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ORIGINAL RESEARCH

Cadaveric Atlas: Reverse Sural Flap Delayed Technique, A Novelty Approach to Stepwise Algorithm Utilizing Skin Substitute Bilayer

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The reverse sural nerve flap is one of many versatile neuro-fasciocutaneous techniques available for staged reconstruction of lower limb and foot. It has been utilized to correct tissue defects often caused by traumatic injury, infection and even tumor resection. These tissue voids create challenges to the limb preservation surgeon as viable, rapid coverage of these areas is often paramount to successful long-term outcomes. The viability of these "axial pattern" flaps is predicated on the vascular supply and perfusion of the sensory superficial network and while this does not sacrifice a main arterial branch, it makes this flap more susceptible to failure with acute transposition along its arc of rotation. For this reason, a delayed method can be utilized to stage the procedure and increase the viability of the flap and provide more reliable successful outcomes.

Keywords: sural flap; delayed; cadaveric; skin substitute; lower limb defect

Indications

The most common location for transposition of the reverse sural flap is to the posterior heel and distal lateral malleolus. However, this flap's versatility allows for the limits of its indications to be increased to include multiple areas of the posterior lower limb with small defects. Much of the literature has provided a discussion of noted reasons to undergo the harvest of the reverse sural flap which include traumatic injuries with soft tissue deficient, severe infections including osteomyelitis which requires both bone and soft tissue resection, failed surgical incisions, tumor resection and for defects to the posterior lower limb that are not amenable for treatment with a more common flap technique. Furthermore, the flap offers the surgeon an alternative to a free tissue transfer and low donor site morbidity. Completing a delayed harvesting technique, the flap is raised over a period of days to weeks insuring the viability of the tissue and may help to produce more successful outcomes that are also more reproducible by many different surgeons. The purpose of the delay technique is to improve vascularity and venous outflow to the pedicle prior to acute transposition.

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Contraindications

Although the reverse sural flap has continued to gain popularity and utilization, its list of complete and relative contraindications to attempting harvest remain present. Complete contraindications are limited but include significant poor circulation, inability to reach the defect site given its arc of rotation of the flap, to large of a tissue deficit and if another flap with better indication can be utilized. Relative contraindications continue to evolve as modifications to the technique improve functionality. Relative contraindications for the reverse sural flap have included patients with one or several of the following comorbidities: history of smoking, current smoker, obesity, diabetes, peripheral vascular disease, venous insufficiency/venous outflow disease and old age [1, 2, 3]. Older literature suggests up to 36% complication rate in these patient populations [1]. More recently, this data was supported further, identifying statistically significant increases in both major and minor reverse sural flap complications in patients with one or multiple noted comorbidities when compared to patients with no comorbidities. Smoking alone was noted to be the most significant independent risk factor for flap necrosis and ultimate failure [4]. One other relative contraindication is in those patients that are extremely high risk for limb loss. In these scenarios, alternative options must be contemplated by the surgeon as a posterior gastrocnemius flap would be required should a below knee amputation be indicated. In higher risk patient populations, a delayed technique for harvesting of the graft should be considered.

Vascular Supply

The anatomic basis of the reverse sural flap has been well documented in the literature [5]. The success of the reverse sural flap is predicated on the ability to correctly incorporate its vascular supply which is based off the sural nerve and, to a greater extent, the sural artery which provides the true vascular network as it continues into the retromalleolar region and communicates with several anastomoses with the peroneal artery. Perforator arteries are identified at reproducible locations with the pivot point along the arc of rotation noted most commonly 5 cm–7 cm proximal to the distal tip of the fibula. Many surgeons have suggested a 3 finger-width proximal to the lateral malleolus technique for locating the pivot point of the flap. The vascular supply determines the proximal location of the circular paddle at the junction of the two heads of the gastrocnemius muscle. Proximal to this level, the sural nerve and vascular bundle are deep to the deep fascial plane within the popliteal fossa.

Venous outflow is provided by the sural vein and its branches and is critically important for successful management of fluid balance. Venous congestion can inhibit adequate fluid exchange and can lead to ultimate failure.

Why Delay?

Utilizing the delayed technique and harvesting the paddle over an extended time period can increase adequate fluid exchange and decrease likelihood of necrosis that often occurs with a more acute transposition. Delaying the flap improves blood flow to the tissue by increasing vessel size and allowing vessels to undergo reorientation [6]. Furthermore, delaying transposition provides time for "choke vessels" to open which in turn, increases perfusion to the flap edges and decrease necrosis [7]. Delay technique is associated with decreased ischemic flap complications in challenging patient populations with significant comorbidities [8].

Operative Technique: A stepwise approach

Identification of the junction of the two heads of the gastrocnemius proximally is completed. Originally, the line of incision was then traced following the course of the sural neurovascular bundle with the pivot point for the arc of rotation at 5 cm–7 cm proximal to the distal tip of the lateral malleolus. More recently, there have been modifications and advancements with multiple different reverse sural flap techniques. This provides the surgeon with options in determining flap design based on lower extremity pathology and patient population (**Figure 1**).

The skin paddle is elevated identifying and isolating the subcutaneous fascial pedicle followed by raising the flap and pedicle with the fascia included (**Figure 2**). The harvested flap must be 1.5 cm larger in diameter then the total defect to account for retraction of the tissues over time. Arterioles can be carefully ligated and cauterized. A fasciocutaneous or adipofacsial harvest can be completed and carried the entire length of the pedicle or alternatively the flap may include a fasciocutaneous proximal paddle and an entirely adipofascial pedicle distally to the level of the pivot point.

Delayed technique provides a stepwise approach to raising the paddle and pedicle in sections and allowing a period of days to weeks with the flap reapproximated

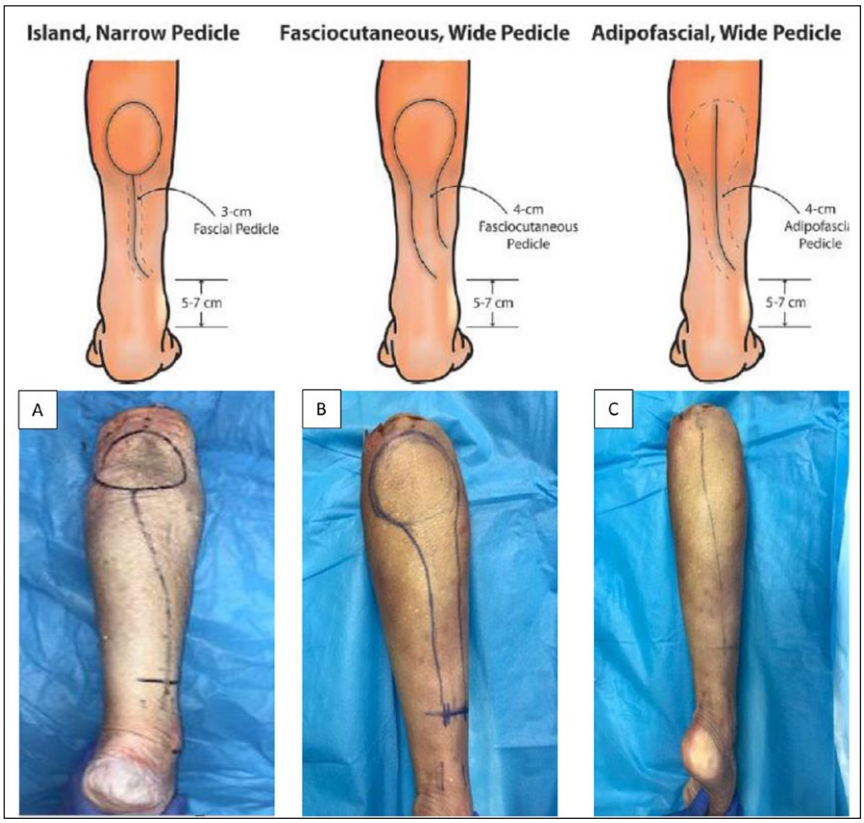

Figure 1: 3-cm adipofascial pedicle with skin paddle **(A)**. 4-cm adipofasciocutaneous pedicle **(B)**. 4-cm adipofascial pedicle **(C)**.

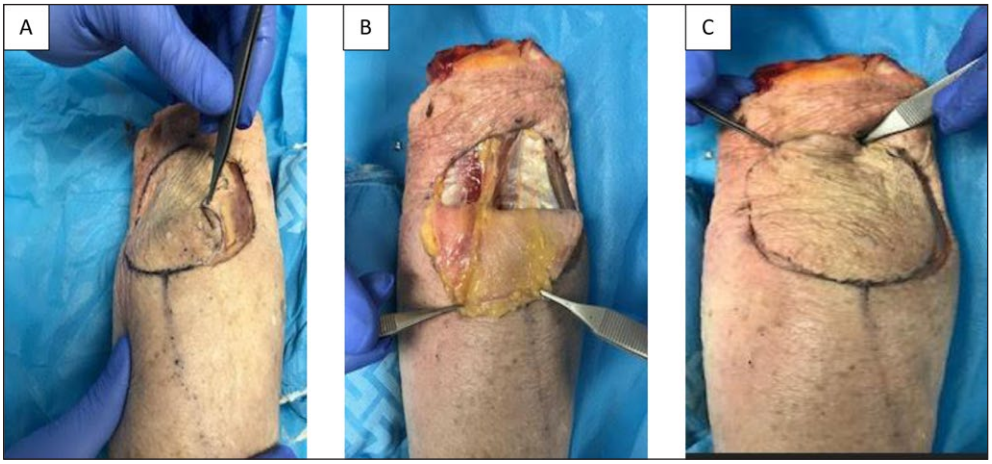

Figure 2: Stepwise approach identifying **(A)** and elevating cutaneofascial pedicle **(B)** followed by reapproximation within harvest site **(C)**.

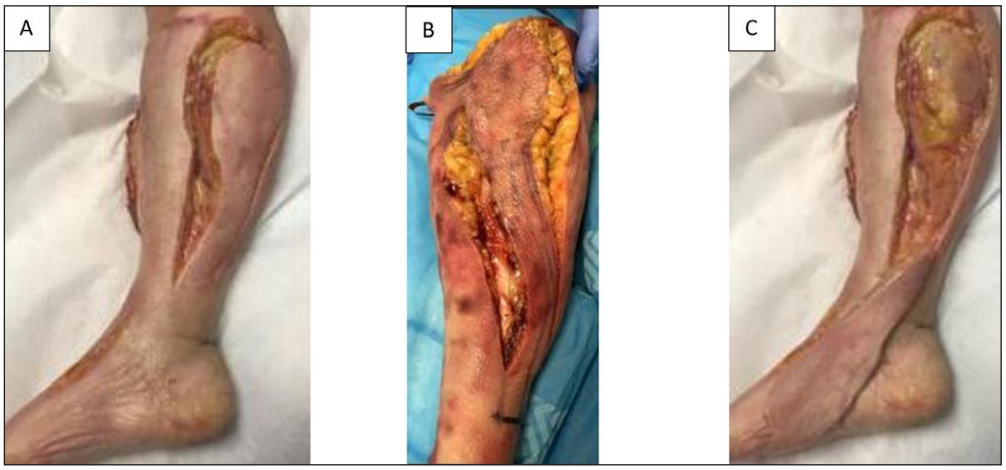

Figure 3: Elevation of medial section of the paddle and pedicle with reapproximation **(A)** complete elevation with reapproximation **(B)** harvest with arc of rotation and transposition **(C)**.

in the donor site for better adaptation of tissues prior to transposition (**Figure 3**).

A sterile glove can sometimes be used as a barrier between the flap and donor site and can be placed prior to re-approximating the flap within the donor site using stitches (**Figure 4**) [3]. The time for delay is variable within the literature, however, 4–15 days of delay leaving the flap approximated within its donor site prior to transposition is well supported. This time frame can be modified based on the pathophysiology and patient population, delaying for a longer time period in more challenging pathology and significant comorbidity history [8]. Furthermore, the utilization of a wider, more pronounced pedicle and its benefits regarding flap viability have been documented in the literature [9, 10]. We feel that no less than 3 cm in a narrow island pedicle flap should be utilized and suggest a 4 cm pedicle whenever possible to increase venous outflow and perfusion of the flap.

The delayed technique also allows preparation of the recipient site. This can be debrided and covered with temporary skin substitute which can often help to provide a granular base to the recipient site with a more vascular micro-network. This is especially important in challenging patient populations.

Modifications in flap design have provided the surgeon with multiple options for harvest based on patient population and noted comorbidities [9]. Each design is well adapted to the delay technique and can be utilized based on patient requirements and noted pathology. A recommended dissection guide summarizing the specifics of each technique is noted in **Table 1** below.

Complications

Despite improved outcomes of the reverse sural flap 2ndary to multiple modifications and better understanding of flap hemodynamics, surgeons continue to encounter several complications with this procedure. Venous congestion, flap compression and flap necrosis have all been well documented within the literature. As stated in literature, there is no functional hemodynamic role for subcutaneous veins in distally based flaps that usually engorge and finally thrombose in the postoperative period; the result is venous hypertension hindering venous drainage through valveless veins within the flap; so it is advisable not to include in the flap or to ligate at the base subcutaneous veins in order to reduce the risk of flap congestion [11].

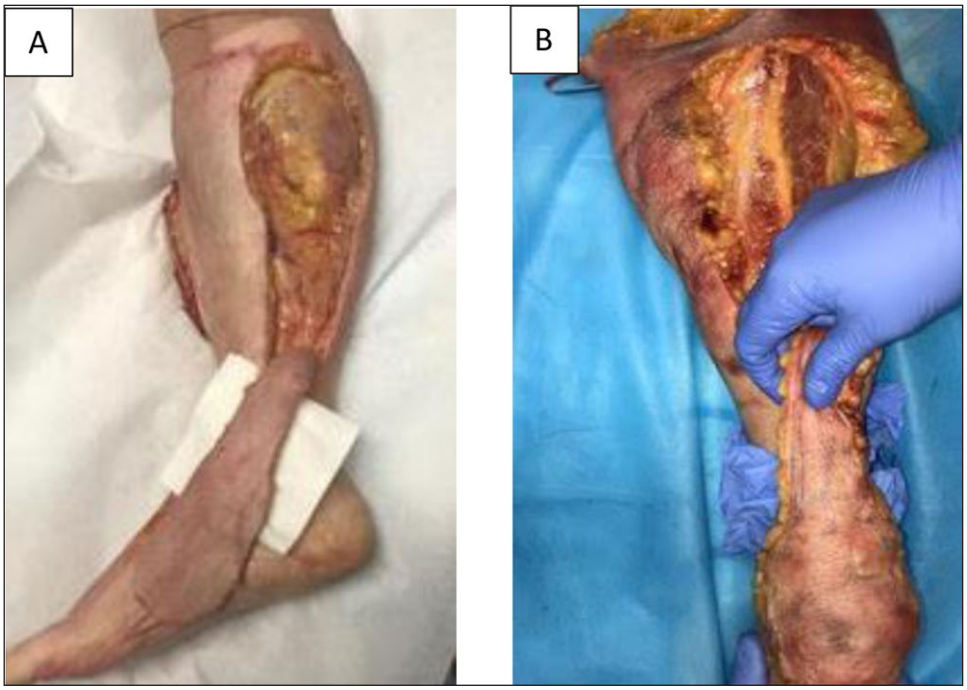

Figure 4: Delay technique with skin spacer **(A)** alternatively utilizing sterile glove spacer **(B)**.

Table 1: Summary of recommended surgical dissection based on modification technique for delayed reverse sural flap.

Flap design	Dissection level	Pedicle width	Vascular supply	Pivot point	Advantages	Disadvantages	Tissue coverage Reach	Time for delay
A. Island narrow pedicle	fasciocutaneous/proximal island Adipofascial/distal pedicle	3 cm	Anastomoses of sural and peroneal branch network	7 cm proximal to distal fibula	-versatile -no skin graft distally -smaller pedicle required -accommodates delay technique -Regional anesthesia	-Requires skin graft proximally -requires better venous outflow	Lower leg, medial & lateral malleoli, posterior heel, dorsum of foot aspect of forefoot	7–15 days
B. Fasciocutaneous wide pedicle	Fasciocutaneous proximal to distal	4 cm	Anastomoses of sural and peroneal branch network	7 cm proximal to distal fibula	-versatile -accommodates delay technique -can detach pedicle and reapproximate once island has incorporated -no skin graft distally -indicated for multiple comorbidities pt populations -Regional anesthesia	-requires skin graft proximally -requires larger pedicle harvest	Lower leg, medial & lateral malleoli, posterior heel, dorsum of foot aspect of forefoot	7–15 days
C. Adipofascial wide pedicle	Adipofascial proximal to distal	4 cm	Anastomoses of sural and peroneal branch network	7 cm proximal to distal fibula	-versatile -accommodates delay technique --no skin graft proximally -provides skin should BKA be required -Regional anesthesia	-requires skin graft distally -requires larger pedicle harvest -requires better venous outflow	Lower leg, medial & lateral malleoli, posterior heel, dorsum of foot aspect of forefoot	7–15 days

Furthermore, flap viability has been evaluated in multiple previous studies suggesting that the length to width ratio of the flap and location of the flap harvest is a significant factor in successful outcome [12]. often this concern leads to a smaller length of flap harvest and decreased arc of rotation and loss of more distal application sites [13]. The delay techniques discussed allow for incorporation of a wider paddle (3–4 cm) essentially decreasing the length to width ratio without necessarily sacrificing distance of flap rotation providing distal targets for flap implantation and increasing indications for flap use.

Summary for Success

Patient selection, extensive pre-operative workup including vascular assessment and a well planned surgical decision making play a large role in successful post-operative outcomes. This combined with utilizing a surgical algorithm to help determine the best modification of the reverse sural nerve flap incorporating the delay technique can decrease the likelihood of many of the complications often encountered with the procedure. This modified delay sural flap technique will provide consistent results mitigating venous congestion and allow time for vascular networks to stabilize increasing successful outcomes.

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Competing Interests

The authors have no competing interests to declare.

Author Contributions

Ryan Vazales, Edgardo Rodriguez-Collazo and Alessandro Thione participated in the dissection studies and preparation of th papers.

Guarantor

Edgardo Rodríguez-Collazo primary responsibility for the integrity of this article and consultant for Integra.

Peer Review

This is a non-commissioned paper that has undergone external peer review according to journal policy.

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