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REVIEW ARTICLE

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One or two venous pedicles by anastomoses for free flaps in reconstruction of the lower extremity: A systematic review and meta-analysis

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Abstract

Background: Microsurgical free tissue transfers are a mainstay of lower extremity reconstruction. Despite being a reliable source of soft tissue, complications do arise. Venous congestion is among the most common causes of flap failure in lower extremity reconstruction, an issue that is attributed to venous stasis and impaired venous return in this region. There remains significant debate whether dual venous drainage improves outcomes. The aim of this study was thus to compare one versus two venous anastomoses in lower limb free flap reconstruction.

Methods: A systematic review of Medline, EMBASE, EBSCO CINAHL, SCOPUS, Proquest Dissertations and Theses Global, Cochrane Library, and PROSPERO from inception to May 20, 2020, was conducted. Two independent reviewers screened titles and extracted data. Our primary outcome was total free flap necrosis. Secondary outcomes were partial flap necrosis, minor complications, flap reoperation, venous thrombosis, and amputation. Methodological quality was assessed using the MINORS criteria and level of evidence.

Results: Three-hundred and fourteen unique titles were identified. All studies were level VI evidence and had a mean MINORS score of 16.1/24. Seven studies (comprising 1499 patients, 910 single venous anastomoses, and 579 double venous anastomoses) met criteria for inclusion. The mean (SD) patient age was 46.5 (7.1) years. Double venous anastomoses did not reduce the rate of minor complications, flap takeback, venous thrombosis, total flap necrosis, or partial flap necrosis when compared to a single vein (all $p > .05$).

Conclusion: In microvascular lower extremity reconstruction, two venous anastomoses did not reduce the rate of minor or major complications.

1 | INTRODUCTION

Microvascular free tissue transfers in lower limb reconstruction, now considered standard of care in many cases (Abdelfattah et al., 2019), are fraught with challenges (Stranix et al., 2016; Lorenzo et al., 2011). Compromised vascularity, a tight and thin envelope, and continuous weight-bearing forces, all contribute to the complexity of reconstruction in the lower extremity (Abdelfattah et al., 2019). The most common cause of flap failure remains venous congestion (Matthews et al., 2018); a problem that is exponentiated in the lower limb due to its position of dependence (Stranix et al., 2018). One proposed method to reduce venous congestion is the addition of a secondary

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vein (Hallock, 2000; Lorenzo et al., 2011; Matthews et al., 2018; Stranix et al., 2016; 2018). Secondary venous anastomosis is thought to decrease venous resistance and therefore maintain venous flow at lower pressure gradients (Mattos et al., 2018; Stranix et al., 2016). Additionally, a secondary anastomosis provides alternative drainage in the case when the primary outflow tract is obstructed (Stranix et al., 2016).

Though the efficacy of single versus dual venous anastomoses has been well studied in head and neck reconstruction (Chaput et al., 2016), results in lower extremity reconstruction remain mixed. Select studies have demonstrated a lower rate of major complications and flap failure in double venous anastomoses compared to a single vein (Stranix et al., 2016; 2018). In contrast, Dornseifer et al. (2017) demonstrated that by increasing the number of outflow tracts, the overall velocity of venous flow decreases, thereby increasing the risk of thrombosis. This theory is supported by literature demonstrating a higher operative re-exploration rate among free flaps with two venous anastomoses (Khan et al., 2020; Lorenzo et al., 2011).

There remains significant debate surrounding the benefit of secondary venous anastomosis in free tissue transfer. The objective of this article was to systematically assess the efficacy of one versus two venous anastomoses in free flap reconstruction of the lower limb.

2 | MATERIALS AND METHODS

This systematic review and meta-analysis was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was registered a priori on PROSPERO (CRD42020197379).

2.1 | Eligibility criteria

Peer-reviewed English language studies describing adult patients (>18 years of age) undergoing lower extremity reconstruction with microvascular free tissue transfers (single or double venous anastomoses) were included. All indications for reconstruction were examined. In-vitro studies, animal studies, letters to the editor, expert opinion, and case reports, were excluded. Studies not reporting rates of flap failure were also excluded. Only studies of level II-VII evidence, according to Jovell and Narvarro-Rubio were included (Jovell & Navarro-Rubio, 1995).

2.2 | Search strategy

A search was executed by a Health Services Librarian (SC) on the following databases: OVID Medline, Ovid EMBASE, EBSCO CINAHL, SCOPUS, Proquest Dissertations and Theses Global, Cochrane Library, and PROSPERO using controlled vocabulary (e.g., MeSH, Emtree, etc.) and keywords representing the concepts "anastomoses" and "single vein" and "double vein" and "free flaps". All searches were conducted in May 2020 and adjusted appropriately for different databases. No other limits were applied. Results were exported to RefWorks citation management system and exported to the COVIDENCE Systematic Review Program (Figure 1).

2.3 | Study selection

Two authors (S.D. and A.M.) independently screened all abstracts for inclusion and exclusion criteria. Studies felt to be relevant were then screened further in full-text review by the same two authors, and included based on consensus. If necessary, a third author (R.G.) was available for arbitration. Any disagreement was resolved through discussion and agreement between the reviewers.

2.4 | Data extraction

Data extraction was completed by two independent authors (S.D. and A.M.), and was recorded on an a priori developed Excel spreadsheet (Microsoft Corp.). The following variables were extracted: publication date; country of origin; sample size; sex; mean age; mean body mass index (BMI); smoking status; coagulopathy; mean operative time; flap type; mean flap size; venous system used for anastomosis; type of venous anastomosis; vein caliber; use of interposition vein grafts or arteriovenous-loops; location of arterial anastomosis; use of perioperative anticoagulation therapy; total flap necrosis; partial flap necrosis; flap takeback/reoperation; venous thrombosis or congestion; arterial thrombosis; minor complications (wound infection, dehiscence, and minor flap necrosis); reconstructive failure (amputation proximal to reconstructive site); and death.

For one of the included studies (Hallock, 2000), the number of single versus double venous anastomoses for lower extremity flaps had to be extrapolated from the figures provided as they were not reported. The study reported this data for the upper extremity flaps (not the lower extremity ones), as well as their total number of free flaps and the total number of anastomoses. This allowed us to calculate how many single and double anastomoses there were in total. The total number of flaps with double venous anastomoses was then subtracted from the number of upper extremity double venous flaps reported to yield the number of lower extremity flaps with two veins.

2.5 | Outcomes

The primary outcome of our study was total flap necrosis. Secondary outcomes were partial flap necrosis, flap takeback/ reoperation, venous thrombosis or congestion, arterial thrombosis, minor complications, amputation proximal to reconstructive site, and death. The MINORS criteria, a validated 12-item tool, were used to assess the methodological quality of included studies. Comparative studies are scored out of 24, and non-controlled studies out of 16. A score of ≥10/16 and ≥ 16/24 for non-controlled and controlled studies,

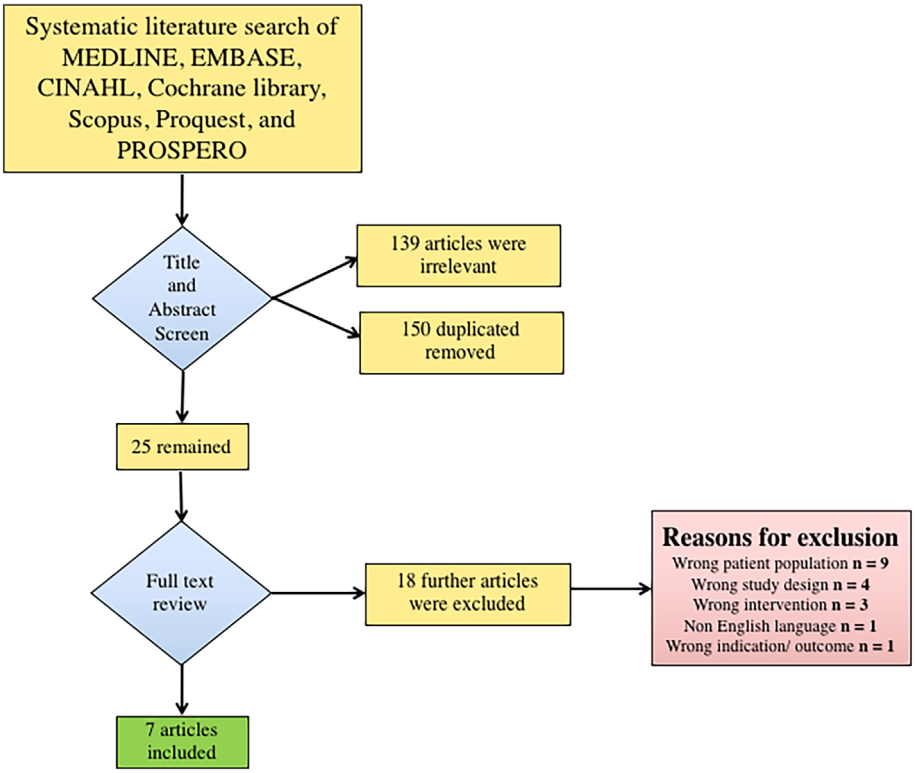

FIGURE 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow scheme

respectively, is considered "high quality". All studies were also classified based on level of evidence (Jovell & Navarro-Rubio, 1995). Heterogeneity was assessed for each included study. Study population, setting, intervention, and outcome were considered.

2.6 | Statistical analysis

Pooled summary statistics were calculated across studies when possible using StatsDirect Version 3 (StatsDirect Ltd, England UK). Pooled summary statistics were generated for all variables. Categorical factors were assessed using frequencies and percentages. Pooled outcomes were computed using Stuart-Ord transformation and random effects meta-analysis of proportions. Categorical factors were reported using frequencies and percentages.

Outcomes with greater than two data points were eligible for meta-analysis. Meta-analysis was conducted using a random effects model in Review Manager (Version 5.3; Nordic Cochrane Center, Cochrane Collaboration). Statistical significance was set at two-sided $p < .05$.

3 | RESULTS

3.1 | Literature search

Our literature search yielded 314 potentially eligible studies. One-hundred and fifty were duplicates and were therefore excluded. A total of seven studies met our inclusion criteria (Table 1; Figure 1).

3.2 | Study characteristics

Studies were published between 2000 and 2020 in Germany, Pakistan, Taiwan and the United States of America (Table 1). The primary objective of 86% ($n = 6/7$) of the included studies was the direct comparison of one versus two venous anastomoses. Reconstruction of traumatic injuries was described in two studies (29%) (Stranix et al., 2016; 2018). Four studies (57%) described mixed etiology wounds (Heidekrueger et al., 2016; Khan et al., 2020; Lorenzo et al., 2011; Mattos et al., 2018), and a single study (14%) did not specify the type of lower limb injury/wound (Hallock, 2000).

A total of 910 single venous anastomoses and 579 double venous anastomoses were included. Of the six studies reporting sex (Heidekrueger et al., 2016; Khan et al., 2020; Lorenzo et al., 2011; Mattos et al., 2018; Stranix et al., 2016; 2018), five reported higher proportions of males (Khan et al., 2020; Lorenzo et al., 2011; Mattos et al., 2018; Stranix et al., 2016; 2018). The mean age of the participants in the studies ranged from 38 to 54.5 years. Only two studies (29%) reported flap type, of which 58.5% were muscle flaps and 41.5% were fasciocutaneous flaps (Table 1). The majority of studies described hand-sewn venous anastomoses ($n = 3/7$, 43%), while a single study employed a coupler device. The remainder did not identify an anastomosis technique.

Two studies discussed recipient vein caliber (Mattos et al., 2018; Stranix et al., 2018), while the remainder of studies did not comment on this. The majority of studies also did not describe where they identified their venous target. The one study that did describe this identified their venous target "outside the zone of injury" (Lorenzo et al., 2011). The use of interposition vein grafting was utilized by a

TABLE 1 Study characteristics

Study	Country of origin	Sample size	Sex, male (%)	Mean age (SD)	Mean BMI (SD)	Smoking status (%)	Coagulopathy (%)	Mean operative time, Min (SD)	Flap type	Mean flap size, cm^3 (SD)	Vein size, mm (SD)	Venous system	Venous anastomosis
Hallock 2000	USA	83	–	–	–	–	–	–	–	–	–	77% deep; 23% SF	–
Lorenzo et al (2011)	Taiwan	362	256 (71)	–	–	119 (33%)	–	–	–	–	–	80% deep; 12% SF; 8% hybrid	–
Heidekrueger et al. (2016)	Germany	386	168 (44)	51.96[a]; 53.39[b]	25.66[a]; 26.25[b]	66 (17%)	–	301[a]; 324[b]	52% FC; 48% Muscle	–	–	–	HS
Stranix et al. (2016)	USA	219	172 (79)	–	–	–	–	–	20% FC; 80% Muscle	–	–	1 vein: 84.4% deep; 16% SF. 2 veins: 81% deep; 2% SF; 17% hybrid	87.5% HS; 12.5% Coupler
Stranix et al. (2017)	USA	361	272 (75)	38 (17)[a]; 36 (14)[b]	–	–	–	–	–	299 (254)[a]; 216 (124)[b]	76%, <1 mm mismatch	1 vein: 89% deep; 6 SF; 4% hybrid. 2 veins: 83% deep; 16% hybrid	80% HS; 20% Coupler
Mattos et al. (2018)	USA	50	39 (78)	50.3 (13.4)[a]; 54.4 (13.8)[b]	27.8 (6.1)[a]; 29.5 (5.9)[b]	18 (26%)	–	451.7 (112.1)[a]; 426.5 (106.8)[b]	–	176.1 (79.6)[a]; 156.0 (58.6)[b]	1 vein, 2.7 (0.6); 2 veins, 2.3 (0.6)	–	Coupler
Khan et al. (2020)	Pakistan	38	–	44.14 (16.235)	–	–	–	–	–	–	–	–	–

[a]Single vein.
[b]Two veins.
Abbreviations: FC, fasciocutaneous; HS, Handsewn; Hybrid, deep and superficial venous systems; SF, superficial.

TABLE 2 Study outcomes and pooled analysis of variables

Study	Number of veins	Sample size	Total flap necrosis *n* (%)	Partial flap necrosis *n* (%)	Reconstructive failure (%)	Death (%)	Flap takeback (%)	Venous thrombosis/ insufficiency (%)	Arterial thrombosis (%)	Minor complications (%)
Hallock (2000)	1	52	3 (5.8)	–	–	–	4 (7.7)	3 (5.8)	–	–
	2	31	0	–	–	–	0	0	–	–
Lorenzo et al. (2011)	1	237	0	12 (5.1)	–	–	–	18 (7.6)	–	–
	2	125	4 (3.2)	2 (1.6)	–	–	–	8 (6.4)	–	
Heidekrueger et al. (2016)	1	157	9 (5.7)	0	–	–	31 (19.7)	18 (11.5)	5 (3.2)	3 (1.9)
	2	229	20 (8.7)	4 (1.7)	–	–	37 (16.2)	19 (8.3)	6 (2.6)	5 (2.2)
Stranix et al. (2016)	1	159	9 (5.7)	47 (29.6)	–	–	–	–	–	81 (50.9)
	2	60	2 (3.3)	7 (11.7)	–	–	–	–	–	17 (28.3)
Stranix et al. (2017)	1	273	23 (8.4)	36 (13.2)	–	–	36 (13.2)	–	–	–
	2	88	8 (9.1)	3 (3.4)	–	–	9 (10.2)	–	–	–
Mattos et al. (2018)	1	21	3 (14.3)	0	1 (4.8)	0	3 (14.3)	3 (14.3)	1 (4.8)	7 (33.3)
	2	29	0	3 (10.3)	1 (3.4)	0	5 (17.2)	1 (3.4)	0	9 (31.0)
Khan et al. (2020)	1	11	1 (9.1)	–	–	–	1 (9.1)	–	–	–
	2	27	3 (11.1)	–	–	–	6 (22.2)	–	–	–
Pooled proportion (95% CI)	1	910	0.059 (0.02–0.11)	0.07 (0.01–0.19)	–	–	0.15 (0.11–0.20)	0.09 (0.07–0.12)	0.04 (0.02–0.07)	0.25 (0.002–0.71)
	2	579	0.05 (0.03–0.09)	0.05 (0.02–0.09)	–	–	0.14 (0.10–0.19)	0.05 (0.02–0.09)	0.03 (0.01–0.05)	0.18 (0.01–0.50)

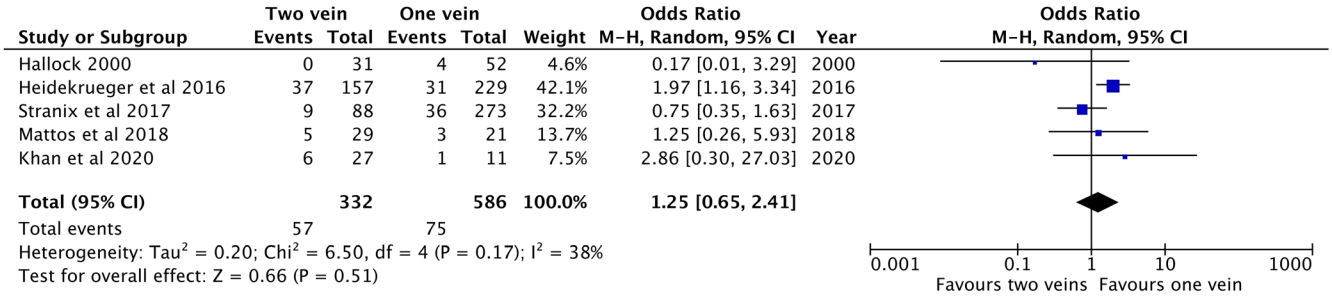

FIGURE 2 Meta-analysis results comparing rates of flap takeback/reoperation between single and double venous anastomoses

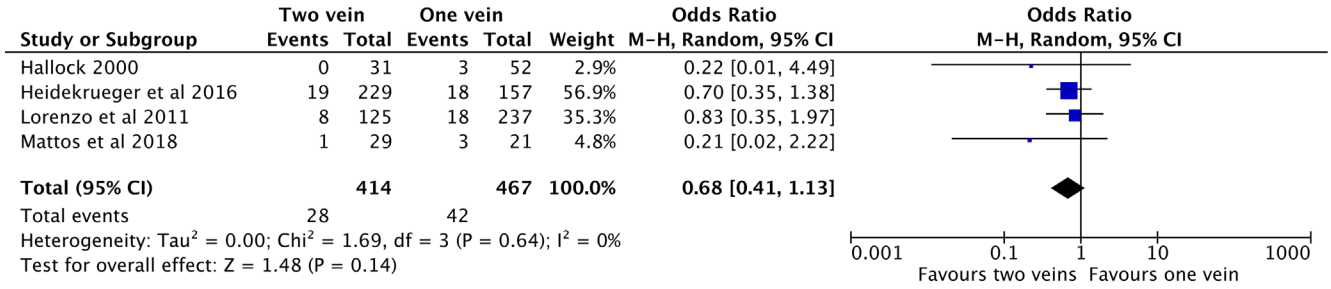

FIGURE 3 Meta-analysis results comparing rates of venous thrombosis between single and double venous anastomoses

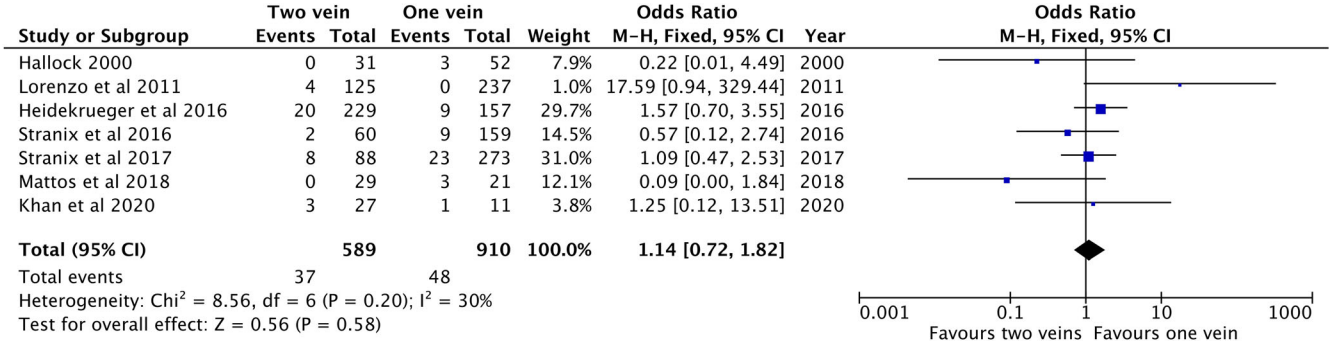

FIGURE 4 Meta-analysis results comparing rates of total flap necrosis between single and double venous anastomoses

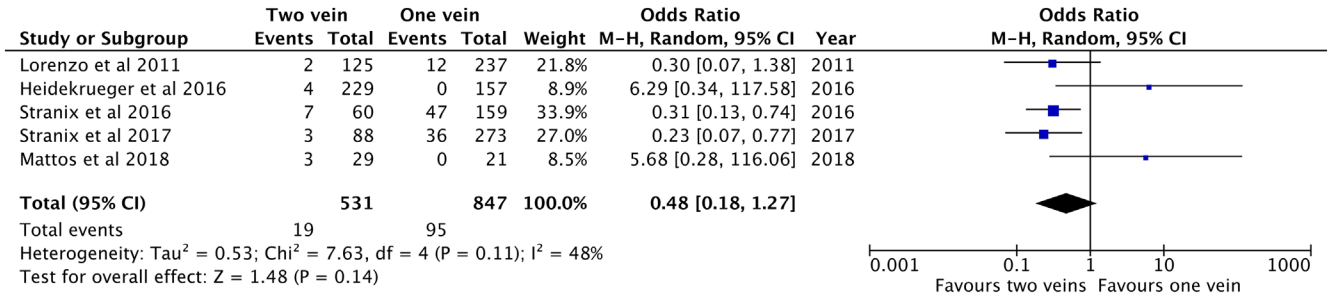

FIGURE 5 Meta-analysis results comparing rates of partial flap necrosis between single and double venous anastomoses

single study in 3.6% of their flaps (Stranix et al., 2018). No description of arterial–venous loops was encountered.

Four studies described the venous system used (Hallock, 2000; Lorenzo et al., 2011; Stranix et al., 2016; 2018). Hallock and Lorenzo et al. primarily employed venous anastomoses to the deep venous system in 77% and 80% of cases, respectively (Hallock, 2000; Lorenzo et al., 2011). Lorenzo et al. described a higher rate of venous insufficiency when the superficial system was used (Lorenzo et al., 2011).

No difference in outcomes between superficial and deep systems was described by Hallock (Hallock, 2000). Stranix et al. describe the use of the deep venous system for anastomoses in 84% of cases and the superficial system in 16% in the case of single vein anastomosis (Stranix et al., 2016). Flaps with two veins used the deep, superficial, and a hybrid approach in 81%, 2%, and 17% of cases, respectively (Stranix et al., 2016). In flaps with a single venous anastomosis, Stranix et al. used the deep venous system in 89% of cases, and if two veins were used, 83% of the venous anastomoses were to the deep system (Stranix et al., 2018). Outcomes comparing single vein anastomoses to deep versus superficial systems were not described in these studies.

No studies included in this analysis reported any deaths, and only one study (14%) reported complications resulting in two amputations (Table 2). Among all seven studies, the proportion of total flap necrosis among dual venous anastomoses was 5.0% (95% CI: 0.03–0.09) whereas single venous anastomoses was 5.9% (95% CI: 0.02–0.11). Partial flap necrosis was only reported by five (71%) studies and proportions were 5.0% (95% CI: 0.02–0.09) for dual venous anastomoses and 7.0% (95% CI: 0.01–0.19) for single venous anastomoses. Three studies (43%) reported minor complications. Pooled proportions of minor complications were 18.0% (95% CI: 0.01–0.50) for dual venous anastomoses and 25% (95% CI: 0.002–0.71) for single vein anastomoses.

3.3 | One versus two venous anastomoses

A random effects model demonstrated no significant reduction in the rate of minor complications with the use of a second venous anastomosis (Pooled OR: 0.59; 95% CI = 0.29–1.19; $p > .05$). Similarly, of the five studies reporting the rate of flap takeback/reoperation (Table 2), no significant difference was seen when using two versus one venous anastomoses (Pooled OR: 1.25; 95% CI = 0.65–2.41; $p > .05$; Figure 2). There were four studies that reported the rates of venous thrombosis (Table 2). Again, a random effects model demonstrated no significant reduction in the rate of venous thrombosis with the use of two venous anastomoses compared to a single venous anastomosis (Pooled OR: 0.68; 95% CI = 0.41–1.13; $p > .05$; Figure 3).

All seven studies reported rates of total flap necrosis (Table 2). Rates ranged from 0% to 14.3% for single venous anastomoses and 0% to 11.1% for dual venous anastomoses. A random effects model demonstrated no significant reduction in the rate of total flap necrosis with the use of a second venous anastomosis (Pooled OR: 1.14; 95% CI = 0.72–1.82; $p > .05$; Figure 4). There was no significant reduction in the rate of partial flap necrosis when two venous anastomoses were used (Pooled OR: 0.48, 95% CI = 0.18 to 1.26, $p > .05$; Figure 5).

3.4 | Methodological quality of studies

All seven studies included in the analysis were comparative. Overall, four studies were considered to have high methodological quality with a mean MINORS score of 16.1/24. The most common methodological pitfalls were the retrospective nature of the studies and the failure to indicate the follow-up period for participants. All studies were classified as level VI evidence.

4 | DISCUSSION

To our knowledge, this is the first systematic review and meta-analysis to assess the efficacy of one versus two venous anastomoses about complications and free flap necrosis in lower limb reconstruction. We found no difference in the overall rate of minor complications, flap takeback/reoperation, venous thrombosis, partial flap necrosis, or total flap necrosis.

Lower extremity reconstruction is associated with a host of challenges. Post-traumatic inflammatory changes associated with the zone of injury, the incidence of peripheral vascular disease, and the unique physiology in the lower limb, all contribute to higher rates of reconstructive failure (Stranix et al., 2016; 2018). The risk of venous congestion and thrombosis is also highest in this anatomical region (Bolleta et al., 2019). The predisposition for lower limb venous stasis is further exacerbated in patients requiring post-operative immobilization, which reduces the efficacy of the natural venous pumps of the soleus and gastrocnemius (Stranix et al., 2018). As such, the overall anticipated success rates for free flaps in the lower limb are significantly lower than those in the head and neck, and breast (Pu, 2017). Despite a lower success rate, free flaps remain essential in lower limb reconstructions due to the paucity of local and regional soft-tissue options (Bajantri et al., 2012), the need for durable soft tissue coverage of weight-bearing surfaces, and the frequent involvement of composite soft tissue and bony defects (Khouri & Shaw, 1989). In order to improve the success rate of lower extremity free flaps, efforts have been made to reduce venous congestion; the most common cause of lower extremity free flap failure (Hallock, 2000; Heidekrueger et al., 2016; Khan et al., 2020; Lorenzo et al., 2011; Matthews et al., 2018; Mattos et al., 2018; Stranix et al., 2016; 2018).

Arguments supporting the use of a second venous anastomosis are typically threefold: (1) it enables flow to be maintained at lower pressure gradients; (2) it acts as a theoretical back-up venous drainage; and (3) it improves the drainage of distal flap perfusion areas. In their studies investigating the efficacy of a secondary venous anastomosis, Stranix et al. (2016; 2018) found that the use of dual venous outflows significantly reduced the rate of flap complications, partial necrosis and total necrosis. In this cohort of 361 patients with traumatic lower extremity defects, they found no effect of age, sex, flap-type, or vein mismatch on overall flap success. The authors noted, however, that the benefit of dual venous drainage they observed was driven by the improved survival of muscle flaps. In contrast, fasciocutaneous flaps in this cohort derived no additional benefit from two venous anastomosis. Unfortunately, we only identified two other studies that specifically reported the types of flaps performed. One of these, Heidekrueger et al. (2016), who performed an equivalent number of fasciocutaneous anterolateral thigh

flaps (ALT) and gracilis muscle flaps, showed no difference in flap related complications when single versus dual venous drainage was compared. Although the lack of homogenous reporting among studies limits further analysis, we suspect that muscle flaps may be less tolerant of venous congestion.

Some authors have suggested that a secondary venous anastomosis may provide a "back-up" in the event of venous thrombosis (Mattos et al., 2018; Stranix et al., 2016). Proponents of two veins stress the importance of ensuring the secondary vein is based on either a secondary pedicle or a separate venous system (superficial versus deep) (Mattos et al., 2018). Our review however, only identified four studies that adequately described the system used for venous anastomosis, with these authors relying primarily on the deep venous system for both venous anastomoses when two veins were used (Hallock, 2000; Lorenzo et al., 2011; Stranix et al., 2016; 2018). Lorenzo et al. (2011) who showed a significantly lower rate of flap-related complications when a single venous anastamosis was performed, astutely pointed out that thorough exploration and identification of an adequate venous recipient was the key factor for flap success. While their study reported that the superficial venous system was associated with higher rates of complications, they described the most common causes of venous congestion as factors not related to the intrinsic nature of the vein (hematoma, compression, and tight closure). Additionally, the use of a second vein may represent the surgeon's confidence, or lack thereof, with the suitability of an adequate recipient vein. This may be particularly true in large zones of injury. Furthermore, the superficial venous system may be primarily selected in cases of perforator anastomoses, when deep veins of the lower extremity are not already available in the operative field. These supermicrosurgical techniques, where vessels are of a diameter of <0.8 mm add an additional layer of complexity (Hong, 2009).

Overall, the data supporting the preferential use of the superficial or deep venous systems for anastomoses is lacking, with conflicting evidence highlighted in this review. While the deep venous system is primarily preferred (Lorenzo et al., 2011), there are situations where it may not be suitable, such as in the case of sub-clinical occult deep venous thrombosis and flap-recipient vein size mismatch (Lorenzo et al., 2011). In these cases, the superficial system may provide a more appropriate and constant vessel diameter. In addition, ease of dissection and surgeon preference may dictate the preferential use of the superficial venous system.

There are a number of surgeons who support the use of a single vein in lower extremity reconstruction (Hanasono et al., 2010; Jovell & Navarro-Rubio, 1995; Lorenzo et al., 2011). Hanasono et al. have demonstrated that increasing the volume of venous drainage decreases venous blood velocity (Hanasono et al., 2010). As a result of venous slowing, such as in the case of secondary venous anastomosis, there is an increased risk of clot formation and subsequent flap failure. While this argument theoretically holds merit, it may not be clinically relevant, as they reported no thrombotic events in their series. Moreover, data presented by Dorseifer et al., suggests that although a secondary venous anastomosis may decrease blood velocity, the reduction in velocity is not sufficient enough to cause thrombosis (Jovell & Navarro-Rubio, 1995).

Single venous anastomosis has also been seen as preferable relative to dual venous anastomoses as it requires less operative time (Khan et al., 2020). Of the studies examined, only two reported operative time, with one study showing an increase, and the other showing no difference when a second venous anastomosis was performed (Heidekrueger et al., 2016; Mattos et al., 2018). Overall, there were no reported adverse events, including deep venous thrombosis or flap-specific complications, as a result of prolonged operative time. Though it cannot be disputed that two anastomoses will take longer than one, Heidekrueger et al. argue that a secondary venous anastomosis typically takes less than 30 min and therefore does not unreasonably prolong operative time (Heidekrueger et al., 2016). In their series, a secondary vein took, on average, an additional 23 min (301 vs. 324 min total operative time). Nevertheless, studies have unequivocally demonstrated an association between longer operative time and an increase in major complications, including re-operation, need for transfusion, and pneumonia (Veith et al., 2019). The use of a secondary vein may also be associated with an increase in cost, though venous coupling may decrease overall expenditures (Head & McKar, 2018).

Recipient vein size is another important consideration in flap success. While some have suggested that a 0.7 mm diameter should be considered an absolute threshold for safe anastomosis (Gilbert, 1985), with the introduction of supermicrosurgery and recent reports from the pediatric and adult literature, absolute vein size should not dictate decision algorithms in microvascular reconstruction (Momeni et al., 2017). In this study, only two articles described vein size (Mattos et al., 2018; Stranix et al., 2018). In both of these studies, flap-to-recipient vein size mismatch was deemed to be the most important anastomotic characteristic, with recipient and flap vein size not conferring any untoward consequence. Clinically, large vein mismatch can lead to turbulence and subsequent thrombus propagation (Francis et al., 2009).

We must acknowledge that determining the etiology of adverse outcomes in microsurgery is complex and often multifactorial. For instance, arterial thrombosis may be the cause of propagation from the venous system, and vice versa, while infection may lead to partial flap necrosis. Furthermore, venous issues cannot account for all flap related complications, and there are etiologies beyond venous drainage that may account for total or partial flap necrosis, a major limitation of this study. Nonetheless, the primary objective of each of the included studies was to examine the association of venous anastomoses (single vs. dual) on flap outcomes (partial and total flap necrosis). It is then impossible to further assign failures to a specific event (venous thrombosis vs. infection vs. arterial thrombosis) as the primary reason for failure, if these data are not presented in sufficient granularity, and are beyond the primary focus of the articles included.

Though reasons for reconstruction were examined for each study, this review is limited by significant reporting heterogeneity. While most studies described mixed etiology defects (malignant, traumatic, infectious, and burns), there are two studies that described only

traumatic injuries (Stranix et al., 2016; 2018). In trauma, a potentially expansive zone of injury makes these cases both difficult and unique. In contrast, oncological and infectious reconstructions have considerably more predictability. In both studies describing only traumatic injuries (Stranix et al., 2016; 2018), there was a significant benefit of adding a secondary vein. The effects observed in our meta-analysis are in part driven by these findings. Further research is necessary to elucidate the benefit of dual venous anastomoses for each specific defect etiology. Our review is also limited by the studies included. All seven studies were retrospective, and thus impart an inherent degree of bias. While most studies were found to be of sound methodological quality, future prospective analyses evaluating the efficacy of a secondary venous anastomosis are warranted.

In summary, this article is the first to pool outcomes across all studies examining the use of two venous anastomoses in lower extremity reconstruction, and thus will be the largest series of free flaps examined for this purpose. Additionally, this study highlights that a secondary venous anastomosis in lower extremity reconstruction may not confer improved outcomes. Finally, this review hopefully encourages further research on this important topic.

5 | CONCLUSION

This systematic review and meta-analysis aimed to assess the efficacy of one versus two venous anastomoses in lower limb reconstruction. Our data failed to support the hypothesis that secondary venous anastomoses reduces the incidence of minor and major complications. Furthermore, we found no significant differences in rates of partial and total flap necrosis between single and dual vein anastomoses. This area of study would ultimately benefit from further investigation.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors have no financial disclosures. No funding was received for this article. None of the authors has a financial interest in any of the products, devices, or drugs mentioned in this manuscript.

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