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Evaluating Postoperative Patency and Flow in Twisted Vascular Pedicles of Propeller Perforator Flaps for Lower Limb Reconstruction; A prospective, Single-Center, Observational Cohort Study

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ABSTRACT

Background: Propeller perforator flaps have emerged as a versatile and effective solution, offering reliable coverage while preserving major vascular axes. However, concerns remain about the vascular patency and flow patterns in twisted pedicles, particularly at high degrees of rotation. Understanding these hemodynamic dynamics is crucial to minimize complications and optimize surgical outcomes.

Objective: To evaluate the postoperative patency and flow patterns in twisted vascular pedicles of propeller perforator flaps used for lower extremity reconstruction.

Methods: This prospective, single-center, observational cohort study was conducted at King Fahad Medical City in Riyadh City, Saudi Arabia between June 2022 and December 2024. Fifteen patients underwent lower extremity soft tissue reconstruction using propeller perforator flaps rotated from 90 to 180 degrees. Flap sizes ranged from 5×12 cm to 9×20 cm, with eight flaps based on peroneal vessels and seven on the posterior tibial artery, using doppler ultrasound for vascular assessment.

Results: Soft tissue defects were due to unstable scar excision in six cases and post-traumatic tissue loss in nine cases. Preoperatively, four patients had osteomyelitis and four had wound infections. Doppler assessments revealed that 47% of patients experienced venous congestion with patent pedicles, while 53% had no congestion. All patients demonstrated patent vessels with biphasic flow patterns at the end of the follow-up period.

Conclusions: Propeller perforator flaps are a versatile and effective option for reconstructing middle and distal third leg defects, offering reliable coverage with minimal donor site morbidity. Despite high degrees of rotation, the flaps maintained patent pedicles with consistent flow patterns, resulting in favorable healing outcomes.

KEYWORDS: Propeller perforator flaps, lower extremity reconstruction, vascular patency, venous congestion, Doppler ultrasound, soft tissue defects, donor site morbidity.

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INTRODUCTION

Lower extremity soft tissue defects, particularly in the middle and distal thirds of the leg, present significant reconstructive challenges due to limited local tissue availability and the complex vascular anatomy of the region ***(1)***. These defects are often caused by post-traumatic tissue loss or complications from scar excisions, leading to exposed bones, tendons, or implants that necessitate reliable and durable coverage. Conventional reconstructive options, such as muscle flaps or free flaps, require microsurgical expertise and can result in donor site morbidity, prolonged operative times, and increased risk of complications, especially in patients with compromised vascular status ***(2).***

Perforator flaps represent a significant advancement in reconstructive surgery, evolving from traditional random pattern flaps, musculocutaneous flaps, and fasciocutaneous flaps ***(3)***. The modern era of perforator flaps began in **1989** when **Koshima and Soeda (4)** introduced the concept of using an inferior epigastric artery skin flap without the rectus muscle for reconstructing mouth and groin defects, demonstrating that large flaps could survive on a single perforator. These flaps are advantageous due to their reliable blood supply, reduced donor site morbidity, and preservation of muscle and source vessels ***(5)***.

A propeller perforator flap is a specialized variant characterized by complete skeletonization of the perforator along with its venae comitantes, enabling the islanded flap to be transferred solely on its pedicle. This design offers exceptional flexibility in pedicle orientation and allows rotation up to 180 degrees, making it highly adaptable for complex reconstructions ***(6; 7).*** The immediate postoperative survival of the transferred tissue hinges on the patency of its vascular pedicle. If rapid neovascularization occurs, maintaining adequate perfusion, the flap may survive even if the pedicle is lost or occluded, as documented in cases of complete tissue survival despite pedicle loss 6-9 days postoperatively ***(8; 9; 10).***

The significance of maintaining a patent vascular pedicle varies based on the flap type and recipient site. In free perforator flaps, the anastomosed pedicle generally remains patent and sustains blood supply for up to 8 years postoperatively, without undergoing architectural changes that could lead to gradual obliteration ***(5)***. However, in pedicled propeller perforator flaps, the reliance on a twisted pedicle introduces the risk of vessel remodeling and wall thickening, potentially causing occlusion over time ***(11)***. The impact of this twisting on the vascular flow pattern and the critical period required for the flap to become independent of the pedicle remain controversial ***(12; 13).*** Consequently, this study was conducted and aimed to comprehensively evaluate the postoperative performance of propeller perforator flaps in lower extremity reconstruction, focusing on vascular dynamics and clinical outcomes. The primary objective was to assess the patency of twisted vascular pedicles under varying degrees of rotation (90°, 120°, and 180°) using Doppler ultrasound, with particular attention to hemodynamic flow patterns (monophasic, biphasic, or triphasic) and their correlation with flap survival. A secondary objective was to determine the relationship between pedicle rotation angles and complications such as venous congestion, flap necrosis, or donor site morbidity. Additionally, the study sought to compare the efficacy of propeller flaps based on different vascular sources (peroneal vs. posterior tibial artery perforators) and their adaptability to diverse defect sizes.

The study tested several hypotheses grounded in biomechanical and clinical principles. First, it posited that propeller perforator flaps would maintain vascular patency and biphasic/triphasic flow patterns even at maximal rotation (180°), challenging concerns about torsion-induced occlusion. Second, it hypothesized that venous congestion and complications would not correlate directly with rotation angles but instead arise from individual anatomical variations or surgical technique, such as perforator selection or pedicle skeletonization. Third, the study proposed that posterior tibial artery-based flaps would demonstrate outcomes equivalent or superior to peroneal-based flaps, irrespective of rotation, due to consistent vascular caliber and perfusion. Lastly, it assumed that conservative interventions (e.g., heparin dressings, leech therapy) would effectively resolve postoperative venous congestion without necessitating surgical revision, underscoring the resilience of propeller flaps. These hypotheses collectively aimed to resolve controversies surrounding pedicle hemodynamics and reinforce propeller flaps as a versatile, reliable option for lower limb reconstruction.

PATIENTS AND METHODS

This study is a prospective, single-center, observational cohort study conducted on 15 patients 18 years or older of both sex underwent lower extremity soft tissue reconstruction by propeller perforator flaps rotated from 90 to 180 degrees at King Fahad Medical City in Riyadh City, Saudi Arabia between June 2022 and December 2024. Patients with comorbidities like smoking, peripheral vascular diseases and diabetes mellitus were excluded. An informed consent was obtained from all patients participating in the study after explanation in accordance to the local ethical committee regulation and patients had been offered the opportunity to withdraw from the evaluation at any time. Each patient underwent the following:

1) Preoperative evaluation:

Patients who fit with our eligibility criteria were assessed clinically regarding evaluation for vascular insufficiency in delayed primary and secondary post traumatic defects. General and loco regional factors favoring the flap cover.

Preoperative Planning

Using hand held 8 mHz pencil Doppler (Hi Dop. Ana Wiz LTD. UK with 8MHz probe, **Fig. (1)),** with 45-degree angulation towards onward flow perforators were located adjacent to the defect. If multiple perforators were located one with the strongest signal was chosen. Also local scars, vascularity, availability of loose tissues were taken into consideration. A provisional flap design can be drawn with the perforator was the pivot point of the flap. First, the distance between the perforator and the distal edge of the defect was measured. This value was then transposed proximally along the axis of the main source vessel, again measured from the perforator, and 1cm was added. This value forms the proximal limit of the flap. Next, the width of the proximal flap needed to cover the defect was determined by measuring the width of the defect. This value was then used to determine the proximal flap width, adding 0.5 cm to allow for flap contraction and to facilitate its inset without tension **(Fig. 2).**

Figure (1): Hand held 8 mHz pencil Doppler device.

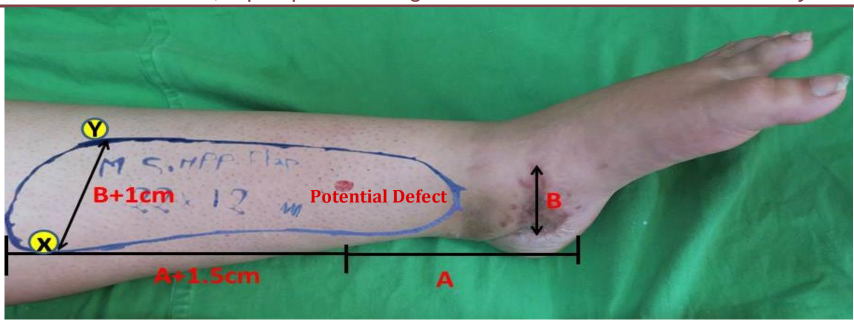

Figure (2): Preoperative design in patient presenting with unstable scar. (A) is the distance of the perforator from the distal edge of the defect while (B) represents the width. Note the position of X and Y.

a) Operative Technique:

We performed a first exploratory longitudinal skin incision on of the margins of the flap to observe the perforator localized preoperative with the handheld Doppler. The distance of the perforator from the proximal edge of the defect determined the length of the minor paddle used to cover or partially cover the donor site. If direct closure of the donor site was not achievable, a skin graft was used to close the residual defect. The elevation of the flap was performed with the patient in supine position, without performing exsanguination of the extremity with an elastic bandage, and at the thigh a controlled tourniquet was placed with a continuous pressure of 250 mmHg. The flap was dissected, under 2.5× magnification, sub-fascially or supra-fascially, with an axial orientation with respect to the affected limb. We choose the single best perforator by the following criteria after deflation of the tournique:

i. With visible pulsation,
ii. Size of fascial defect through which perforator travels (wider the fascial defect better the perforator),
iii. Size of the perforator at fascial level after lignocaine wash and waiting for 10 min,
iv. Those with one or two venae comitantes,
v. Differential clamping.

After confirming the single best perforators complete skeletonization of the selected pedicle was done with release of all fascial strands and clipping of all muscular side branches **(Fig. 3 and 4).** Once the pedicle has been dissected, complete flap elevation was done **(Fig. 5).** The ischemia is released to assess the irrigation of the flap and before its transposition; it is left in its native orientation for 10 minutes to then corroborate the adequate capillary filling of the borders of the flap.

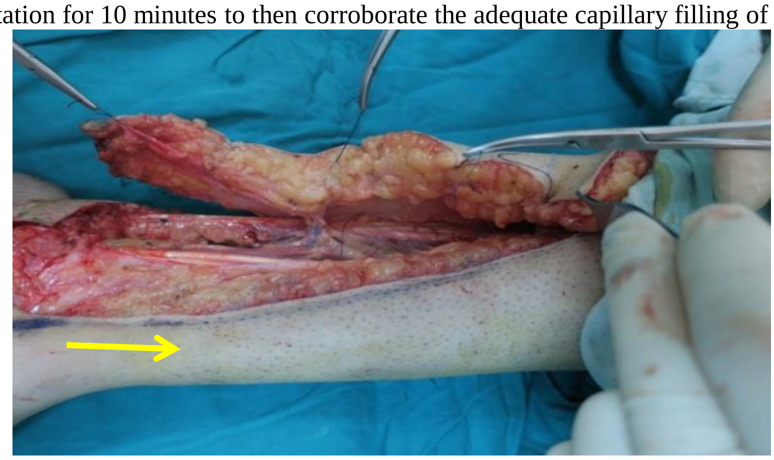

Figure (3): Showing the pedicle dissection; note the short pedicle (yellow arrow) that doesn't allow flap advancement so it was rotated 180 °.

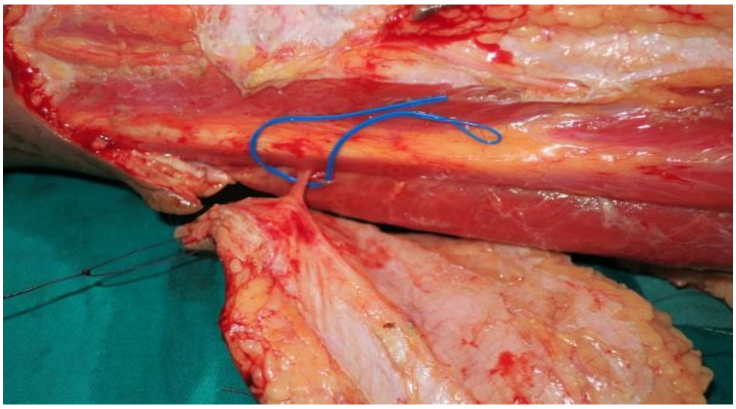

Figure (4): Showing the pedicle dissection; note the short pedicle (blue tape).

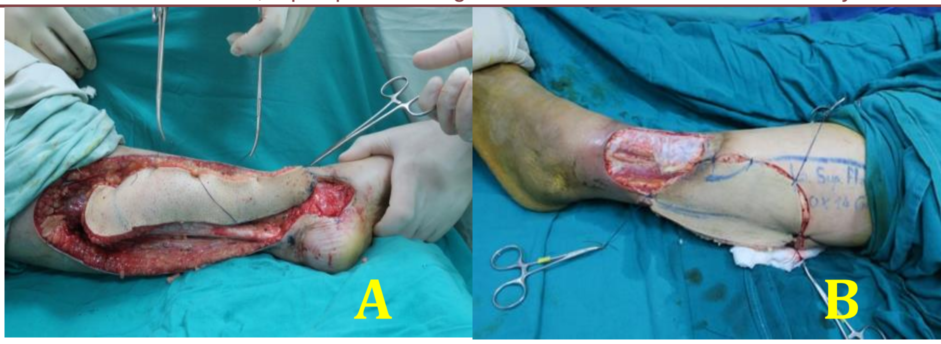

Figure (5): Showing flap elevation in the sub-fascial plane into different cases; in case A the flap was rotated 180°, in case B the flap was rotated 90°.

Critical assessment of choosing clockwise or anticlockwise rotation to avoid the venous congestion and whether any kinking of perforator occurred decided the best fit and the final inset of the flap was done **(Fig. 6)** ***(14).*** The exact location of the perforator following flap inset was recorded for future reference. **Fig. (7)** shows the flap at three months postoperatively.

Figure (6): Showing final flap inset with arc of rotation 90º and donor site coverage by split thickness skin graft.

Figure (7): Showing the patients at 3 months postoperatively. Note the position of X and Y in case A.

b) Data analysis and documentation:

Patients' records had been documented in regards to age, gender, comorbidities, bacterial contamination or infection, cause of tissue loss. Flap size, source vessel, flow pattern evaluated by handheld Doppler device, arc of rotation and donor site closure had been documented and acted as a control for the study.

2) Postoperative evaluation:

A Handheld Doppler device (Hi Dop. Ana Wiz LTD.UK) with 8 MHz probe (Hi Dop. Ana Wiz LTD.UK) had been used to localize the vascular pedicle, evaluate its patency and assess the flow pattern to a minimum period of 3months postoperatively in all patients. The flow pattern had been categorized as monophasic, biphasic and triphasic flow, both the triphasic and biphasic flow are normal while the monophasic flow indicates loss of vessel elasticity due to intimal thickening.

Outcomes Measures:

- **Primary Outcomes:**
  - **Vascular Patency:** Presence of blood flow in the pedicle, confirmed by Doppler ultrasound (biphasic/triphasic flow = patent; monophasic = compromised).
  - **Flow Pattern:** Categorized as monophasic (abnormal), biphasic, or triphasic (normal), assessed via Doppler ultrasound.
- **Secondary Outcomes:**
  - **Flap Survival:** Complete integration of the flap without necrosis.
  - **Venous Congestion:** Clinical observation of flap discoloration/swelling, confirmed by Doppler.
  - **Complications:** Includes partial/total flap loss, donor site morbidity (e.g., skin graft failure), and infections.
  - **Donor Site Morbidity:** Assessed by wound healing status (direct closure vs. split-thickness skin graft).

Sample Size Justification

The study included 15 patients. The sample size of 15 patients was determined based on the rarity of eligible cases meeting strict inclusion criteria (e.g., absence of comorbidities, specific defect locations) and the exploratory nature of this single-center study. Similar studies in propeller flap literature have employed comparable sample sizes (5–20 patients) due to the specialized surgical technique and ethical considerations. We acknowledge the reduced statistical power and recommend multicenter collaborations for future validation

Statistical Analysis:

Data collected included age, gender, comorbidities, bacterial contamination or infection, cause of tissue loss, flap size, source vessel, flow pattern, arc of rotation, and donor site closure. These variables served as controls for the study. Handheld Doppler ultrasound was used postoperatively to assess the vascular pedicle's patency and flow patterns for a minimum of 3 months. Flow patterns were categorized as monophasic, biphasic, or triphasic, with biphasic and triphasic considered normal, while monophasic indicated loss of vessel elasticity due to intimal thickening. The results were compared to preoperative records and statistically analyzed using SPSS Version 20. The study also recorded postoperative complications, including scarring, sinus formation, and other issues. If venous congestion occurred, the pedicle was evaluated for patency and flow during the congestion period, with any salvage measures documented.

Ethical Considerations: The patient data were anonymous. Data presentation were not being by the patient's name but by diagnosis and patient confidentiality was protected. An informed consent was taken from all participants, it was in Arabic language and confirmed by date and time. confidentiality was preserved by assigning a number to patients initials and only the investigator knew it.

RESULTS

In the study period fifteen patients were operated upon for the reconstruction of middle and distal third defects of the leg.
Soft tissue defects were caused by unstable scar excision in six patients while nine patients experienced post-traumatic tissue loss. Preoperatively, four patients had osteomyelitis and four had wound infection. The rest of patients, seven patients, did not report any infection before the operation.

Table (1) shows the age and sex of the patients included. The sample size included 4 females, and 11 males, none of the included patients suffered from comorbidities.

Table (1): Age and gender of the included patients

Patient No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Age, years	45	40	43	30	38	40	48	52	18	34	29	40	34	18	21
Gender	M	M	F	F	M	M	M	M	M	F	F	M	M	M	M

Flap size ranged from 5_x12 cm to 9_x20 cm A detailed description of the size of different flaps used in the operation is explained in Table 2. Additionally, eight out of fifteen patients used perforators from peroneal vessel source, while seven patients used posterior tibial artery source (Table 2).

Table (2): The size of different flaps used in the operation and the source vessel

No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Flap Size	10x14cm	7x14	6x14	10x17	9x20	9x15	7x16	8x15	6x14	8x18	10x17	8_x18	4x13	5x12	7x20
Source Vessel	Peroneal	Peroneal	PTA	PTA	PTA	Peroneal	PTA	Peroneal	Peroneal	Peroneal	PTA	PTA	Peroneal	ATA	Peroneal

As regard the arc of rotation, in 33.3% of patients the arc of rotation was 90º, 26.7% was 120º and 40% was 180 as shown in **Figure 8**.

Only one patient (patient #3) experienced direct closure of the donor site, all other patients were closed using the STSG technique.

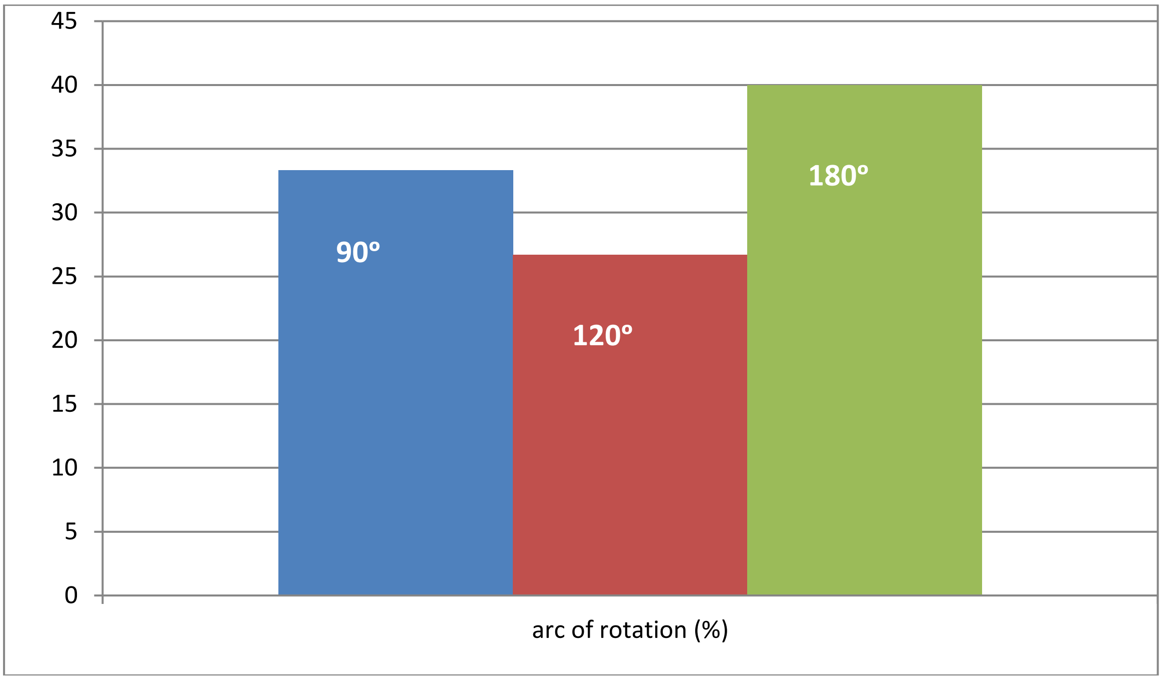

Figure (8): Shows arc of rotation angle.

Complications were present in 7 cases, five patients experienced early post-operative congestion that was treated by conservative methods as illustrated in details in table 3, one patient reported skin graft loss **(Fig. 9),** and one patient reported skin graft loss in addition to distal congestion and skin necrosis **(Fig. 10).** Eight patients passed the operation with no complications.

Table (3): Post-operative complications

No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Postoperative complications	early postoperative congestion	early postoperative congestion	early postoperative congestion	early postoperative congestion	No	skin graft loss-distal congestion - distal superficial necrosis	No	early postoperative congestion	No	No	No	Skin graft loss	No	No	No

Figure (9): Showing a patient with skin graft loss.

Figure (10): Showing patient with distal superficial necrosis (A) and skin graft loss in the same patient (B).

Table 4 shows the Doppler findings during the congestion period in cases that developed venous congestion, the arc of rotation and flap dimension, the results revealed that 47% patients had congestion with patent pedicle, while 53% of patients had no congestion. Note that even in the highest degrees of rotation despite the congestion if patent pedicle was auscultated in the flap without change in the flow pattern.

Table (4): Doppler findings after the operation

No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Doppler findings	patent pedicle	patent pedicle	patent pedicle	patent pedicle	not congested	patent pedicle	patent pedicle	patent pedicle	not congested	not congested	not congested	not congested	not congested	not congested	not congested
Arc of rotation	90º	90º	180º	120º	90º	120º	180º	180º	120º	120º	180º	180º	90º	180ºº	90º
Flap dimentios (cm)	10x14	7x14	6x14	10x17	9x20	9x15	7x16	8x15	6x14	8x18	10x17	8x18	4x13	5x12	7x20

Two patients had suture removal, one patient was self-limited, one patient did not require salvage methods, one patient used leech, and three patients required heparin dressings. At the end of follow up period all patients had patent vessels with biphasic flow pattern

DISCUSSION

Propeller perforator flaps have emerged as a versatile and effective solution for lower extremity reconstruction. These flaps are based on localized perforator vessels, allowing for rotation arcs of up to 180 degrees to cover complex defects while preserving the major vascular axes. Their ability to provide "like with like" tissue coverage with minimal donor site morbidity has made them a preferred choice in reconstructive surgery. However, concerns remain regarding the vascular patency and flow patterns in the twisted pedicles of these flaps, particularly when rotated at high degrees. Understanding the hemodynamic behavior of these pedicles is crucial to minimize complications such as venous congestion, flap necrosis, and compromised wound healing ***(15)***.

A perforator flap is created by harvesting a cutaneous paddle based on a direct cutaneous or septofasciocutaneous / musculocutaneous perforator, which is isolated through meticulous dissection around the perforator. Propeller flaps consist of two asymmetrical skin paddles arranged around a perforator, allowing rotation around the most suitable perforator to cover the primary defect, while the secondary paddle can be used to fill a secondary defect, thereby minimizing tension on the perforator pedicle ***(14).***

However, despite these advantages, propeller flaps are associated with certain challenges. One of the primary complications is the risk of partial or, in rare cases, total flap loss due to venous insufficiency. This risk is comparable to that seen with free flaps ***(10; 16; 17; 18; 19).***

Additionally, secondary procedures, such as flap thinning, bone grafting, or tendon transfers, are sometimes necessary after limb salvage, requiring the flap to be re-elevated. This can potentially compromise the flap's blood supply and lead to tissue necrosis. Therefore, understanding the process of flap autonomization and determining whether the pedicle is still essential for blood supply—if it remains patent and unobstructed over time—is vital for ensuring flap survival and optimal surgical outcomes ***(20)***.

Based on hemodynamic studies, it was revealed that the flow through a perforator in normal anatomic conditions is much smaller than in the source vessel, while for the same perforator when used as pedicle of a flap the flow through is still smaller than in the source artery, but much greater than in the former situation ***(21).*** Based on the equation of continuity derived from Bernoulli principal of fluid dynamics by that stated that liquids must maintain their volume as they flow in a pipe since they are nearly incompressible, this means that the volume of liquid that flows into a pipe in a given amount of time must equal the volume of liquid that flows out of a pipe in the same amount of time (Q=A1.V1=A2.V2 where Q = the volumetric flow rate, A = the cross sectional area of flow, V = the mean velocity) ***(22).*** We suggest that the effect of torsion on the twisted pedicle is compensated by the increase in the total amount of flow within the twisted pedicle due to perforator hyperperfusion and the increase in velocity caused by decreasing the cross sectional area of the vessel at the torsion points. Consequently, our study was conducted and aimed to evaluate the postoperative patency and flow patterns in twisted vascular pedicles of propeller perforator flaps used for lower extremity reconstruction. By analyzing Doppler ultrasound findings and clinical outcomes, we sought to provide evidence on the reliability and safety of this technique, particularly in terms of vascular integrity and complication rates. Additionally, we aimed to compare our findings with existing literature to identify best practices and potential modifications that could enhance surgical outcomes.

This prospective clinical study was conducted at King Fahad Medical City in Riyadh City, Saudi Arabia, between June 2022 and December 2024. We included 15 patients aged 18 years or older who required lower extremity soft tissue reconstruction using propeller perforator flaps. Patients with comorbidities such as smoking, peripheral vascular diseases, and diabetes mellitus were excluded to minimize confounding factors and provide a clearer assessment of flap performance. The patient group comprised individuals who had either post-traumatic tissue loss or soft tissue defects due to unstable scar excision. Specifically, six patients required reconstruction following the excision of unstable scars, while nine patients suffered from tissue loss due to trauma. Before the surgery, four patients were diagnosed with osteomyelitis, and another four presented with wound infections. The remaining seven patients had no preoperative infections.

In comparison, ***Mishra et al. (15)*** conducted a smaller study with five male patients to evaluate propeller flaps with an additional venous pedicle for enhanced drainage. Their patients had 6×5 cm trauma-induced defects, focusing solely on males. ***Mendieta et al. (20)*** studied 28 patients with middle and distal leg defects, mostly post-traumatic, across multiple hospitals. They aimed to demonstrate versatility and safety but included patients with diabetes mellitus and hypertension, unlike our exclusion criteria. **Shahabuddin et al. (23)** analyzed 40 patients with leg defects, dividing them by rotation angles (150-180 degrees vs. 90-150 degrees). They excluded patients with degloving injuries, peripheral vascular disease, and diabetes, aligning with our criteria. **Vaienti et al. (24)** explored polar safety stitches in seven patients to reduce pedicle twisting and minimize venous congestion. **Jakubietz et al. (10)** conducted a long-term follow-up on 22 patients, focusing on vascular pedicle patency, including lower extremity (19) and trunk defects (3), showing a more diverse anatomical distribution.

Eldahshoury et al. (25) included 23 patients with compromised vascularity, using ultrasound arterial duplex to measure peak arterial velocity, providing insights into flap safety in high-risk patients. **Hifny et al. (26)** evaluated 11 male patients with trauma-induced defects, achieving high flap viability using posterior tibial artery perforators. **Dong et al. (27)** reviewed 20 patients with diverse leg and foot defects, using color Doppler ultrasound preoperatively for precise perforator localization. **Tos et al. (19)** evaluated 22 patients with mixed etiologies, demonstrating the adaptability of local perforator flaps. **Karki et al. (28)** conducted a prospective study on 20 patients with distal leg and ankle defects, emphasizing flap versatility and achieving primary donor site closure in all cases, unlike our use of split-thickness skin grafts (STSG).

Regarding Flap Size, Source Vessel, and Arc of Rotation, the propeller perforator flaps used in the reconstruction varied in size, ranging from 5x12 cm to 9x20 cm. The selection of flap size was influenced by the location and extent of the soft tissue defects. In terms of vascular supply, eight out of the fifteen patients received flaps nourished by perforators from the peroneal vessels, while the remaining seven patients had flaps sourced from the posterior tibial artery (PTA). The largest flap used measured 9x20 cm and was supported by the PTA, while the smallest, measuring 5x12 cm, was supplied by the anterior tibial artery. This variation in flap size and source vessel highlights the adaptability of the propeller perforator flap technique in addressing diverse reconstructive needs.

In addition, the arc of rotation varied, with 33.3% at 90 degrees, 26.7% at 120 degrees, and 40% at 180 degrees. This variability highlights the versatility of propeller perforator flaps in addressing middle and distal third leg defects. Notably, the highest degree of rotation (180 degrees) was most frequently used, underscoring its importance in achieving adequate defect coverage.

Mishra et al. (15) reported smaller flap dimensions averaging 12.8×6 cm, with rotations between 90 to 180 degrees. They incorporated the great saphenous or short saphenous vein to enhance venous drainage, resulting in no flap loss or congestion. **Mendieta et al. (20)** documented an average flap size of 50 cm², with 82% of flaps rotated at 180 degrees. They predominantly used posterior tibial artery perforators (50%), followed by anterior tibial artery (39.3%) and peroneal artery (10.7%). In contrast, our study had a higher usage of peroneal vessels. **Shahabuddin et al. (23)** divided their patients into two groups based on rotation angles: 150-180 degrees and 90-150 degrees. They observed total flap necrosis in two cases with 150-180-degree rotations, leading to a protocol adjustment.

Dong et al. (27) reported larger flap sizes ranging from 5x11 cm to 12x28 cm, using the terminal branch of the peroneal artery in 15 cases and PTA in 5 cases**. Tos et al. (19)** emphasized the preservation of major vascular axes with local perforator flaps, demonstrating adaptability across different indications. **Karki et al. (28)** exclusively used posterior tibial and peroneal artery perforators, achieving primary closure in all cases, contrasting with our use of split-thickness skin grafts (STSG) for donor site closure.

Regarding Donor Site Closure, of the 15 patients, only one patient underwent direct closure of the donor site. For the remaining patients, closure was accomplished using the split-thickness skin graft (STSG) technique. This approach was necessary due to the larger size of the donor defects and the high degree of flap rotation in most cases. The choice of closure technique played a crucial role in minimizing complications and enhancing postoperative healing outcomes.

Mishra et al. (2023) primarily managed donor sites with STSG, with partial closure in one case. **Mendieta et al. (2018)** achieved primary closure in 85.7% of cases, with the remaining sites treated with partial thickness skin grafts. **Dong et al. (2014)** reported direct closure in 12 cases and skin grafting in 8, while **Jakubietz et al. (2017)** achieved primary closure in 9 patients, with 13 requiring skin grafts. **Karki et al. (2012)** closed all donor sites primarily, demonstrating better donor site management compared to our study. These variations highlight the importance of individualized approaches based on flap size, rotation arc, and donor site characteristics.

Regarding Postoperative Complications, complications were observed in 7 out of 15 cases in our study, including early postoperative congestion (5 patients), skin graft loss (1 patient), and distal superficial necrosis (1 patient). Conservative methods effectively managed most complications, and 8 patients had uneventful postoperative courses. The study findings suggest that while propeller perforator flaps are highly adaptable, careful monitoring and management are essential to address potential complications effectively.

Mishra et al. (15) observed no flap loss or congestion, likely due to the inclusion of additional venous pedicles. **Mendieta et al. (20)** reported partial necrosis in 14% of cases, predominantly in flaps based on the PTA. **Shahabuddin et al. (23)** encountered total flap necrosis in 2 cases with 150-180-degree rotations and minor complications such as transient venous congestion and mild dehiscence. **Vaienti et al. (24)** successfully minimized complications using polar safety stitches to reduce pedicle twisting. **Jakubietz et al. (10)** observed superficial tip necrosis in 3 patients and fistula formation in **6**, all of which resolved without major surgical interventions.

Regarding Doppler Findings and Follow-Up, our study results showed that 47% of the patients experienced venous congestion with patent pedicles, while the remaining 53% had no signs of congestion. Even in cases with high degrees of rotation, a patent pedicle with a consistent flow pattern was observed, which correlated with favorable healing outcomes. At the end of the follow-up period, all patients demonstrated patent vessels with a biphasic flow pattern, indicating successful flap survival and integration.

Jakubietz et al. (10) conducted a long-term follow-up study on 22 patients, evaluating the patency of twisted vascular pedicles in propeller perforator flaps using Doppler ultrasound. Their results showed that all patients maintained intact vascular pedicles, with a biphasic Doppler signal detected in each case. This finding is consistent with our study, where patent vessels with consistent flow patterns were observed despite high degrees of rotation. The long-term follow-up (averaging 43 months) in Jakubietz et al.'s study confirmed that the vascular pedicle of propeller flaps remains patent over time, supporting the safety and durability of this reconstructive technique.

Eldahshoury et al. (25) explored the vascular impact of propeller perforator flaps using ultrasound arterial duplex to measure peak arterial velocity (PA velocity) pre- and postoperatively. The results showed no statistically significant difference in PA velocity before and after surgery, suggesting that propeller flaps do not adversely affect distal limb vascularity.

Dong et al. (27) utilized color Doppler ultrasound preoperatively to locate perforator vessels, ensuring accurate flap design and placement. Postoperatively, Doppler assessments confirmed the survival of all flaps, with patent pedicles and satisfactory appearances of the flaps. The use of color Doppler ultrasound facilitated precise perforator selection, contributing to high flap viability and minimal complications. Although our study did not utilize preoperative Doppler mapping, the postoperative assessments demonstrated consistent flow patterns and patent pedicles, underscoring the reliability of propeller perforator flaps.

Moreover, **Mishra et al. (15)** also utilized Doppler ultrasound to evaluate vascular patency but introduced an innovative approach by incorporating a superficial vein into the flap design to enhance venous drainage. This modification involved the inclusion of either the great saphenous vein or short saphenous vein, ensuring effective retrograde or antegrade venous drainage. As a result, no flap congestion or necrosis was observed in their study, demonstrating the effectiveness of this technique in preventing venous complications. Doppler assessments confirmed the patency of the incorporated vein, highlighting the potential benefit of this approach in enhancing flap viability.

STRENGTHS OF THE STUDY

Our study's main strengths include its prospective clinical design, which enabled systematic data collection and real-time monitoring of outcomes, reducing recall bias. By excluding patients with comorbidities such as smoking, peripheral vascular diseases, and diabetes mellitus, we minimized confounding factors, enhancing the reliability of our findings on vascular patency and flow patterns in twisted pedicles.

Additionally, the use of high-resolution Doppler ultrasound for postoperative evaluation provided robust hemodynamic data, offering a comprehensive assessment of flap performance. Additionally, the inclusion of varied flap sizes, source vessels, and rotation arcs demonstrated the versatility of propeller perforator flaps in managing complex lower extremity defects.

LIMITATIONS OF THE STUDY

Despite its strengths, the study had limitations, including a small sample size of 15 patients, which limits the generalizability of the findings. Conducting the study at a single center may also introduce selection bias. A short follow-up period restricted the assessment of long-term complications, such as flap thinning or donor site morbidity. Although Doppler ultrasound was effective for postoperative evaluation, more advanced imaging techniques like CT angiography could provide a more detailed analysis of vascular flow dynamics, particularly in high-degree rotations. Future multi-center studies with larger cohorts and extended follow-up periods are recommended to validate these findings.

CONCLUSION

Our study demonstrated that propeller perforator flaps are a versatile and effective option for reconstructing middle and distal third leg defects. The findings revealed that these flaps provide reliable coverage with minimal donor site morbidity while preserving the major vascular axes. Doppler ultrasound assessments showed that despite high degrees of rotation, patent pedicles with consistent flow patterns were maintained, leading to favorable healing outcomes. Complications were relatively low and manageable, with most cases of venous congestion resolving with conservative methods. The study confirmed that propeller perforator flaps offer a reliable solution for lower extremity reconstruction, with the flexibility to accommodate varying flap sizes, source vessels, and rotation arcs.

Based on our findings, we recommend the continued use of propeller perforator flaps for middle and distal third leg defects, given their adaptability and favorable outcomes. Surgeons should carefully evaluate the perforator vessel source and plan the rotation arc based on defect location and size to minimize complications. Incorporating additional venous pedicles, as demonstrated in other studies, could be considered to enhance venous drainage and reduce the risk of congestion.

List of Abbreviations

Abbreviation	**Full Term**
STSG	Split Thickness Skin Graft
PTA	Posterior Tibial Artery
ATA	Anterior Tibial Artery
cm	Centimeters
MHz	Megahertz
SPSS	Statistical Package for the Social Sciences

Ethical Considerations

This study was approved by the Institutional Review Board of King Fahad Medical City, Riyadh, Saudi Arabia. All procedures were carried out in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants in Arabic, and participants retained the right to withdraw at any stage without affecting their medical care. Patient confidentiality was preserved by coding data, and no identifiable information was disclosed.

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Conflicts of Interest

The authors declare no conflict of interest related to this study.

Confidentiality of Data

All patient data were anonymized and secured. No patient-identifiable information was disclosed in this research or manuscript. Data access was restricted to the research team.

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