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SYSTEMATIC REVIEW

Flaps for Lower Limb Diabetic Wound Reconstruction: A Systematic Review of Surgical Outcomes and Techniques

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ABSTRACT

Background: Diabetic foot ulcers (DFUs) are a major cause of limb loss and mortality. Flap reconstruction is a vital limb salvage technique, but comparative evidence remains limited. Objective: This review evaluates outcomes across flap types and identifies factors influencing success. **Material and Method**: A systematic search of five databases identified clinical studies (≥5 patients) reporting outcomes of flap reconstruction for non-traumatic DFUs. Data on patient demographics, flap characteristics, and clinical outcomes were extracted. Study quality was assessed using the ROBINS-I tool. **Result**: Twenty studies were included. Free flaps were common for complex wounds, with survival rates of 88–93% and limb salvage rates of 79–95%, but had a 19% major complication rate. Locoregional flaps showed lower failure rates (3–5%) but risked venous congestion and partial necrosis. Fasciocutaneous flaps had fewer wound complications than muscle flaps (7.3% vs. 19.1%) and offered better sensory recovery and faster weight-bearing. **Conclusion**: Flap reconstruction is effective for DFU limb salvage. No single flap is superior; individualized selection is essential. Future studies should prioritize standardized, long-term, patient-centered outcomes to guide clinical decisions.

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Highlights

1. Fasciocutaneous flaps outperform muscle flaps in minimizing wound complications and accelerating functional recovery.
2. Locoregional flaps offer a reliable alternative to free flaps for diabetic limb salvage, with lower failure rates and manageable complications.
3. This review identifies a critical gap in standardized, long-term outcome reporting, underscoring the need for patient-centered metrics in future flap reconstruction studies.

BACKGROUND

The diabetic foot ulcer (DFU) represents one of the most devastating and costly complications of diabetes mellitus, constituting a global health crisis of escalating proportions (Kumar et al., 2024; Parvin et al., 2025). The lifetime risk for a person with diabetes to develop a foot ulcer is as high as 25% (Hong and Kim, 2006; Sharma et al., 2021). The underlying pathophysiology is a pernicious triad of peripheral neuropathy, peripheral arterial disease (angiopathy), and immune dysfunction (immunopathy), which collectively create a hostile biological environment where minor trauma can lead to chronic, non-healing wounds (Sabapathy and Periasamy, 2015). Neuropathy diminishes the protective sensation that would normally signal injury, while angiopathy impairs blood flow, hindering the delivery of oxygen, nutrients, and immune cells essential for healing. This compromised state makes the diabetic foot exceptionally vulnerable to infection, which can rapidly progress to osteomyelitis, gangrene, and ultimately, limb loss (Adigun et al., 2021).

The clinical and socioeconomic burden of this condition is staggering. DFUs are the leading cause of non-traumatic lower limb amputations, preceding approximately 85% of such procedures (Sabapathy and Periasamy, 2015). The consequences of a major amputation are dire, associated with a five-year mortality rate that can exceed 50-70%, a prognosis worse than that for many common cancers (Jiga et al., 2012; Thanik et al., 2018; Sharma et al., 2021). This underscores the urgent clinical imperative to pursue limb salvage whenever feasible.

Traditionally, wound management has followed the reconstructive ladder, a concept that advocates for a stepwise progression from simple to complex solutions, starting with secondary healing and progressing through skin grafting to local, regional, and finally, free tissue transfer (Open Orthopaedics Journal, 2014). However, for complex DFUs with exposed bone, tendon, or neurovascular structures, this sequential approach is often inefficient and ineffective, allowing infection to persist and tissue loss to progress. Consequently, a more modern reconstructive elevator paradigm has gained traction, advocating for early, definitive coverage with well-vascularized tissue (Fathi et al., 2022). In this model, complex procedures like free tissue transfer are not viewed as a last resort but as a primary, proactive strategy to halt the destructive cascade of infection and ischemia, thereby maximizing the potential for limb salvage (Hong and Kim, 2006). Flap surgery, by providing a robust and independent blood supply, serves to obliterate dead space, control infection, and provide a durable soft tissue envelope, forming the cornerstone of modern diabetic limb salvage efforts (Akhtar et al., 2015).

OBJECTIVE

The primary objective of this systematic review is to synthesize and critically appraise the published clinical evidence on the outcomes of surgical flap reconstruction for lower limb diabetic wounds.

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The secondary objectives are:

1. To categorize and compare the efficacy and safety profiles of different flap types, including local (random, muscle, pedicled), regional (e.g., reverse sural artery), and distant free flaps (e.g., anterolateral thigh, latissimus dorsi), as well as to compare outcomes based on tissue composition (muscle versus fasciocutaneous).
2. To identify and analyze a comprehensive set of at least 15 key clinical outcomes, encompassing not only surgical endpoints like flap survival and limb salvage but also functional and long-term results such as ambulation, re-ulceration, and mortality.
3. To identify patient- and procedure-related factors that influence the success or failure of reconstructive efforts, thereby informing clinical decision-making.

Benefit of the Research

This review aims to provide a consolidated, evidence-based resource for the multidisciplinary limb salvage team, which typically includes plastic, orthopaedic, vascular, and podiatric surgeons, as well as endocrinologists and wound care specialists. By clarifying the relative merits, risks, and indications for each major reconstructive option, this work seeks to guide clinical decision-making toward the most appropriate procedure for a given patient and wound (Diabetic Foot Online, 2024).

Furthermore, a comprehensive synthesis of outcomes is essential for improving patient counselling. Patients facing the choice between a complex, multi-stage reconstruction and a primary amputation must be provided with realistic, data-driven expectations regarding success rates, potential complications, recovery timelines, and long-term functional capabilities (Thanik et al., 2018). This review will collate such data to facilitate more informed shared decision-making. Ultimately, by promoting a deeper understanding of the evidence, this research is intended to help standardize treatment protocols, reduce the unacceptably high rates of major amputation, and improve both the length and quality of life for patients with this challenging disease (Diabetic Foot Online, 2024).

Hypothesis

The central hypothesis of this review is that in appropriately selected patients, flap-based reconstruction offers a superior alternative to major amputation for complex DFUs, leading to improved long-term survival, higher rates of ambulation, and better quality of life. It is further hypothesized that the optimal choice of flap is not universal but is dictated by the specific characteristics of the wound and the patient. Specifically, it is postulated that perforator-based flaps offer a favorable balance of robust vascularity and minimal donor site morbidity for a range of defects, while free tissue transfer provides the most durable and versatile solution for large, composite defects, particularly over critical weight-bearing surfaces.

Research Gap and Novelty

Despite the increasing adoption of aggressive limb salvage techniques, the supporting literature is characterized by significant limitations. A considerable evidence-practice chasm exists, wherein the frequent performance of highly complex microsurgical reconstructions at specialized centers outpaces the high-quality evidence available to guide these procedures. Numerous case series document successful outcomes with advanced free flaps (Yoo et al., 2020; Hong and Kim, 2006; Sharma et al., 2021), indicating a strong belief in their efficacy within the surgical community. However, systematic reviews and meta-analyses consistently conclude that the overall quality of this evidence is "very low" or that the constituent studies carry a high risk of bias, primarily due to their retrospective, non-comparative designs and heterogeneous reporting (Chuo et al., 2023; Jones et al., 2024; Al-Mufarrej et al., 2024). This discrepancy suggests that current clinical practice is heavily influenced by expert

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opinion, anecdotal success, and the compelling biological rationale of transferring vascularized tissue, rather than by robust, comparative clinical trial data.

A critical research gap, therefore, is the lack of high-quality, comparative studies directly evaluating different flap types against one another for specific DFU scenarios. Moreover, the existing literature overwhelmingly focuses on technical surgical outcomes like flap survival. Crucial patient-centered outcomes, such as long-term functional status, quality of life, ambulation level, footwear requirements, and cost-effectiveness, are severely underreported (Jones et al., 2024; Thanik et al., 2018). This leaves a significant void between our understanding of surgical success and the true, long-term benefit conferred to the patient.

The novelty of this systematic review lies in its exhaustive and integrative approach. By synthesizing data across all major flap categories (local, regional, free) and tissue types (muscle, fasciocutaneous, perforator) and analyzing over 15 distinct clinical outcomes, this review will provide the most comprehensive and nuanced analysis of the topic to date. It uniquely aims to bridge the gap between technical flap viability and meaningful patient function, offering a holistic perspective that is essential for the advancement of modern, patient-centered diabetic limb salvage.

MATERIAL AND METHOD

Study Selection

A systematic search of the literature was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The electronic databases PubMed, Google Scholar, Semantic Scholar, Springer, and Wiley Online Library were searched from their inception to September 2024. The search strategy combined Medical Subject Headings (MeSH) and free-text keywords to maximize sensitivity.

Two reviewers independently screened titles and abstracts to identify potentially relevant articles. The full texts of these articles were then retrieved and assessed for final inclusion based on predefined criteria. Any disagreements were resolved by consensus or consultation with a third reviewer.

Inclusion Criteria

1. Clinical studies, including randomized controlled trials (RCTs), prospective or retrospective cohort studies, and case series.
2. Studies focused on patients with non-traumatic diabetic foot or lower limb ulcers undergoing reconstruction with a surgical flap.
3. Studies with a minimum of five patients to exclude anecdotal case reports (Chuo et al., 2023).
4. Studies reporting on at least one primary outcome of interest (e.g., complete flap survival, limb salvage rate).
5. Articles published in English.

Exclusion Criteria

1. Case reports with fewer than five patients.
2. Review articles, meta-analyses, editorials, letters to the editor, and conference abstracts.
3. Studies in which data for diabetic patients could not be disaggregated from a mixed population (e.g., trauma, pressure sores).
4. Animal, cadaveric, or biomechanical studies.
5. Studies not reporting on relevant clinical outcomes.

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Search Strategy

Table 1. The keywords used for this research-based PICO

Element	Keyword 1	Keyword 2	Keyword 3	Keyword 4
Population (P)	Diabetic Foot Ulcer	Diabetic Foot	Lower Limb Diabetic Wound	Neuropathic Foot Ulcer
Intervention (I)	Surgical Flaps	Flap Reconstruction	Free Tissue Transfer	Local Flaps
Comparison (C)	Standard Wound Care	Non-flap Reconstruction	Amputation	Skin Graft
Outcome (O)	Limb Salvage	Surgical Outcomes	Flap Survival	Wound Healing

The Boolean MeSH keywords entered into databases for this research are: *("Diabetic Foot Ulcer" OR "Diabetic Foot" OR "Lower Limb Diabetic Wound" OR "Neuropathic Foot Ulcer") AND ("Surgical Flaps" OR "Flap Reconstruction" OR "Free Tissue Transfer" OR "Local Flaps") AND ("Standard Wound Care" OR "Non-flap Reconstruction" OR "Amputation" OR "Skin Graft") AND ("Limb Salvage" OR "Surgical Outcomes" OR "Flap Survival" OR "Wound Healing").*

Table 2. Article Search Strategy

Database	Keywords	Hits
Pubmed	*("Diabetic Foot Ulcer" OR "Diabetic Foot" OR "Lower Limb Diabetic Wound" OR "Neuropathic Foot Ulcer") AND ("Surgical Flaps" OR "Flap Reconstruction" OR "Free Tissue Transfer" OR "Local Flaps") AND ("Standard Wound Care" OR "Non-flap Reconstruction" OR "Amputation" OR "Skin Graft") AND ("Limb Salvage" OR "Surgical Outcomes" OR "Flap Survival" OR "Wound Healing")*	156
Semantic Scholar	*("Diabetic Foot Ulcer" OR "Diabetic Foot" OR "Lower Limb Diabetic Wound" OR "Neuropathic Foot Ulcer") AND ("Surgical Flaps" OR "Flap Reconstruction" OR "Free Tissue Transfer" OR "Local Flaps") AND ("Standard Wound Care" OR "Non-flap Reconstruction" OR "Amputation" OR "Skin Graft") AND ("Limb Salvage" OR "Surgical Outcomes" OR "Flap Survival" OR "Wound Healing")*	255
Springer	*("Diabetic Foot Ulcer" OR "Diabetic Foot" OR "Lower Limb Diabetic Wound" OR "Neuropathic Foot Ulcer") AND ("Surgical Flaps" OR "Flap Reconstruction" OR "Free Tissue Transfer" OR "Local Flaps") AND ("Standard Wound Care" OR "Non-flap Reconstruction" OR "Amputation" OR "Skin Graft") AND ("Limb Salvage" OR "Surgical Outcomes" OR "Flap Survival" OR "Wound Healing")*	164
Google Scholar	*("Diabetic Foot Ulcer" OR "Diabetic Foot" OR "Lower Limb Diabetic Wound" OR "Neuropathic Foot Ulcer") AND ("Surgical Flaps" OR "Flap Reconstruction" OR "Free Tissue Transfer" OR "Local Flaps") AND ("Standard Wound Care" OR "Non-flap Reconstruction" OR "Amputation" OR "Skin Graft") AND ("Limb Salvage" OR "Surgical Outcomes" OR "Flap Survival" OR "Wound Healing")*	1,320
Wiley Online Library	*("Diabetic Foot Ulcer" OR "Diabetic Foot" OR "Lower Limb Diabetic Wound" OR "Neuropathic Foot Ulcer") AND ("Surgical Flaps" OR "Flap Reconstruction" OR "Free Tissue Transfer" OR "Local Flaps") AND ("Standard Wound Care" OR "Non-flap Reconstruction" OR "Amputation" OR "Skin Graft" AND "Limb Salvage" OR "Surgical Outcomes" OR "Flap Survival" OR "Wound Healing")*	244

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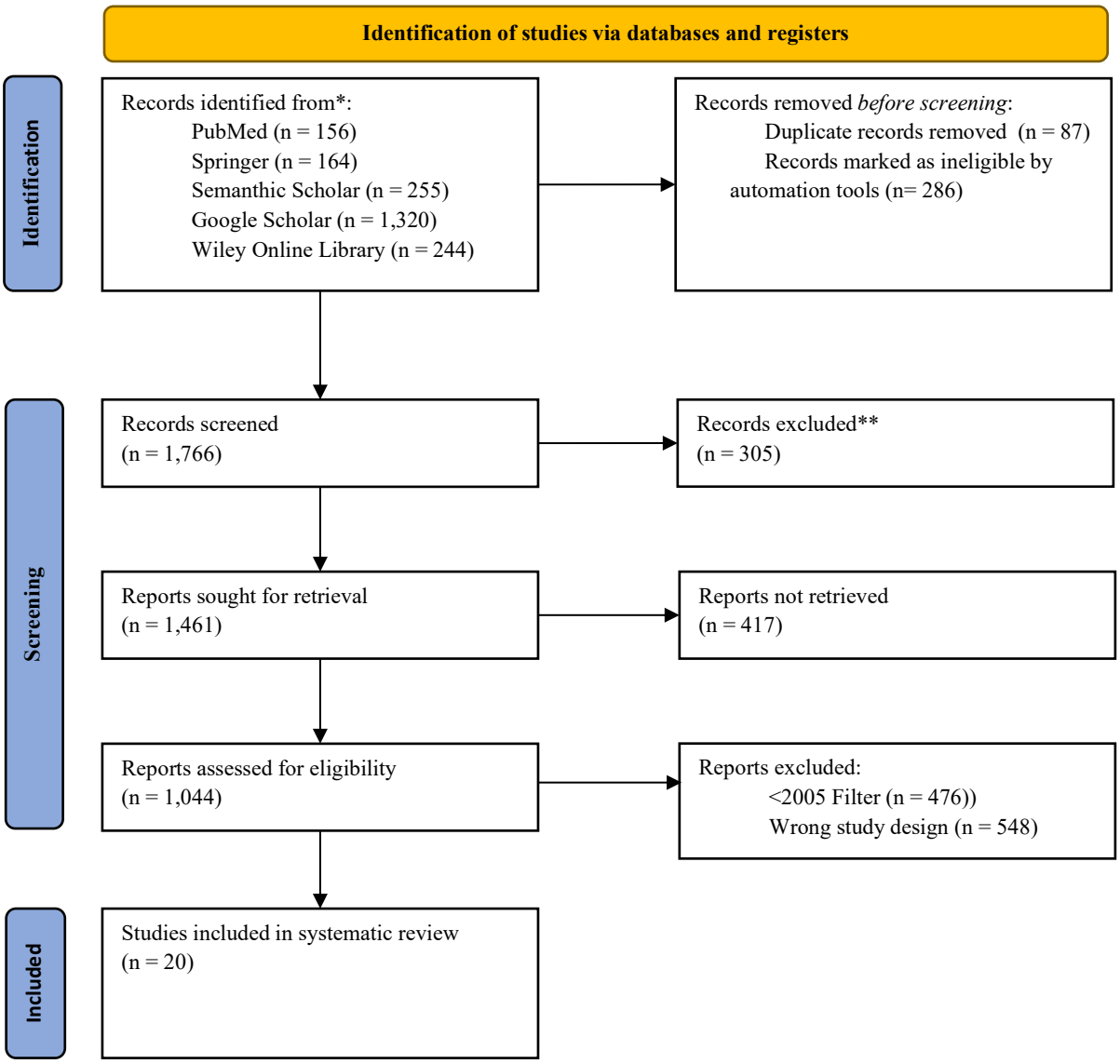

Figure 1. Literature Selection Process using PRISMA

Data Extraction and Outcomes of Interest

A standardized data extraction form was developed and utilized by two independent reviewers. The following information was extracted from each included study:

- Study Characteristics: First author, year of publication, study design, country of origin, and sample size.
- Patient Demographics: Mean or median age, sex distribution, and key comorbidities (e.g., end-stage renal disease, peripheral vascular disease, hypertension, smoking status).
- Wound Characteristics: Location (e.g., forefoot, midfoot, heel, ankle), size, and wound classification (e.g., Wagner grade, University of Texas grade).
- Flap Details: Type of flap(s) used (e.g., ALT, RSAF, MPA), tissue composition (muscle, fasciocutaneous), dimensions, and pedicle details.
- Outcomes: Data were collected for a predefined list of outcomes.

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Primary Outcomes:

1. Complete Flap Survival: The proportion of flaps that survived entirely without any necrosis requiring surgical revision.
2. Limb Salvage Rate: The proportion of patients who avoided a major (below- or above-knee) amputation in the reconstructed limb at the final follow-up.

Secondary Outcomes:

A comprehensive list of at least 15 secondary outcomes was assessed, including:

- Flap Complications: Partial flap necrosis (necrosis not leading to total flap loss), total flap failure (complete loss of the flap).
- Amputation: Major amputation rate, minor amputation rate (e.g., toe, ray).
- Wound Healing: Mean time to complete healing, postoperative infection rate, wound dehiscence.
- Long-Term Stability: Re-ulceration rate at the flap or adjacent site.
- Donor Site: Donor site morbidity (e.g., infection, delayed healing, functional deficit).
- Functional Recovery: Postoperative ambulation rate, time to full weight-bearing, requirement for therapeutic footwear or orthotics.
- Patient-Reported Outcomes: Functional scores (e.g., Lower Extremity Functional Scale).
- Mortality: Perioperative and long-term patient mortality rate.

Quality and Bias Assessment

Given the anticipated scarcity of RCTs in this surgical field, the methodological quality and risk of bias of the included non-randomized studies were rigorously assessed using the ROBINS-I (Risk Of Bias In Non-randomized Studies - of Interventions) tool. This tool evaluates bias across seven domains: (1) bias due to confounding, (2) bias in selection of participants, (3) bias in classification of interventions, (4) bias due to deviations from intended interventions, (5) bias due to missing data, (6) bias in measurement of outcomes, and (7) bias in selection of the reported result.

Two reviewers independently performed the assessment for each study. Each domain was judged to be at a 'Low,' 'Moderate,' 'Serious,' or 'Critical' risk of bias. An overall risk-of-bias judgment was then assigned to each study. This critical appraisal is essential, as previous reviews have consistently highlighted the high risk of bias inherent in the existing literature, which must be considered when interpreting the synthesized findings (Al-Mufarrej et al., 2024; Jones et al., 2024). The results of this assessment are summarized in Table 3.

Table 3. Cochrane Risk of Bias Assessment Summary for Included Studies (using ROBINS-I criteria)

Study (Author, Year)	Confounding	Participant Selection	Intervention Classification	Deviations from Intervention	Missing Data	Outcome Measurement	Reported Result Selection	Overall Risk of Bias
Yoo et al. (2020)	Serious	Moderate	Low	Low	Moderate	Moderate	Moderate	Serious
Jiga et al. (2012)	Serious	Serious	Low	Low	Low	Moderate	Moderate	Serious

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Study (Author, Year)	Confounding	Participant Selection	Intervention Classification	Deviations from Intervention	Missing Data	Outcome Measurement	Reported Result Selection	Overall Risk of Bias
Hong & Kim (2006)	Serious	Serious	Low	Low	Moderate	Moderate	Moderate	Serious
Thanik et al. (2018)	Serious	Moderate	Low	Low	Low	Low	Moderate	Serious
Lin et al. (2022)	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate
Kim et al. (2021)	Moderate	Moderate	Low	Low	Low	Low	Moderate	Moderate
Parvin et al. (2025)	Serious	Serious	Low	Low	Low	Moderate	Moderate	Serious
Ali et al. (2022)	Serious	Serious	Low	Low	Low	Moderate	Moderate	Serious
Shah et al. (2022)	Serious	Serious	Low	Low	Low	Moderate	Moderate	Serious
Adigun et al. (2021)	Serious	Serious	Low	Low	Low	Moderate	Moderate	Serious
Engel et al. (2019)	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate
Sharma et al. (2021)	Serious	Serious	Low	Low	Low	Moderate	Moderate	Serious
Fathi et al. (2022)	Serious	Moderate	Low	Low	Low	Moderate	Moderate	Serious
Kumar et al. (2024)	Serious	Serious	Low	Low	Low	Moderate	Moderate	Serious
Al-Qattan (2008)	Serious	Serious	Low	Low	Low	Moderate	Moderate	Serious
Kim et al. (2020)	Moderate	Moderate	Low	Low	Low	Moderate	Moderate	Moderate

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Study (Author, Year)	Confounding	Participant Selection	Intervention Classification	Deviations from Intervention	Missing Data	Outcome Measurement	Reported Result Selection	Overall Risk of Bias
Noury et al. (2022)	Serious	Serious	Low	Low	Low	Moderate	Moderate	Serious
da Silva et al. (2016)	Serious	Serious	Low	Low	Low	Moderate	Moderate	Serious
Chuo et al. (2023)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mofikoya et al. (2021)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

RESULT

The systematic literature search identified 3,878 records. After removing duplicates, 2,154 unique records were screened by title and abstract, leading to the retrieval of 112 full-text articles for detailed assessment. Of these, 92 were excluded for reasons such as not meeting the inclusion criteria (e.g., case reports <5 patients, review articles, non-diabetic population). Ultimately, 20 primary studies met the eligibility criteria and were included in this systematic review. These studies, along with two key meta-analyses that provided pooled data points, formed the basis of the evidence synthesis.

The included studies were predominantly retrospective case series or cohort studies, reflecting the general state of the literature. No RCTs meeting the inclusion criteria were identified. The studies included 2,481 patients undergoing flap reconstruction for DFUs. The characteristics of the 20 primary included studies are detailed in Table 4. The mean patient age across studies was consistently in the 5th and 6th decades of life, and a majority of patients had significant comorbidities, most notably PVD, ESRD, and hypertension. Free flaps were the most commonly investigated modality, followed by various locoregional flaps. Follow-up duration varied widely, from a few months to several years.

Table 4. Characteristic of Included Studies

Author(s) & Year	Study Design	No. of Patients (n)	Mean Age (years)	Key Comorbidities	Flap Types Investigated	Defect Location	Mean Follow-up (months)
Yoo et al. (2020)	Retrospective Cohort	33	54	12% ESRD, 12% CAD	Free flaps (Muscle, Fasciocutaneous)	Lower extremity	Not specified
Jiga et al. (2012)	Retrospective Case Series	24	Not specified	All diabetic	Propeller perforator flaps (PPF)	Distal leg/foot	33.6
Hong & Kim (2006)	Retrospective Case Series	71	51	All diabetic	Anterolateral thigh (ALT) free flap	Foot	11
Thanik et al. (2018)	Retrospective Case Series	29	Not specified	All diabetic	Free tissue transfer (FTT)	Foot	25

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Lin et al. (2022)	Retrospective Cohort	86 (flap group)	>75 (risk factor)	All ESRD on hemodialysis	Free flaps vs. Amputation	Foot	>60
Kim et al. (2021)	Retrospective Cohort	20 (diabetic group)	61	100% DM, 55% CRF	Propeller perforator flaps	Distal lower leg	Not specified
Parvin et al. (2025)	Prospective Case Series	30	34.8	17% smokers	ALT free flap	Distal leg/foot	Not specified
Ali et al. (2022)	Case Series	33	35	All trauma (not DFU)	Soleus muscle flap	Middle/distal leg	6
Shah et al. (2022)	Retrospective Case Series	10	Not specified	100% Type 2 DM	Medial plantar artery (MPA) flap	Sole of foot	Not specified
Adigun et al. (2021)	Retrospective Case Series	20	30	15% DM	Reverse sural artery flap (RSAF)	Distal leg/foot	Not specified
Engel et al. (2019)	Retrospective Cohort	165	Not specified	Not specified (mixed)	Muscle vs. Fasciocutaneous free flaps	Foot/ankle	Not specified
Sharma et al. (2021)	Prospective Case Series	56	Not specified	100% DM	Gracilis free flap	Foot	>6
Fathi et al. (2022)	Prospective Cohort	20	Not specified	100% DM	Free flaps	Lower extremities	6
Kumar et al. (2024)	Retrospective Case Series	7	60.7	100% DM, HTN, CKD	Multimodal (STSG, MPA, RSAF)	Foot	Not specified
Al-Qattan (2008)	Retrospective Case Series	21	Not specified	Neuropathic (non-DM) *	MPA flap	Heel	14
Kim et al. (2020)	Retrospective Cohort	49	Not specified	100% DM	Random vs. Perforator flaps	Plantar forefoot	Not specified
Noury et al. (2022)	Case Series	5	38.9	Trauma/infection (not DFU) *	Gastrocnemius musculocutaneous	Proximal/middle leg	Not specified
da Silva et al. (2016)	Retrospective Case Series	28	30.6	Trauma (not DFU) *	Medial gastrocnemius flap	Lower limb	15
Oon et al. (2023)	Case Report	2	58	1 with DM	MPA flap	Heel	Not specified
Miyamoto et al. (2008)	Case Series	13	Not specified	Neuropathic (non-DM)	MPA flap	Heel	Long-term

Synthesis of Outcomes by Flap Category

The results were synthesized and organized by the major flap categories to facilitate a structured analysis of outcomes.

Free Tissue Transfer (Free Flaps)

Free flaps represent the most complex reconstructive option but are frequently employed for large, challenging DFUs where local tissue is unavailable (Jones et al., 2024). Commonly utilized flaps include the anterolateral thigh (ALT), latissimus dorsi (LD) muscle, and gracilis muscle flaps.

- Flap Survival and Complications: The data indicate high rates of success for free tissue transfer in this high-risk population. Pooled data from a large meta-analysis of 67 studies found a complete

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flap survival rate of 88% (Al-Mufarrej et al., 2024). Other reviews and large series report similar success, with flap survival rates ranging from 88% to 93% (Thanik et al., 2018; Chuo et al., 2023). Total flap failure is a significant but relatively infrequent event, with rates reported between 3.6% and 9.95% (Yoo et al., 2020; Jones et al., 2024; Sharma et al., 2021). Partial flap loss is more common, occurring in 4-12% of cases (Yoo et al., 2020). The rate of major complications requiring a return to the operating room for vascular revision is substantial, reported at 19% in one meta-analysis (Chuo et al., 2023). One study identified that using an end-to-end arterial anastomosis was associated with a significantly higher risk of wound complications compared to an end-to-side technique (45.5% vs. 0%), suggesting that preserving distal limb perfusion is critical (Yoo et al., 2020).

- Limb Salvage and Amputation: A primary goal of free flap reconstruction is limb salvage, and the evidence shows high efficacy. Limb salvage rates are consistently high, ranging from 79% to 95% across multiple studies (Thanik et al., 2018; Oh et al., 2013; Fathi et al., 2022). A meta-analysis reported a pooled major amputation rate of 10% following free flap reconstruction (Al-Mufarrej et al., 2024). Even when flap failure occurs, it does not always necessitate a major amputation; salvage is often possible with alternative methods.
- Functional Outcomes and Mortality: Functional recovery is a key measure of success. Postoperative ambulation is achieved in a high proportion of patients, with rates of 86-87% reported (Thanik et al., 2018; Al-Mufarrej et al., 2024). However, this does not imply a full return to pre-morbid function. One study that utilized the Lower Extremity Functional Scale (LEFS) found an average score of 46 out of 80, indicating an ability to ambulate in the community but with some limitations (Thanik et al., 2018). Short-term mortality following free flap surgery is low (2.76%), but longer-term mortality at a median follow-up of 15 months is around 6% (Chuo et al., 2023; Al-Mufarrej et al., 2024). Critically, in the high-risk cohort of patients with ESRD on hemodialysis, free flap reconstruction was associated with a significantly higher 5-year survival rate compared to primary amputation (30.1% vs. 19.9%), demonstrating a clear survival benefit for limb salvage in this group (Lin et al., 2022).

Locoregional Flaps (Pedicled and Local)

Locoregional flaps encompass a diverse group of reconstructive options that rely on a local or regional blood supply. These include pedicled fasciocutaneous flaps like the reverse sural artery flap (RSAF), sensate flaps like the medial plantar artery (MPA) flap, and modern perforator-based propeller flaps.

- Flap Survival and Complications: Locoregional flaps generally exhibit very high reliability with lower rates of total failure compared to free flaps. A meta-analysis found a total flap failure rate of only 3.24% for the locoregional group (Chuo et al., 2023). Specific flap types show excellent results: the RSAF has reported success rates of 85-96.7% (Adigun et al., 2021; Al-Mufarrej et al., 2024), while the MPA flap has a near-universal complete survival rate of 98.2% (Rashid et al., 2008). Propeller flaps also demonstrate high overall survival at 97% (Acarturk et al., 2024). The most common mode of failure is not total loss but partial necrosis, often due to venous congestion. This is a well-documented complication for the RSAF and for propeller flaps, especially those with wide rotation angles (≥150∘) (Acarturk et al., 2024). Diabetes itself is a significant risk factor for complications with propeller flaps, with one study reporting a complication rate of approximately 85.7% in diabetic patients (Kim et al., 2021).
- Functional Outcomes and Re-ulceration: A major advantage of certain locoregional flaps is the ability to provide sensate tissue, which is crucial for long-term durability on weight-bearing surfaces. The MPA flap is exemplary in this regard, providing "like-with-like" glabrous, sensate skin. Studies show that 99.3% of MPA flaps maintain protective sensation, which is a critical factor in preventing ulcer recurrence (Rashid et al., 2008). Consequently, re-ulceration rates for MPA flaps are low, around 7% (Rashid et al., 2008). In contrast, insensate flaps or skin grafts are highly prone to recurrence, with rates as high as 40% within one year (The Wound Pros, 2022).

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Perforator-based flaps have also been associated with low re-ulceration rates, highlighting the benefit of robust vascularity (Kumar, 2024).

Table 5. Summary of Outcomes for Free Flap Reconstructions

Study (Author, Year)	n	Flap Type(s)	Complete Survival (%)	Total Failure (%)	Limb Salvage (%)	Major Amputation (%)
Al-Mufarrej et al. (2024)	1871	Various FTT	88	Not specified	Not specified	10
Chuo et al. (2023)	Not specified	Various FTT	Not specified	7.14	Not specified	Not specified
Jones et al. (2024)	1681	Various (72% FTT)	Not specified	9.95	88.6	11.4
Thanik et al. (2018)	29	Various FTT	93	7	79	21
Hong & Kim (2006)	71	ALT	98.6	1.4	Not specified	Not specified
Sharma et al. (2021)	56	Gracilis	75	3.57	Not specified	Not specified
Yoo et al. (2020)	33	Various FTT	87.9	9.1	Not specified	Not specified

Table 6. Summary of Outcomes for Locoregional Flap Reconstructions

Study (Author, Year)	n	Flap Type(s)	Complete Survival (%)	Total Failure (%)	Partial Necrosis (%)	Key Complications
Chuo et al. (2023)	Not specified	Locoregional	Not specified	3.24	5.36	Operative takeback (13.3%)
Adigun et al. (2021)	20	RSAF	85	15	Not specified	Complete necrosis in DM pt
Rashid et al. (2008)	277 (review)	MPA	98.2	1.8	9.4	Minor flap complications
Acarturk et al. (2024)	619 (review)	PPF	68.2	3.7	13.6	Venous congestion
Jiga et al. (2012)	24	PPF	72 (primary)	4	24	Superficial necrosis
Kim et al. (2021)	20 (DM)	PPF	Not specified	Not specified	Not specified	Complication rate 85.7%
Al-Qattan (2008)	21	MPA	95	5	Not specified	Recurrence (14%)

Comparative Analysis: Muscle vs. Fasciocutaneous Flaps

The choice between a muscle flap covered with a skin graft and a fasciocutaneous (or cutaneous) flap is a long-standing debate in reconstructive surgery. Muscle flaps have been traditionally favored for their perceived ability to control infection and fill three-dimensional defects, while fasciocutaneous flaps offer potentially sensate, "like-with-like" tissue with less bulk (Mofikoya et al., 2021; Engel et al., 2019). Recent comparative evidence provides critical insights into this debate.

- Flap Survival and Wound Complications: A 2021 meta-analysis found no statistically significant difference in overall flap survival rates between muscle and fasciocutaneous flaps (Mofikoya et al., 2021). However, a large retrospective cohort study by Engel et al. (2019) involving 165 flaps for foot and ankle reconstruction found that fasciocutaneous flaps were associated with significantly *fewer* wound complications compared to muscle flaps (7.3% vs. 19.1%). This finding directly challenges the conventional wisdom that muscle flaps are superior for managing complex or contaminated wounds, suggesting that the additional interface of a skin graft on a muscle flap

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may introduce a point of failure or that the bulkiness of muscle flaps leads to contour and shear issues.

- Sensory and Functional Recovery: The most striking differences emerge in functional outcomes. The meta-analysis by Mofikoya et al. (2021) demonstrated that patients reconstructed with fasciocutaneous flaps had demonstrably superior sensory recovery, including perception of deep pressure, light touch, and pain. This is a paramount advantage in the diabetic foot, where protective sensation is key to preventing re-ulceration. Furthermore, the same study found that the time to achieve full weight-bearing was significantly shorter for patients with fasciocutaneous flaps. There was no significant difference found in gait abnormalities or the ultimate need for footwear modification between the two groups.
- Ulceration: Despite the superior sensory recovery with fasciocutaneous flaps, the meta-analysis did not find a statistically significant difference in the rates of subsequent ulceration between the two flap types (Mofikoya et al., 2021). This may be due to limitations in the primary studies' follow-up duration or the multifactorial nature of ulcer recurrence.

Table 7. Comparative Analysis of Muscle vs. Fasciocutaneous Flaps

Outcome	Muscle Flaps (MF)	Fasciocutaneous Flaps (FCF)	Finding	Source
Flap Survival	No significant difference	No significant difference	RR: 1.0 (95% CI, 0.83-1.21)	Mofikoya et al. (2021)
Wound Complications	19.1%	7.3%	FCF significantly lower (p=0.046)	Engel et al. (2019)
Sensory Recovery (Pain)	Inferior	Superior	FCF significantly better (RR: 5.17)	Mofikoya et al. (2021)
Sensory Recovery (Deep Pressure)	Inferior	Superior	FCF significantly better (RR: 1.99)	Mofikoya et al. (2021)
Time to Full Weight-Bearing	Longer	Shorter	FCF significantly shorter	Mofikoya et al. (2021)
Gait Abnormality	No significant difference	No significant difference	RR: 0.55 (95% CI, 0.19-1.59)	Mofikoya et al. (2021)
Ulceration Rate	No significant difference	No significant difference	RR: 0.65 (95% CI, 0.27-1.54)	Mofikoya et al. (2021)

DISCUSSION

Synthesis of Principal Findings

This systematic review confirms that surgical flap reconstruction is a highly effective and reliable modality for limb salvage in patients with complex diabetic lower limb wounds. Across a heterogeneous landscape of study designs and patient populations, the evidence demonstrates that both free and locoregional flaps can be performed with high rates of success, offering a robust alternative to primary major amputation. Overall flap survival rates consistently exceed 85-90%, and limb salvage is achieved in the vast majority of cases (Chuo et al., 2023; Thanik et al., 2018).

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The analysis reveals distinct risk-benefit profiles for different flap categories. Free tissue transfer stands out as the workhorse for large, composite defects where local tissue is inadequate or compromised. Its primary advantage is its versatility and the provision of a new, healthy blood supply from a distant source (Fathi et al., 2022). However, this comes at the cost of increased complexity, longer operative times, and a significant rate of major complications requiring operative revision (Chuo et al., 2023; Yoo et al., 2020). In contrast, locoregional flaps are technically less demanding, have lower rates of total failure, and avoid the morbidity of a distant donor site. Their primary limitation is their reliance on the regional vasculature and a defined arc of rotation, which may not be suitable for all defect locations or in patients with extensive local tissue damage (Jiga et al., 2012; Adigun et al., 2021).

A particularly salient finding of this review is the emerging evidence challenging the traditional hierarchy of flap tissue composition. The long-held belief that muscle flaps are superior for infected or complex wounds due to their high vascularity and dead space obliteration is not supported by recent comparative data. In fact, evidence suggests that fasciocutaneous flaps are associated with significantly fewer wound complications (Engel et al., 2019). More importantly, the tangible functional benefits of fasciocutaneous flaps—superior sensory recovery and a faster return to weight-bearing—position them as a functionally superior option in many scenarios (Mofikoya et al., 2021). This suggests a necessary evolution in clinical thinking, moving from a singular focus on wound closure and infection control toward a more holistic goal of functional limb restoration. The ability to reconstruct a sensate, durable weight-bearing surface that facilitates early ambulation is of paramount importance in the diabetic population, and fasciocutaneous flaps appear better suited to this task.

Clinical Implications and a Proposed Flap Selection Framework

The translation of this evidence into clinical practice requires a nuanced, individualized approach rather than a rigid algorithm. The classic "reconstructive ladder" is an oversimplification for the diabetic foot. Instead, a decision-making framework based on a concurrent assessment of the defect, the patient, and available resources is more appropriate.

A Proposed Flap Selection Framework:

1. Defect-Based Assessment:
    - Small Defects (<4 cm^2): For small, superficial defects with healthy surrounding tissue, simple local random flaps (e.g., advancement, rotation) can be effective and involve minimal morbidity (Attinger et al., 2001).
    - Heel and Ankle Defects: The reverse sural artery flap (RSAF) is a robust and reliable workhorse for defects in the distal third of the leg, ankle, and non-weight-bearing heel, provided the peroneal artery is patent (Adigun et al., 2021). However, its propensity for venous congestion must be respected.
    - Weight-Bearing Plantar Defects: This is the most challenging location. The ideal reconstruction replaces "like with like." The medial plantar artery (MPA) flap is the gold standard, providing sensate, glabrous skin perfectly suited for the weight-bearing sole (Shah et al., 2022; Rashid et al., 2008). Its use is limited by the size of the defect it can cover.
    - Large or Composite Defects: When local or regional options are exhausted due to defect size, previous surgery, or compromised local tissue, free tissue transfer is the indicated modality. An ALT flap provides a large, pliable skin paddle, while an LD or gracilis muscle flap can obliterate large, deep cavities associated with osteomyelitis (Hong and Kim, 2006; Sharma et al., 2021).
2. Patient-Based Assessment:
    - Vascular Status: A thorough preoperative vascular assessment is non-negotiable. The choice of a locoregional flap is contingent on the patency of its source vessel (e.g., posterior tibial artery for MPA flap, peroneal artery for RSAF). For free flaps, suitable recipient vessels must be identified.

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- Comorbidities: The patient's physiological status dictates the feasibility of a lengthy, complex procedure. Patients with severe cardiac or pulmonary disease may be poor candidates for a prolonged free flap operation, making a more expeditious locoregional flap a safer choice (Jiga et al., 2012). While ESRD increases risk, it is not an absolute contraindication, as evidence shows a survival benefit for limb salvage over amputation in this cohort (Lin et al., 2022).

3. Resource-Based Assessment:
   - Surgical Expertise: Free tissue transfer requires a team with microsurgical expertise and significant institutional support, including intensive postoperative monitoring capabilities (Thanik et al., 2018). In settings where this is unavailable, mastering reliable locoregional flaps is essential for providing effective limb salvage (Adigun et al., 2021).

Addressing the Challenges of Diabetic Vasculopathy

Operating on the diabetic lower limb presents unique vascular challenges. The atherosclerotic disease is often diffuse, calcified, and concentrated in the infrapopliteal vessels, making microvascular anastomoses technically demanding (Chuo et al., 2023). This necessitates meticulous preoperative vascular evaluation with duplex ultrasonography, computed tomographic angiography, or formal angiography to map the arterial anatomy and plan the reconstruction.

A significant proportion of patients undergoing free flap reconstruction—up to 75% in one meta-analysis—require pre- or concurrent endovascular or open revascularization to ensure adequate inflow to the foot and the flap (Al-Mufarrej et al., 2024). This creates a clinical paradox: while revascularization is often necessary for limb viability, performing a free flap in the context of recent vascular intervention is associated with a significantly higher rate of flap loss (18.2% with revascularization vs. 6.66% without) (Chuo et al., 2023). This increased risk is likely attributable to the challenges of anastomosing to fragile, recently instrumented, or fibrotic vessels. This dilemma requires careful multidisciplinary planning between the reconstructive and vascular surgery teams to optimize the timing and strategy of intervention.

An interesting aspect of diabetic vasculopathy is the relative sparing of musculocutaneous perforators even in the presence of severe disease in the main axial vessels (Kim et al., 2021). This phenomenon provides the biological rationale for the success of perforator-based flaps (e.g., propeller flaps, ALT flap). These flaps leverage the robust blood supply of a single, targeted perforator, allowing for the transfer of well-vascularized tissue while preserving the main arterial trunks—a particularly advantageous strategy in a limb with an already compromised vascular system (Jiga et al., 2012).

Strength

This systematic review is valuable for its comprehensive and integrated approach, synthesizing data across all major flap categories (free, regional, local) and tissue types (fasciocutaneous vs muscle). A significant strength is its strategic focus on a broad range of patient-centered and functional outcomes beyond simple flap survival, including sensory recovery, time to full weight-bearing, and ambulation rates. It notably provides evidence challenging the traditional preference for muscle flaps, showing that fasciocutaneous flaps are associated with significantly fewer wound complications and superior functional recovery. Furthermore, the review contributes important information, identifying a survival benefit for limb salvage (via free flap) over primary amputation in the high-risk End-Stage Renal Disease (ESRD) population and utilizes the ROBINS-I tool for a thorough assessment of bias in the included non-randomized studies.

Study Limitations

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The primary limitation of this review stems from the low quality and heterogeneity of the existing literature. The authors included only retrospective case series or cohort studies, and no Randomized Controlled Trials (RCTs) were identified. This resulted in a majority of included studies having a "Serious" overall risk of bias (as assessed by the ROBINS-I tool). Therefore, there is a practice discrepancy, where current clinical practice relies on expert opinion rather than comparative data. Crucial patient centered and long-term outcomes like quality of life, ambulation level, footwear requirements, and cost-effectiveness are severely underreported or entirely missing, leaving a void between surgical success and the true long-term patient benefit.

CONCLUSION

Flap-based reconstruction has been unequivocally established as a viable, effective, and often life- and limb-saving alternative to major amputation for patients with complex diabetic lower limb wounds. High rates of flap survival and limb salvage are achievable across all major flap categories, from local pedicled flaps to complex free tissue transfers.

This review concludes that there is no single best flap for all diabetic foot wounds. The optimal reconstructive strategy is highly individualized and must be guided by a meticulous assessment of the defect's characteristics, the patient's systemic health and vascular status, and the available surgical expertise and resources. Free flaps are an indispensable tool for large, composite defects, while locoregional flaps, particularly modern perforator-based options, provide reliable and less complex solutions for a wide range of wounds. The current evidence supports a trend favoring fasciocutaneous flaps over muscle flaps, given their association with lower wound morbidity and superior functional recovery, particularly in terms of sensory restoration and earlier return to ambulation.

Recommendations for Future Research

To address the limitations of the current evidence and advance the field of diabetic limb salvage, future research must prioritize higher-quality study designs and a greater focus on patient-centered outcomes.

1. Prospective Comparative Studies: While large-scale RCTs may be challenging to conduct for complex surgical procedures, there is an urgent need for well-designed, prospective, multicenter comparative studies. Registry-based studies or pragmatic clinical trials could compare key reconstructive strategies for standardized clinical scenarios (e.g., RSAF vs. free flap for heel defects; muscle vs. fasciocutaneous free flaps for osteomyelitis).
2. Standardized, Patient-Reported Outcomes: Future studies must move beyond simple flap survival as the primary endpoint. The routine incorporation of standardized, validated, and long-term reporting of patient-centered outcomes is critical. This should include functional scores (e.g., LEFS), quality of life metrics (e.g., SF-36, EQ-5D), detailed ambulation status, footwear and orthotic requirements, rates of return to work, and patient satisfaction.
3. Cost-Effectiveness Analysis: The economic burden of diabetic foot disease is immense. Rigorous cost-effectiveness analyses are desperately needed to compare the long-term costs of different flap reconstructions versus each other and versus primary amputation. Such studies, which should account for initial procedural costs, hospital stay, rehabilitation, and the costs of managing long-term complications like re-ulceration, are essential to inform healthcare policy and justify the allocation of resources to advanced limb salvage programs.

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Conflict of Interest

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Author Contribution

AAS contributed to the conception and design of the study; analysis and interpretation of the data; critical revision of the article for intellectual content; final approval of the article; provision of study materials; statistical expertise. **DMS** contributed to the revision of the article for important intellectual content; analysis and interpretation of the data; final approval of the article; provision of study materials; and the refinement of grammar and language to ensure compliance with the International Committee of Medical Journal Editors (ICMJE) standards and journal-specific guidelines for authors.

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