap reconstruction was first introduced by Sir Harold Gillies in the early 20th century during World War I for treatment if severe facial injuries in soldiers.[1] Gillies pioneered pedicled flaps to transfer tissue with an intact blood supply which laid foundations for modern reconstructive surgery. Technique involved introduction of microsurgical free flaps in the 1970s allowing for greater precision in complex reconstructions. Microvascular flaps use was increased in 1980s and clinicians started using it for various purposes including extensive abdominal wall defects providing durable, autologous tissue coverage in challenging postoperative scenarios.[2]

Repairing postoperative defects following complex abdominal surgery presents is challenging especially in large tissue defects that arise from oncological resections, infections, or prior surgical interventions. Such defects need robust and functional reconstructions due to the critical role of the abdominal wall in maintaining anatomical integrity and supporting visceral functions.[3] Traditional approaches like primary closure and synthetic mesh implantation are inadequate in cases involving extensive tissue loss or compromised vascularity, these microvascular flaps have gained prominence as a critical reconstructive option, providing both structural stability and improved recovery outcomes.[4] Microvascular flap surgery involves meticulous transfer of autologous tissue from a distant site with vascular continuity preserved through microsurgical anastomosis of small-caliber vessels. Precision and adaptability of this technique allow for tailored reconstructions for specific characteristics of the defect while considering the patient's overall health status. Recent advancements in flap harvesting and microsurgical methods have enhanced the success of these procedures and have improved functional recovery and have minimized donor site morbidity.[5]

Advanced microvascular flaps in postoperative abdominal surgery include perforator flaps for instance, deep inferior epigastric artery perforator (DIEP) and superior gluteal artery perforator (SGAP) flaps which utilize specific vessels to transfer tissue while preserving underlying muscle, minimizing donor site morbidity.[6] Free flaps like TRAM and latissimus dorsi flaps are providing adequate tissue coverage and function for extensive abdominal reconstructions.[7] Composite flaps like pectoralis major and tensor fascia lata (TFL) flaps integrate various tissue types to address complex defects. Propeller flaps are known for their complete rotation around a central axis and free muscle flaps like gracilis, provide precise and versatile solutions for severe defects.[8]

We will discuss latest advancements in the use of microvascular flaps for repairing postoperative defects in complex abdominal surgeries. In this paper, we will analyze innovative strategies employed in these reconstructions, highlighting importance of microvascular techniques currently used techniques in 2024, in overcoming the limitations of conventional methods.

METHODS

We decided following systematic literature review focusing on studies related to the use of microvascular flaps in postoperative abdominal surgery. We identified studies through PubMed, cochrane and Google Scholar. We designed keywords such as "microvascular flaps," "abdominal wall reconstruction," "postoperative defect repair," and "complex gastrointestinal surgery." Other secondary keywords were: perforator flaps (DIEP, SGAP), free flaps (TRAM, latissimus dorsi), composite flaps (pectoralis major, TFL), propeller flaps, free muscle flaps (gracilis), flap harvesting techniques, cell sheet technology, prefabricated flaps, 3D biodegradable scaffolds, stem cell integration, autologous free flaps with iPSCs, tissue engineering chambers (TECs), external suspension TECs, and vascularized flap creation.

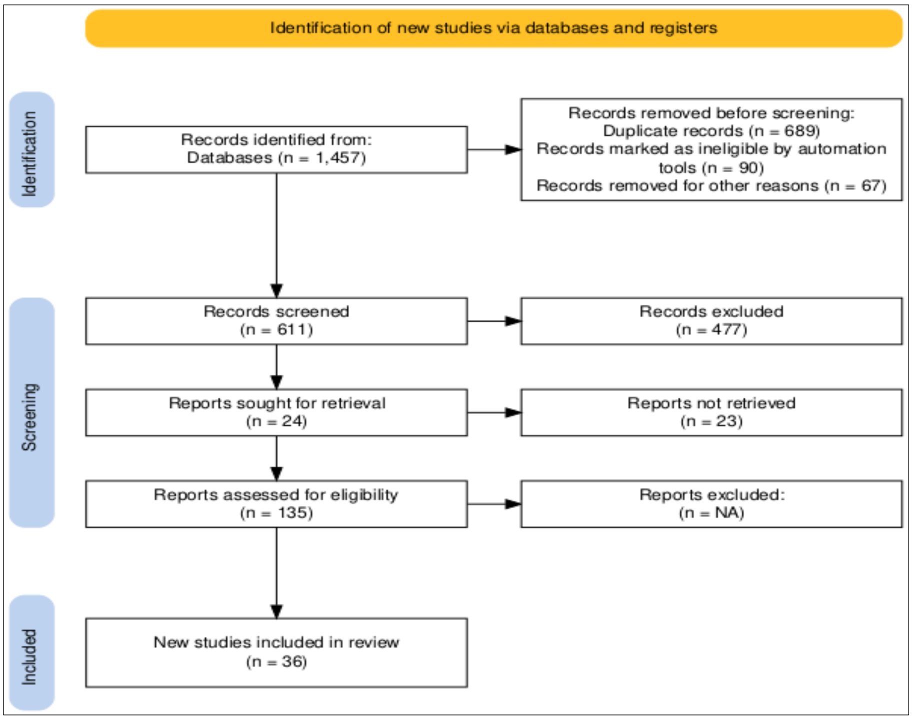

Figure 1: PRISMA flow chart.

Inclusion and exclusion criteria

This paper includes studies published from 2020 to 2024 which are primarily focusing on advancements. We selected peer-reviewed articles, clinical trials, case series, and reviews that specifically addressed advancements in flap techniques. Studies were excluded if they lacked sufficient clinical data or were about microvascular techniques but main focus was solely on non-abdominal applications. Selected studies underwent critical analysis for methodology, outcomes, and relevance to current surgical practices.

Data extraction

We also followed a systematic process for data extraction that began with scanning article titles to identify relevant studies. Abstracts were then reviewed to determine their alignment with the study's focus. We included high-level evidence, prioritizing papers graded as 1a or 1b. Only relevant data was extracted.

RESULTS

Above results in Table 1 highlight critical advancements in microvascular flap surgery emphasizing precision in techniques such as perforator, free, composite, propeller, and free muscle flaps. These innovations including enhanced flap harvesting methods improve functional and aesthetic outcomes in complex abdominal reconstructions by minimizing donor site morbidity and tailoring reconstructions to individual patient needs.

Recent advancements in microvascular techniques highlight integration of innovative approaches like cell sheet technology, prefabricated flaps, 3D biodegradable scaffolds, and stem cell integration. Novel innovations of medical technology show promise in enhancing vascularization, tissue integration, and creation of personalized vascularized flaps, though challenges remain in clinical application such as scale limitations, durability, and complications in defect repairs (Table 2).

Table 1: Critical advancements in microvascular flap surgery emphasizing precision in techniques.

Advancement	Technique/improvement	Clinical relevance/application
Precision in microvascular flap surgery	Microvascular flap surgery involves the meticulous transfer of autologous tissue from a distant site, with vascular continuity preserved through microsurgical anastomosis of small-caliber vessels.	This advancement allows for tailored reconstructions that address the specific characteristics of the defect while considering the patient's overall health, improving surgical outcomes.[9]
Perforator flaps	Deep inferior epigastric perforator (DIEP) and superior gluteal artery perforator (SGAP) flaps utilize specific vessels to transfer tissue while preserving underlying muscle.	These flaps minimize donor site morbidity and are essential for achieving functional and aesthetic outcomes in complex abdominal wall reconstructions.[10]
Free flaps	Transverse rectus abdominis muscle (TRAM) and latissimus dorsi flaps provide robust tissue coverage and function, crucial for extensive abdominal reconstructions.	These flaps are vital for providing the necessary bulk and vascularized tissue needed to repair large abdominal defects effectively.[11]
Composite flaps	Pectoralis major and tensor fasciae latae (TFL) flaps integrate various tissue types to address complex defects.	Composite flaps offer versatility in reconstructing intricate defects, combining different tissue components to restore both form and function.[12]
Propeller flaps	Flaps that rotate around a central axis, such as the propeller flaps, offer precise solutions for localized defects.	These flaps provide enhanced flexibility in reconstructive surgery, allowing for customized solutions that optimize both functional and aesthetic outcomes.[13]
Free muscle flaps	Gracilis free muscle flaps offer a reliable option for severe defects, providing precise reconstruction capabilities.	Free muscle flaps like the gracilis are instrumental in repairing complex abdominal defects, especially when precise muscle coverage is needed.[14]
Innovations in flap harvesting	Recent advancements in flap harvesting techniques have enhanced the ability to preserve blood supply and minimize damage to the donor site.	Improved harvesting techniques have led to better functional recovery, superior aesthetic results, and minimized donor site morbidity, enhancing overall patient outcomes.[15]

Table 2: Latest advancements in microvascular techniques.

Advancement	Technique improvement	Benefits	Clinical relevance
Cell sheet technology	Use of femoral blood vessels sandwiched between layers of	Enhances keratinization and structural similarity	Promising in constructing vascularized flaps for large skin

Continued.

Advancement	Technique improvement	Benefits	Clinical relevance
	artificial dermis to create skin substitutes. Involves ex-vivo perfusion in a bioreactor with epidermal sheets cultured from animal cells.	to native skin. Novel approach to creating skin flaps with potential for large-scale application.	defects, though still limited by size and clinical application due to harvesting issues and area restrictions.[16]
Prefabricated flaps	Implantation of a vascular pedicle under a flap to induce revascularization and create a new axial flap. Combines multiple tissue types like cartilage with neovascularized axial flaps.	Offers stable perfusion, good elasticity, and the potential for multi-tissue integration in complex reconstructions. Proven role of capillary networks in long-term flap survival.	Applicable for complex defect repair involving different tissue types, although the requirement for two-stage procedures and flap necrosis in early trials remain significant limitations.[17]
Three-dimensional (3D) biodegradable scaffolds	Combines myoblasts, fibroblasts, and endothelial cells within a 3D scaffold to generate muscle tissue with pre-formed capillary networks.	Rapid vascularization post-grafting with potential for mechanical performance and tissue integration. Scale limitations still impede clinical translation.	Significant for muscle defect repairs but necessitates enlargement for application in human patients due to scale disparities.[18]
Stem cell integration	Use of human adipose-derived stem cells (ASCs) and vascular growth factor-containing microspheres to promote neovascularization in engineered flaps.	Enhanced fat tissue creation, ECM production, and improved vascularization.	Demonstrates utility in creating vascularized adipose tissue for abdominal reconstructions, but further validation needed for clinical consistency.[19]
Autologous free flaps with iPSCs	Development of vascularized flaps using human-induced pluripotent stem cells (iPSCs) combined with endothelial and smooth muscle cells.	Capillary network formed within 24 hours of seeding, with successful inosculation in vivo, showing potential for autologous free flap creation.	Innovative for personalized tissue engineering, though durability of the engineered vessels requires further research for abdominal surgeries.[19]
Tissue engineering chamber (TEC) techniques	Use of perforated dome-shaped chambers to induce in vivo tissue growth. Incorporates mechanical forces to stimulate angiogenesis and adipogenesis.	Achieves flap volumes up to 50 ml, though limited by fibrous capsule formation and durability.	Adaptable to various tissue types, with ongoing advancements in human applications for defect repair. TECs hold promise for breast reconstruction, but still face issues like fibrous encapsulation and foreign body reactions.[20]
External suspension TECs	Implementation of external traction devices and biodegradable meshes to enhance adipogenesis and reduce capsule formation.	Improved flap size, better tissue integration, and reduction in foreign body response with thinner, less restrictive capsules.	Potential for scaling TEC models to human applications, particularly in adipose tissue reconstruction. Minimizes complications from synthetic TECs in abdominal settings.[22]

DISCUSSION

Nassar et al discussed about recent advancements in microvascular flap reconstruction for abdominal defects. It was known that technologies now enable precise visualization of vascular anatomy, enhancing surgical outcomes.[21] Techniques such as handheld Doppler ultrasound remain widely used for their accessibility and ease, although newer modalities like computed tomography angiography (CTA) offer more detailed imaging, reducing operative times and costs. Magnetic resonance angiography (MRA) is non-invasive alternative for patients with contrast allergies. Emerging technologies like indocyanine green fluorescence angiography and dynamic infrared thermography offer real-time perfusion assessment without radiation.

The study by Ogunleye et al explores about three-dimensional (3D) models in complex microsurgical reconstruction in breast surgeries involving deep inferior epigastric perforator (DIEP) and muscle-sparing transverse rectus abdominis myocutaneous (MS-TRAM) flaps. Retrospective review compared outcomes between surgeries planned with conventional computed tomography angiography (CTA) and enhanced with 3D printed models. Finding suggests both methods resulted in successful outcomes with no flap loss, 3D models reduced flap harvest time in bilateral MS-TRAM procedures, and minimized intraoperative decision changes.[9] Neck burn contracture, lower extremity lymphedema, and breast reconstruction following abdominal surgery has enhanced visualization and accurate surgical planning of 3d models for successful operative outcomes. 3D models are also valued in preoperative planning offer improved spatial awareness and reducing operative time.[9]

Proliferator flap techniques

Perforator flaps, for instance DIEP flap have revolutionized reconstructive surgery by harvesting skin and fat while preserving underlying muscles and reducing donor site morbidity like hernias. Preoperative imaging, Doppler ultrasound or CT angiography are used for mapping perforator vessels to ensure adequate blood supply and minimize complications like vascular compromise or fat necrosis. Microsurgical techniques connect the flap's vessels to the recipient site but it demands critical precision to prevent thrombosis or venous congestion.[22] Postoperatively, flap monitoring via Doppler or oxygen-level devices detect vascular issues early. While proliferator flaps enhance aesthetic outcomes and reduce abdominal wall weakness but risks remain these can lead to infection and potential abdominal wall integrity loss which are its major complications. Innovations like robotic-assisted surgery and bioengineered flaps promise further advancements, improving outcomes not only in abdominal procedures but also in head, neck, and lower extremity reconstructions, making perforator flaps as a cornerstone of modern reconstructive surgery.[22] Evidence by Nanda Deepa Thimmappa focused MRA for perforator flap surgeries, especially for autologous breast reconstructions procedures, suggesting that MRA has become preferred imaging modality due to its ability to provide highly detailed and accurate visualization of the perforator anatomy. The advantages of MRA such as superior soft tissue contrast and multiplanar imaging capabilities make this tool essential for preoperative planning, intraoperative guidance, and postoperative management for complex microsurgical procedures. Technical aspects and specific imaging protocols associated with MRA, along with its limitations and potential areas for improvement. Notable emphasis is placed on recent advancements in the field like use of artificial intelligence AI and machine learning ML which are poised to enhance the precision and efficiency of MRA interpretations suggesting tMRA is instrumental in optimizing the outcomes of perforator flap surgeries and is likely to see further refinement and increased application with ongoing technological developments.[23]

Khajuria et al suggested innovations of perforator flaps that these flaps preserve donor-site integrity while providing robust vascularization have improved reconstructive outcomes in extensive defects. For instance, the DIEP flap is critical in abdominal wall reconstruction due to its superior tissue adaptability and reduced donor site morbidity. Refinements in super microsurgery enable anastomosis of vessels under 0.8 mm have expanded the utility of microvascular flaps. Critical issues, however, persist for instance, concerning ischemic complications and flap necrosis where the integration of real-time intraoperative perfusion monitoring has shown promise. Advanced imaging and 3D modelling can guide surgical planning for individualized and patient-specific reconstructions with improved long-term functionality and aesthetic outcomes.[24]

Bond et al suggests perforator flaps in abdominally based autologous breast reconstruction among patients with prior abdominal surgery remains a safe and viable option. A systematic review and meta-analysis was based on population with patients who had undergone abdominal procedures previously, revealed no significant increase in flap-related complications such as total or partial flap loss when using perforator flaps. These patients experienced slight increase in donor-site delayed wound healing, showing reliability of perforator flaps in complex cases even when previous abdominal surgeries have occurred.[25]

Free flap technique

Free flap techniques have advanced complex abdominal surgery by allowing for precise postoperative defect repair through microvascular tissue transfer. Surgeons now use microvascular flaps such as DIEP and ALT flaps are now being used to reconstruct large defects while preserving donor site function. Improved preoperative imaging and refined microsurgical skills have reduced flap failure rates. Critical to this success is meticulous anastomosis of blood vessels for ensuring flap viability. Innovations like perforator-sparing techniques and robotic-assisted surgery further optimize results are now being utilized for minimizing complications like abdominal wall weakness and enhancing both functional and aesthetic outcomes in complex abdominal reconstructions.[26]

The scapular free flap (SFF) is another advancement in microvascular reconstruction for complex abdominal defects. Systematic review and meta-analysis by Escobar-Domingo et al stated SFF demonstrates remarkable versatility and reliability in reconstructive surgery. This analysis encompasses 1447 flaps across 110 studies and results indicated SFF's efficacy in addressing intricate defects with compromised local tissue integrity. SFF's success is evident in its low flap failure rate of 2% and minimal complications such as partial flap loss or infection. The flap's adaptability, with its capacity to incorporate various tissue types including osteocutaneous, cutaneous, and chimeric components enhances its application in complex reconstructions profoundly and is more commonly used for head and neck surgery. The SFF provide customizable dimensions and integrate multiple tissue types makes it an invaluable tool for surgeons facing multicomponent defects.[27]

Composite flaps

Composite flaps contain multiple tissue types such as skin, muscle, bone, and fats which are in reconstructive surgery for repairing complex defects of abdomen. These flaps allow for transfer of a combination of tissues in a single surgical unit tailored to match the intricate needs of the defect. Advances in microsurgical techniques and vascular anastomosis have improved composite flaps viability and has reduced complications such as tissue necrosis. Composite flaps can be integrated in different tissues and provide superior structural support and functional restoration making them essential for reconstructing areas where single-tissue flaps are insufficient. Clinical application of composite flaps demonstrates effectiveness in managing large abdominal defects for both soft and hard tissues. The osteocutaneous free flap exemplified by the fibula or iliac crest flap is a notable innovation in this area. These flaps provide essential structural support and coverage and improve functional and aesthetic outcomes. The success rates for composite flaps often exceed 90% which means these are reliable and can be effectively used in complex cases.[28,36]

Recent innovations in composite flap techniques include refinement of flap design and enhanced preoperative planning. With the advent of 3D imaging and computer-assisted planning tools, surgeons can customize composite flaps according to the specific characteristics of the defects and obtained optimal surgical outcomes with minimal complications because of precise flap fit and adequate vascularization. Use of new biomaterials and regenerative techniques such as stem cell therapy and growth factor application has further advanced the capabilities of composite flaps and has improved flap integration and promoted tissue regeneration. Challenges of composite flaps are complexity of surgical implementation and the need for precise vascularization. Addressing these challenges involves ongoing research focused on improving flap design, enhancing vascularization techniques, and exploring new biomaterials. Future developments are anticipated to further reduce surgical complications and expand application of composite flaps to a wider range of reconstructive scenarios.[29]

Propeller flaps

Propeller flaps are a type of perforator flap that rotate around a central axis up to 180 degrees to cover complex defects without the need for microsurgical anastomosis. Propeller flaps are based on a single perforator vessel which allow wide arc of rotation while minimizing donor site morbidity. Imaging advancements and surgical techniques provides precision of these flaps. Propeller flaps use is versatile which makes them ideal for challenging reconstructions where traditional flaps may be inadequate. A significant modification is the evolution of perforator propeller flaps from traditional pedicled flaps enabling up to 180-degree rotation and enhanced blood flow through techniques like supercharging which involves anastomosing an additional vein or artery to reduce venous congestion. Axial propeller flaps are based on defined vessels like the supratrochlear artery which offer predictable vascularity making them a reliable option for reconstructions in the head, neck, and abdominal regions. In complex abdominal surgeries propeller flaps based on the DIEP or ALT perforator can be promising for full coverage with minimal morbidity. Selective muscle inclusion, when tailored muscle amount is harvested around the perforator, contrasts with older methods that required entire musculocutaneous flaps, offering better aesthetic and functional outcomes. Preoperative planning with Doppler assessment ensures optimal flap design while meticulous dissection and rotation techniques manage vessel torsion risks and ensuring consistent blood flow.[30]

Gracilis free muscle flaps

Lyons and Goldman 2023 discussed about advancements of the Gracilis free muscle flap for abdominal surgery following defect repair reflects critical evolution in microsurgical techniques, yet its application presents both strengths and limitations. Initially described as pedicled myocutaneous flap by Orticochea in 1972, gracilis muscle flap has since become a “workhorse” for reconstructive surgeons due to its reliable pedicle and versatile nature as well as lower donor-site morbidity. Its application in abdominal surgery for soft tissue coverage is valued for its consistent blood supply from the descending branch of the medial femoral circumflex artery and its ability to be harvested with a skin paddle. These features make gracilis flap a versatile tool and procedure’s technical demands and potential complications, such as flap failure and partial necrosis which necessitate highly skilled surgical team.[31]

Technique for gracilis flap harvest is straightforward but meticulous because it needs careful dissection to preserve vascular and nerve pedicles which are critical for ensuring flap viability and functional transfers. This precision is essential as complications such as skin necrosis and flap loss are associated with increased patient age and higher ASA scores which needs careful patient selection. Despite these risks, the gracilis flaps in abdominal surgery is enhanced by its adaptability being used for both functional and non-functional reconstruction including complex defects post-tumor resection or trauma.[31]

Innovations of microvascular flap engineering

Microvascular flap engineering has is evolved significantly for repairing postoperative defects in complex abdominal surgeries. Innovations in flap engineering, including cell sheet technology, prefabricated flaps, tissue engineering chambers (TECs), decellularized flap matrices offer new avenues for improving recovery and functionality in patients.[32]

Cell sheet technology involves constructing simple vascularized skin substitutes that can act as cutaneous pedicled flaps. Fujisawa et al pioneered a technique for extracorporeal skin flap fabrication which involved sandwiching femoral blood vessels between two layers of artificial dermis. The construct was placed in a porous chamber then connected to a perfusion system in a bioreactor. After a few days, fabricated flaps exhibited good keratinization and structural similarity to native skin. Despite these promising results, method remains clinically inapplicable due to the sacrifice of nourishing vessels and limitations in the size of the flaps produced.[32]

Prefabricated flaps

Prefabrication of flaps is another innovative approach where a vascular pedicle is implanted under a cutaneous flap to create a new axial flap through revascularization. Staudenmaier et al successfully created a prefabricated flap using a combination of chondrocytes and a vascular loop implanted under a random skin flap. Prefabrication technique resulted in well-perfused flaps with stable and elastic properties, resembling hyaline cartilage. Similarly, Zhang et al enhanced flap construction by using collagen-chitosan scaffolds seeded with human adipose-derived stem cells (ASCs) and polymer microspheres containing vascular endothelial growth factor (VEGF), achieving better vascularization and fat tissue formation in vivo, paving the way for more effective defect repairs.[32]

Tissue engineering chambers (TECs)

Tissue engineering chambers (TECs) are making strides in flap engineering as TEC insert perforated dome-shaped hollow chamber around a tissue flap in vivo to promote flap growth and tissue regeneration. Findlay et al demonstrated that TECs filled with small-volume fat flaps and implanted on an arteriovenous ligated pedicle could achieve significant flap growth reaching volumes over 50 ml. Fibrous capsule often forms around the flap which limit its clinical application. To mitigate this Luo et al introduced nano fibrous meshes on the inner side of TECs resulting in thinner capsules, less inflammation, and larger flaps.[32]

Decellularized flap matrix

Decellularized flap matrices is also a promising solution to mitigate challenges of immune rejection and donor morbidity. Zhang et al developed a novel technique for creating a decellularized skin/adipose flap which involved harvesting tissue from an animal and decellularizing them and then reseeding it with human cells. This method successfully maintained the vascular structures including the main pedicle and microvascular network without eliciting an immune response. Although this technique shows potential but more research trials can improve decellularization methods and validate these findings in larger models.[32]

Future innovations

Future innovations of flap surgery are poised to enhance reconstructive techniques and patient outcomes. One promising area is regenerative medicine where stem cell therapy is improving flap viability and promote faster healing but its use is still limited. For example, adipose-derived stem cells have shown potential in enhancing free flaps survival by boosting vascularization and tissue regeneration. Tissue engineering is advancing with the development of bioengineered tissues that can integrate seamlessly with native tissues and reducing need for extensive donor site harvesting and improving functional restoration.

In future, exciting development will be 3D bioprinting which will be allowing for creation of highly customized flaps with precise anatomical and functional characteristics. 3D bioprinting will enhance production of complex tissue structures that closely mimic natural tissues. For instance, researchers have successfully 3D-printed cartilage and bone tissues that can be used in reconstructive surgeries, improving the alignment and functionality of reconstructed areas while minimizing donor site morbidity. Smart technology into flaps is also represented as a significant leap forward. Incorporating biosensors and electronic monitoring within flaps provide real-time data on tissue health and perfusion for example, smart flaps equipped with embedded sensors can monitor oxygen levels and detect early signs of vascular compromise which helps us to detect prompt intervention need and potentially reducing the incidence of flap failure. Advancements of biomaterials are also making strides, with new materials being developed to improve flap integration and functionality. Bioactive scaffolds and smart polymers such as those infused with growth factors or designed to resist infection are now being tested to enhance tissue regeneration and reduce complications. Scaffolds embedded with antimicrobial agents are promising in preventing infection and promoting faster healing in experimental models. Minimally invasive techniques continue to evolve as innovations of robotic-assisted and endoscopic surgeries leading to less traumatic procedures and faster recovery times. Robotic-assisted flap surgeries for instance da Vinci surgical system offer improved precision and control and enhance flap placement accuracy and reduce postoperative complications. Enhanced endoscopic methods are also being developed to perform complex reconstructions with smaller incisions, minimizing scarring and improving patient comfort.

Artificial intelligence (AI) and machine learning are increasingly being applied to flap surgery to enhance preoperative planning and intraoperative navigation. AI algorithms can analyze imaging data and optimize flap design and also predict potential complications, AI-driven tools can be used to detect vascular patterns and predict flap viability leading precise surgical planning and better outcomes.[33-35]

CONCLUSION

Recent advancements in microvascular flap techniques have revolutionized postoperative defects repair in complex abdominal surgeries. Innovations such as perforator flaps including the DIEP and SGAP, and free flaps like the TRAM and latissimus dorsi are being used currently for their ability to address extensive tissue loss while minimizing donor site morbidity. Composite and propeller flaps offer versatile solutions for complex reconstructions, providing precise coverage with reduced complications. Advanced imaging modalities such as MRA and CTA provide detailed visualization of vascular anatomy. Innovations in flap engineering including cell sheet technology, prefabricated flaps, and decellularized matrices, promise future improvements in flap viability and patient recovery. All these advancements along with use of digital tools such as AI and ML with advanced imaging modalities have enhanced functional and aesthetic outcomes.

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REFERENCES

1. Piccinini PS, Girelli P, Dias GF, Chedid GB, Ramos R, Matta F, et al. History of plastic surgery: sir Harold Gillies, a pioneer of reconstructive plastic surgery. Revista Brasileira de Cirurgia Plástica. 2023;32:608-15.
2. Tamai S. History of microsurgery from the beginning until the end of the 1970s. Microsurgery. 1993;14(1):6-13.
3. Sugamata N, Okuyama T, Takeshita E, Oi H, Hakozaki Y, Miyazaki S, et al. Surgical site infection after laparoscopic resection of colorectal cancer is associated with compromised long-term oncological outcome. World J Surg Oncol. 2022;20(1):111.
4. Manktelow RT. Microvascular reconstruction: anatomy, applications and surgical technique. Springer Science & Business Media. 2012.
5. Nykiel M, Hunter C, Lee GK. Algorithmic approach to the design and harvest of abdominal flaps for microvascular breast reconstruction in patients with abdominal scars. Ann Plast Surg. 2015;74:S33-40.
6. Martineau J, Kalbermatten DF, Oranges CM. Safety and efficacy of the superior gluteal artery perforator (SGAP) flap in autologous breast reconstruction: Systematic review and meta-analysis. Cancers. 2022;14(18):4420.
7. Gaster RS, Bhatt KA, Shelton AA, Lee GK. Free transverse rectus abdominis myocutaneous flap reconstruction of a massive lumbosacral defect using superior gluteal artery perforator vessels. Microsurgery. 2012;32(5):388-92.
8. Weitz J, Kreutzer K, Bauer FJ, Wolff KD, Nobis CP, Kesting MR. Sandwich flaps as a feasible solution for the management of huge mandibular composite tissue defects. J Cranio-Maxillofac Surg. 2015;43(9):1769-75.
9. Ogunleye AA, Deptula PL, Inchauste SM, Zelones JT, Walters S, Gifford K, et al. The utility of three-dimensional models in complex microsurgical reconstruction. Arch Plast Surg. 2020;47(05):428-34.
10. Wagner RD, Carr L, Netscher DT. Current indications for abdominal-based flaps in hand and forearm reconstruction. Injury. 2020;51(12):2916-21.
11. Wenny R, Schmidt M, Zaussinger M, Zucal I, Duscher D, Huemer GM. Microvascular free flaps from the lower abdomen for preservation of amputation length in the lower extremity. Clin Hemorheol Microcirc. 2021;78(3):283-90.
12. Bauder A, Othman S, Asaad M, Butler CE, Kovach SJ. Microvascular free tissue transfer for reconstruction of complex abdominal wall defects. Plast Reconstruct Surg. 2022;149(1):74-8.
13. Kedar DJ, Pak CJ, Suh HP, Hong JP. Propeller flaps in the posterior trunk. Semin Plast Surg. 2020;34(03):176-83.
14. Hölzle F, Ehrenfeld M. Microsurgical Flaps. In: Oral and maxillofacial surgery: Surgical textbook and atlas. Berlin, Heidelberg: Springer Berlin Heidelberg. 2023;717-84.
15. Anolik RA, Sacks JM. Advances and innovations in Breast Microsurgery. Missouri Med. 2021;118(2):153.
16. Guo HL, Peng XF, Bao XQ, Wang L, Jia ZM, Huang YC, et al. Bladder reconstruction using autologous smooth muscle cell sheets grafted on a pre-vascularized capsule. Theranostics. 2020;10(23):10378.
17. Chuang DC, Fang F, Lu JC, Huang YL, Chang TN. Prefabricated venous flap, an advanced free venous flap for distant transfer: An experimental rat study. Formosan J Surg. 2024;57(2):43-51.
18. Kawai T, Pan CC, Okuzu Y, Shimizu T, Stahl AM, Matsuda S, et al. Combining a vascular bundle and 3D printed scaffold with BMP-2 improves bone repair and angiogenesis. Tissue Engineering Part A. 2021;27(23-24):1517-25.
19. Egro FM, Schilling BK, Fisher JD, Saadoun R, Rubin JP, Marra KG, et al. The future of microsurgery: vascularized composite allotransplantation and engineering vascularized tissue. J Hand Microsurg. 2022;14.
20. Lei C, Cai B, Chen X, Huang Z, Wang B. Introduction of ligated vessels promote the retention and regeneration of free fat: constructing a fat flap in tissue engineering chamber. Adipocyte. 2020;9(1):108-15.
21. Nassar AH, Maselli AM, Manstein S, Shiah E, Slatnick BL, Dowlatshahi AS, et al. Comparison of various modalities utilized for preoperative planning in microsurgical reconstructive surgery. J Reconstruct Microsurg. 2021;38(03):170-80.
22. Rozen WM, Yogaraj V, Siddiqui M, Lok E, Hunter-Smith DJ. Surgical delay in abdominal based flap

surgery: a scoping review. Ann Transl Med. 2024;12(3):51.
23. Thimmappa ND. MRA for Preoperative Planning and Postoperative Management of Perforator Flap Surgeries: A Review. J Magnetic Resonance Imaging Internet. 2023;17.
24. Khajuria A, Charles WN, Prokopenko M, Beswick A, Pusic AL, Mosahebi A, et al. Immediate and delayed autologous abdominal microvascular flap breast reconstruction in patients receiving adjuvant, neoadjuvant or no radiotherapy: a meta-analysis of clinical and quality-of-life outcomes. BJS Open. 2020;4(2):182-96.
25. Bond ES, Soteropulos CE, Yang Q, Poore SO. The Impact of Prior Abdominal Surgery on Complications of Abdominally Based Autologous Breast Reconstruction: A Systematic Review and Meta-Analysis. J Reconstr Microsurg. 2021;37(7):566-79.
26. Escandon JM, Ciudad P, Mayer HF, Pencek M, Mantilla-Rivas E, Mohammad A, et al. Free flap transfer with supermicrosurgical technique for soft tissue reconstruction: A systematic review and meta-analysis. Microsurgery. 2023;43(2):171-84.
27. Escobar-Domingo MJ, Bustos VP, Akintayo R, Mahmoud AA, Fanning JE, Foppiani JA, et al. The versatility of the scapular free flap: A workhorse flap? A systematic review and meta-analysis. Microsurgery. 2024;44(5):e31203.
28. Chandra SR, Morlandt A, Ying Y, Rana M, Acero J, Parmar S. Deep Circumflex Iliac Artery-Based Composite Flap or Vascularized Iliac Crest Flap. Atlas Oral Maxillofac Surg Clin North Am. 2023;31(2):113-20.
29. Zhang Q, Chiu Y, Chen Y, Wu Y, Dunne LW, Largo RD, et al. Harnessing the synergy of perfusable muscle flap matrix and adipose-derived stem cells for prevascularization and macrophage polarization to reconstruct volumetric muscle loss. Bioactive Materials. 2023;22:588-614.
30. D'Arpa S, Toia F, Pirrello R, Moschella F, Cordova A. Propeller flaps: a review of indications, technique, and results. Biomed Res Int. 2014;2014:986829.
31. Lyons ME, Goldman JJ. Gracilis tissue transfer. StatPearls. 2023.
32. Kouniavski E, Egozi D, Wolf Y. Techniques and Innovations in Flap Engineering: A review. Plast Reconstruct Surg Global Open Internet. 2022;10(9):e4523.
33. Akhtar ZB. Exploring Biomedical Engineering (BME): Advances within Accelerated Computing and Regenerative Medicine for a Computational and Medical Science Perspective Exploration Analysis. J Emerg Med OA. 2024;2(1):1-23.
34. Mohammadi AT, Mohammadzadeh I, Sajedifar M, Shabani M, Khonche S, Asgari R, et al. Emerging Frontiers in Surgical Advancements: Exploring Cutting-Edge Technologies and Pioneering Techniques. Nobel Sciences. 2024.
35. Sureshkumar S, Sudharsanan S, Vijayakumar C, Anandhi A. Abdominal Wall Reconstruction: Advances in the Last Decade. Int J Adv Med Health Res. 2024;11(1):4-14.
36. Fry A, Cascarini L. Improving the success rates of composite flap reconstructions. Br J Oral Maxillofac Surg Internet. 2020;58(10):e176-7.

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