“Racing-stripe” Modification of Radial Forearm Free Flap: Technique and Experience (704 Consecutive Cases)

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Background: The radial forearm fasciocutaneous free flap (RFFF) has proven to be a versatile and reliable tool for the reconstructive microsurgeon when addressing soft-tissue defects. A significant drawback of the traditional RFFF is related to donor site morbidity and wound healing complications, especially when coverage of sizable defects is planned. The authors describe the “racing-stripe” modification of the RFFF (RS-RFFF) that involves harvesting a large segment of the deep forearm fascia with a narrow strip of skin overlying the radial vessels, thus allowing primary closure of the donor site.

Methods: Retrospective chart review was conducted of a single surgeon’s (E.G.M.) experience of patients who underwent RS-RFFF.

Results: Seven hundred four RS-RFFFs were performed in 698 patients over a 19-year period (2000–2019) for lower extremity reconstruction (657 flaps, 93.3%), upper extremity reconstruction (32 flaps, 4.5%), and head and neck reconstruction (15 flaps, 2.1%). Wounds secondary to trauma were the most common reason for flap reconstruction (655 wounds, 93.8%). Five hundred four RS-RFFFs were used for soft-tissue defects of the foot (129 flaps, 18.3%), ankle (309 flaps, 43.9%), and heel (66 flaps, 9.4%; 27 of which provided coverage for Achilles tendon repair or exposure). There were three flap losses (0.4%). Limb salvage rate was 100% for extremity wounds. Forearm donor site wound complications were minimal.

Conclusions: The RS-RFFF can be consistently and safely harvested and permits low-profile, reliable coverage of small-to-medium size soft-tissue defects. Primary closure of the donor site is possible in all cases, thus minimizing wound healing complications. (Plast Reconstr Surg Glob Open 2022;10:e4682; doi: 10.1097/GOX.0000000000004682; Published online 28 November 2022.)

INTRODUCTION

Since its original description from China in 1981 by Yang et al., the radial forearm fasciocutaneous free flap (RFFF) has proven to be a workhorse flap in the armamentarium of the reconstructive microsurgeon because of its versatility, thin and pliable soft tissue, consistent long and large caliber vascular pedicle, and relative ease of elevation. However, a significant drawback of the traditional RFFF is the associated donor site morbidity, which has been well documented. Wound healing problems may develop when split-thickness skin grafting (STSG) is required for coverage of the forearm flap donor site. In areas of marginal skin graft take, there is potential for tendon exposure and subsequent wound healing issues that may necessitate an extended period of dressing changes to heal secondarily. This has been reported to be as high

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as 16%\textsuperscript{2,5} to 28%.\textsuperscript{4,5} In addition, the grafted donor site scar has been described as conspicuous\textsuperscript{9} and with poor cosmesis.\textsuperscript{7}

Different measures have been proposed in an attempt to minimize donor-site wound healing problems. There are proponents of suprafascial radial forearm flap harvest,\textsuperscript{1,10} which preserves a reliable fascial recipient bed for skin grafting, diminishes the risk of postoperative tendon exposure,\textsuperscript{10} and prevents flexor tendon bowstringing.\textsuperscript{11} Some surgeons have utilized various local skin flaps for coverage of the forearm donor site to eliminate the requirement for a graft altogether\textsuperscript{12-14}; however, these techniques are sometimes limited by the size of the forearm defect. Alternative strategies proposed to address some of the aesthetic concerns related to the forearm donor site include the use of full-thickness skin grafts,\textsuperscript{16} acellular dermal matrix,\textsuperscript{17} and artificial dermal templates.\textsuperscript{18}

In an effort to minimize the wound healing issues of the forearm donor site and the potential aesthetic deformity often associated with a healed skin graft of the forearm, the senior author adopted a straightforward modification of the RFFF, which allows primary donor site closure in all cases. The purpose of this study is to describe the technique of the “racing-stripe” modification of the RFFF (RS-RFFF) and to review a single surgeon’s 19-year experience using this flap for coverage of soft-tissue defects in different anatomic locations.

**METHODS**

Institutional review board approval was obtained for this study (IRB ID: HSC-MS-20-0066). We conducted a retrospective chart review of a single surgeon’s practice to collect data on all patients who underwent RFFF utilizing the described RS-RFFF. We identified 704 flaps, all performed by the senior author (E.G.M.), over a period of 19 years (2000–2019). Relevant data were recorded, including patient demographics, etiology of defect/mechanism of injury in cases of trauma, wound location, recipient vessels, and the number of veins used for flap drainage. Data were also collected on flap complications, donor site complications, and any secondary procedures that were performed, such as future flap re-elevation or revision/debulking procedures. Outcome measures included flap survival and limb salvage when the flap was used for extremity reconstruction.

**Surgical Technique**

Preferably, the nondominant forearm is selected for the flap site. [See Video 1 (online), which shows the RS-RFFF flap design, marking, and dissection.] The adequacy of collateral circulation through the ulnar artery is assessed with a preoperative Allen test and confirmed intraoperatively with a handheld Doppler (Fig. 1A). The course of the radial artery is marked out on the skin. The flap is designed with a 1–2-cm-wide longitudinal skin island centered on the axis of the radial vessels, which will permit primary closure of the donor site (Fig. 1A).

Under tourniquet control, the narrow “stripe” of skin is incised circumferentially. [See Video 2 (online), which shows the RS-RFFF flap dissection (continued); see Video 3 (online), which shows the RS-RFFF flap dissection (continued), division, donor site closure, flap inset, and postoperative appearance; see Video 4 (online), which shows the RS-RFFF representative cases by location (ankle, foot, heel, lower leg, middle leg, upper leg, arm, elbow, forearm, hand, head, bilateral lower extremities, and flow through)]. Electrocautery dissection proceeds through the subcutaneous plane until the antebrachial fascia is identified. Dissection continues in the suprafascial plane, radial and ulnar to the skin island, exposing a large segment of the deep fascia from 1-cm radial to the cephalic vein to 1-cm ulnar to the palmaris longus tendon (Fig. 1B). The deep fascia is incised ulnar to the palmaris longus, and dissection proceeds in the subfascial plane, elevating the fascia from the palmaris longus and flexor carpi radialis tendons and musculature. The interval between flexor carpi radialis and brachioradialis is reached, and the intermuscular septum is elevated, incorporating the radial artery and its paired vena comitans (Fig. 1C). The antebrachial fascia is then incised radial to the cephalic vein, and dissection continues in the subfascial plane in continuity with the cephalic vein. The branches of the superficial radial nerve are meticulously dissected and preserved. The radial vessels are ligated at the wrist, and the flap is islanded on its pedicle (Fig. 1D). Dissection of the flap pedicle can proceed proximally up to the origin of the radial vessels, depending on pedicle length requirements. Typically, a flap width of 7.5 cm can be obtained while flap length can be adjusted according to recipient wound dimensions. The tourniquet is deflated, and appropriate perfusion to the hand is verified. A closed suction drain is placed, and the forearm donor site is closed in a layered fashion.

Following flap transfer and microvascular anastomoses, the fascial component of the flap is sutured to the periphery of the soft-tissue defect (Fig. 1E, F). The flap is covered with an STSG. The cutaneous island of the flap can be deepithelialized where aesthetically objectionable. Postoperatively, patients are admitted to a dedicated microsurgery unit. Flaps are monitored closely by clinical examination and with the use of a handheld Doppler.
Dressings are changed on postoperative day 4, and a dangling protocol is started. Donor and recipient sites are followed postoperatively for healing progress (Fig. 1G, H).

RESULTS

Over a period of 19 years (2000–2019), 704 RFFFs with the described “racing-stripe” modification were utilized for soft-tissue reconstruction in 698 patients (Table 1): 481 men (68.9%) and 217 women (31.1%) with a mean age of 42.2 years (range, 4–88 years). One hundred nineteen (17%) patients were active smokers. Six hundred fifty-five (93.8%) patients had soft-tissue defects that were of traumatic origin' with the most common etiology being motor vehicle collisions (228 patients, 34.8%) followed by falls (102 patients, 15.6%) and motorcycle collisions (94 patients, 14.3%).

Soft-tissue defects of the lower extremity (Table 1) comprised the majority of the wounds that underwent RS-RFFF reconstruction (657 flaps, 93.3%). Most of these free flaps were used for coverage of ankle wounds (309 flaps, 43.9%). The RS-RFFF was also utilized for soft-tissue reconstruction in other areas of the lower extremity, including the foot (129 flaps, 18.3%), heel (66 flaps, 9.4%; 27 of which provided coverage for Achilles tendon repair or exposure), and distal-third level (102 flaps, 14.5%). Compared with lower extremity reconstruction, the RS-RFFF was used less frequently for reconstruction of head/neck soft-tissue defects (15 flaps, 2.1%) and upper extremity wounds (32 flaps, 4.5%).

Flap microvascular data are presented in Table 2. The posterior tibial artery was selected most often as a recipient artery for lower extremity reconstruction (411 flaps, 58.4%). Overall, arterial anastomosis of the radial artery to recipient vessels was performed in an end-to-side manner in 459 (65.2%) flaps. For flap venous drainage, at least two veins were used for venous anastomosis in 678 (96.3%) flaps. The most common flap venous drainage pattern consisted of a single vena comitans and the cephalic vein in 566 (80.4%) flaps.

Mean follow-up was 14 months (range, 4 months–12 years). There was a 1.4% rate (10 cases) of emergent return to the operating room for the following reasons (Table 3): flap ischemia (two cases, 0.3%), flap congestion (four cases, 0.6%), and flap hematoma (four cases, 0.6%). There were three flap losses (0.4%). Forearm donor site complications included wound dehiscence (two cases, 0.3%) and infection (three cases, 0.4%). Reconstruction of the radial artery at the forearm donor site was not required in any cases.

Secondary reelevation procedures (Table 3) were performed in 76 flaps (10.8%) for various reasons, including the following: removal of symptomatic hardware (18 flaps, 2.6%), hardware infection/osteomyelitis (32 flaps, 4.5%), and additional reconstruction (26 flaps, 3.7%), such as bone grafting, revision hardware, and tenolysis. Operations solely undertaken for flap debulking were performed in four flaps (0.6%). There were no documented postoperative wound healing complications following flap reelevation procedures. Limb salvage rate was 100% (689 cases) when the flap was performed for extremity reconstruction.

Figures 1–3 and Videos 1–4 (online) show wound, flap inset, and long-term results of representative patients treated with this technique.
DISCUSSION

The RFFF has been an invaluable tool for the reconstructive microsurgeon since its original description in 1981. The exceptional reliability of the flap is mainly due to the presence of a large caliber artery with numerous perforating vessels supplying a large cutaneous territory and the availability of both the cephalic vein and vena comitans to be used alone or in combination as a venous outflow system. With the goal of minimizing forearm donor site morbidity often associated with the traditional RFFF, the senior author (E.G.M.) developed a simple flap design revision that we have referred to as the “racing-stripe” modification. The aim of this study was to describe the technique of the RS-RFFF and to report on a single surgeon’s 19-year experience using the flap for soft-tissue reconstruction.

The RS-RFFF has been a workhorse flap at our institution because of its reliability and utility, particularly in the reconstruction of foot and ankle soft-tissue wounds where thin coverage is essential for proper shoe fitting. The forearm donor site morbidity often associated with the traditional RFFF has been minimized. The RS-RFFF can be raised expeditiously because of the straightforward, consistent anatomy; and in most cases, allows a comfortable two-team approach, thus adding to the operative efficiency of the procedure that has been beneficial for a high-volume reconstructive microsurgery practice.

The modification consists of harvesting a large segment of the deep forearm fascia while incorporating a narrow skin paddle overlying the radial vessels (Fig. 4), thus permitting tension-free primary closure of the donor site. The final design of the flap modification was based on years of clinical observations indicating all of the following: the deep fascia initially becomes congested and subsequently hypertrophies, large vessels supplying a small amount of tissue remain patent, and careful dissection in the suprafascial plane with wide undermining of the forearm skin is well tolerated. The full-thickness strip of skin helps facilitate flap dissection, provides a measure of protection against injury to the underlying radial vessels

Table 1. Patient and Wound Characteristics

| Patient Characteristics                  | 698 Patients |
|-----------------------------------------|--------------|
| Male, n (%)                             | 481 (68.9)   |
| Female, n (%)                           | 217 (31.1)   |
| Mean age (range, 4–88 y)                | 42.2 y       |
| Smoking, n (%)                          | 119 (17.0)   |
| Mean follow-up (range, 4 mo–12 y)       | 14 mo        |

Table 2. Flap Microvascular Characteristics

| Recipient Artery                          | 704 Flaps, n (%) |
|------------------------------------------|------------------|
| Head and neck                            | 15 (2.1)         |
| Superficial temporal                     | 4 (0.6)          |
| Facial                                   | 5 (0.7)          |
| External carotid                         | 2 (0.3)          |
| Superior thyroid                         | 4 (0.6)          |
| Upper extremity                          | 92 (13.5)        |
| Brachial                                 | 16 (2.2)         |
| Radial                                   | 3 (0.4)          |
| Ulnar                                    | 11 (1.6)         |
| Vascular graft                           | 2 (0.3)          |
| Lower extremity                          | 657 (93.3)       |
| Femoral                                  | 1 (0.1)          |
| Peroneal                                 | 5 (0.7)          |
| Anterior tibial                          | 186 (26.4)       |
| Posterior tibial                         | 411 (58.4)       |
| Dorsalis pedis                           | 33 (4.7)         |
| Medial plantar                           | 18 (2.6)         |
| Vascular graft                           | 3 (0.4)          |
| Arterial anastomosis                     | 704 Flaps, n (%) |
| End-to-end                               | 245 (34.8)       |
| Flow-through flap                        | 5 (0.7)          |
| End-to-side                              | 459 (65.2)       |
| Flap venous drainage                     | 704 Flaps, n (%) |
| One vena comitans and cephalic vein      | 566 (80.4)       |
| Two vena comitans                        | 104 (14.8)       |
| Cephalic vein only                       | 8 (1.1)          |
| One vena comitans                        | 18 (2.6)         |
| Two vena comitans and cephalic vein      | 8 (1.1)          |

Table 3. Flap Complications, Donor Site Complications, and Secondary Flap Operations

| Flap Complication                        | 704 Flaps, n (%) |
|------------------------------------------|------------------|
| Emergent return to operating room        | 10 (1.4)         |
| Flap ischemia                            | 2 (0.3)          |
| Flap congestion                          | 4 (0.6)          |
| Flap hematoma                            | 4 (0.6)          |
| Flap loss                                | 3 (0.4)          |
| Skin graft loss                          | 5 (0.7)          |
| Donor Site Complications                 | 704 Donors, n (%)|
| Infection                                | 3 (0.4)          |
| Wound dehiscence                         | 2 (0.3)          |
| Hematoma                                 | 0 (0)            |
| Hand ischemia                            | 0 (0)            |

| Secondary Flap Operations                | 704 Flaps, n (%) |
|------------------------------------------|------------------|
| Reclevation procedure                    | 76 (10.8)        |
| Symptomatic hardware                     | 18 (2.6)         |
| Hardware infection/osteomyelitis         | 32 (4.5)         |
| Additional reconstruction (bone grafting, revision hardware, and tenolysis) | 26 (3.7) |
| Flap debulking procedure                 | 4 (0.6)          |
during flap harvest and at the recipient site, and serves an important role in clinical postoperative flap monitoring in conjunction with handheld Doppler evaluation. Inclusion of the narrow, longitudinal skin component with flap elevation eliminates excess laxity from the forearm donor site and allows for a smooth linear closure.

Most of the flaps in this series were performed for reconstruction of lower extremity soft-tissue wounds secondary to trauma (Table 1). Although the flaps were utilized for coverage in various locations of the lower extremity, the most common regions in which the flap was used were for soft-tissue reconstruction included foot wounds (129 flaps) and ankle wounds (309 flaps), where bulk is not well tolerated. Also, the RS-RFFF was used for coverage of distal-third lower extremity wounds (102 flaps) as well as in heel wounds (66 flaps, 27 of which provided coverage for Achilles tendon repairs or exposures). The RS-RFFF has the potential to be designed as a flow-through flap and was used for the dual purpose of arterial reconstruction and extremity coverage in five cases (Table 2).

With a flap success rate of greater than 99% in this series, the RS-RFFF has been a reliable coverage option for shallow, small- to medium-sized soft-tissue defects in a variety of anatomic regions (Tables 1, 3). This flap success rate compares favorably with other published data, specifically for lower extremity trauma.23,26 There were three flap failures in our series, all of which occurred late (12, 14, and 21 days postoperatively) (Table 3). All had been performed for coverage of lower extremity injuries. Two of these flap losses were managed with debridement, serial wound VAC dressing changes, and subsequent adjacent tissue advancement/STSG. The third flap failure required free flap coverage, and the contralateral RS-RFFF was used. We have found that the RS-RFFF can be safely reelevated for secondary procedures such as hardware removal or bone grafting without compromising flap viability or causing wound healing issues. Flap debulking procedures are rarely required. For extremity wounds, limb salvage rate was 100%.

Our preference for venous drainage of the RS-RFFF was to use at least two veins (678 flaps, 96.3%), most often a single vena comitans and the cephalic vein for dual venous drainage (566 flaps, 80.4%) (Table 2). Anastomosis of at least one vena comitans was performed in most cases (696 flaps, 98.9%) since we believe that the deep system represents the more reliable drainage pathway, particularly for the RS-RFFF that we describe in this series. With the presence of a superficial (cephalic vein) and deep (vena comitans) venous drainage system, there has been considerable discussion as to what constitutes the optimal venous outflow of the RFFF. Although some surgeons advocate for a single, superficial venous
Fig. 3. RS-RFFF representative case (left lower extremity). This 60-year-old woman was involved in a motorcycle collision and transferred from an outside hospital with an open grade III B distal tibial-fibular pilon fracture of the left lower extremity. A, Wound following serial irrigation and debridement and bone stabilization with pins, screws, and application of an external fixator. B, RS-RFFF inset just before placement of STSG. Microvascular anastomoses consisted of end-to-side arterial anastomosis to the anterior tibial artery and two venous anastomoses for flap drainage (using both flap vena comitans). C, The patient is shown here at 18 months postoperatively with the flap well-healed and with good contour. Flap reelevation was required for bone grafting and fixation of a distal tibia nonunion. There were no wound healing sequelae following the secondary flap reelevation procedure. D, Forearm donor site well-healed and with good contour.

Fig. 4. Schematic drawing illustrating RS-RFFF cross-sectional anatomy and dissection planes. A, Radial vessels. B, Antebrachial fascia. C, Cephalic vein. D, Superficial branches of the radial nerve.
anastomosis with good success,\textsuperscript{21,22} others report higher failure rates due to venous thrombosis when the superficial system is used alone for flap drainage.\textsuperscript{23,24} There are proponents of using the deep system alone for flap drainage.\textsuperscript{25} Studies have documented the reliability of using a single vena comitans for flap drainage.\textsuperscript{26} Hemodynamic studies of the radial forearm flap document the importance of the deep venous system, which accounts for a significantly higher flow volume compared with a superficial vein.\textsuperscript{27} Nevertheless, there still does not seem to be definitive evidence as to the best strategy to ensure adequate flap drainage with regard to the use of the deep and/or superficial system. In addition, the benefit of performing one versus two venous anastomoses remains debatable.

Wound healing complications of the RFFF donor site have been reported to be as high as 16%\textsuperscript{25} to 28%\textsuperscript{4,5} and can be due to marginal skin graft take, tendon exposure, and subsequent healing delays.\textsuperscript{2,4} We report a forearm donor site complication rate of 0.7% (five cases) (Table 3). Secondary skin grafting of the forearm donor site was required in one case for an extensive area of dehiscence. Since the flap modification allows primary tension-free closure of the donor site, wound problems have rarely been encountered. In addition, primary closure may reduce the potential for an unfavorable and unstable scar that can follow skin grafting of the forearm donor site in the traditional RFFF. We have utilized this “racing-stripe” principle in the planning and execution of lateral arm free flaps with the similar goal of minimizing donor site wound healing issues.

We recognize that there may be limited applicability of this flap in certain clinical situations. For example, the RS-RFFF would not be suitable for cases that require a large cutaneous component, as in many head and neck oncologic reconstructions. Also, we do not believe this flap is the best coverage option for deep, large surface area extremity wounds with substantial fracture and hardware exposure, such as many of the Gustilo IIIB fractures that are encountered at our level I trauma center. Alternative flap options are considered for these more complex wounds. The exceptional flap success rate in our study likely reflects its intentional use for coverage of less complicated wounds from lower energy injuries.

There are limitations to this case series, which is retrospective in nature and subject to the inherent limitations of such a study. We do not have a control group for comparison. Ideally, these flaps could be compared with the traditional RFFF with analysis of both donor site data and recipient site data. In our study, the following donor site data were not consistently available: incidence of cold intolerance, range of motion measurements, sensory disturbances of the superficial branch of the radial nerve, and scar quality of the forearm. Such data collection would be useful for future studies of this flap.

**CONCLUSIONS**

The described RS-RFFF has proven to be a safe, reliable alternative to the traditional RFFF for coverage of small-to-medium size soft-tissue defects with potential applicability at different anatomic locations. The skin paddle modification has minimized donor site wound problems such as delayed healing and tendon exposure because the forearm donor site is closed primarily in a tension-free manner in all cases.
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