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CLINICAL ARTICLE

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The radial forearm free flap as a "vascular bridge" for secondary microsurgical head and neck reconstruction in a vessel-depleted neck

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Background: In a vessel-depleted neck, distant recipient sites may be the only option for secondary free flap reconstruction. While interposition vein grafts and arteriovenous loops can bridge the gap between the recipient and donor pedicle, they are not without risks. In these scenarios, we examinate the reliablity of a radial forearm free flap (RFFF) as an alternative vascular conduit.

Patients and methods: A retrospective review of cases between March 2005 and May 2016 was performed. Demographic data, prior surgical history, intraoperative details and outcomes were recorded. A total of ten patients, eight male and two female, with a mean age of 54.2 years (range, 39–74) were identified. The RFFF was initially anastomosed to either the thoracoacromial ($n = 6$) or internal mammary vessels ($n = 4$) and subsequently served as the recipient pedicle for the second "main" flap, an anterolateral thigh ($n = 4$), jejunum ($n = 3$) or fibula flap ($n = 3$).

Results: The average RFFF dimensions were 13.8 cm by 5.8 cm. All twenty flaps, ten RFFF and ten "main' flaps survived completely with only one case of minimal epidermal loss. One patient with esophageal reconstruction with jejunum developed a fistula that required closure with a local falp. At a mean follow-up of 18.4 months (range 8–29), the reconstructive goals had been achieved in all cases.

Conclusions: The RFFF serves as a reliable "vascular bridge" that extends the reach of distant recipient sites to free flaps in secondary head and neck reconstruction.

1 | INTRODUCTION

Head and neck reconstruction in a vessel-depleted neck can be a arduous task and the choice of vessels can directy affect the outcome (Yazar et al., 2005). Previous surgical insult and/or irradiation can make it difficult to identify reliable recipient vessels within the reach of the flap. In an attempt to overcome this problem and achieve a successful secondary reconstruction, several strategies have been suggested including flaps with long pedicles and/or recipient neck vessels outside the zone of injury such as the transverse cervical artery in an antegrade or retrograde fashion (Ciudad et al., 2017; Hanasono, Barnea, & Skoracki, 2009; Head et al., 2002; Wong, Higgins, & Enepekides, 2010; Yu, 2005).

In certain situations these options are either suboptimal due to the geometry of the pedicle or unavailable (Urken, Vickery, Weinberg, Buchbinder, & Biller, 1989). The thoracoacromial and internal mammary vessels have both been used in this context and many times vein grafts and arteriovenous loops are used to reach these relatively distant sites (Angel et al., 1993; Furr, Cannady, & Wax, 2011; Hanasono et al., 2009; Harris, Lueg, Genden, & Urken, 2002; Jacobson, Smith, & Urken, 2013; Lin et al., 2004; Miller, Schusterman, Reece, & Kroll, 1993; Nelson et al., 2015; Roche, Houtmeyers, Vermeersch, Stillaert, & Blondeel, 2012; Urban & Fritsche, 2006; Urken, Higgins, Lee, & Vickery, 2006; Wong et al., 2010; Yagi, Kamei, Fujimoto, & Torii, 2007). Nevertheless, the severely fibrotic nature of the irradiated neck tissue may not be pliable enough to allow tunneling or reliable coverage of these vascular conduits, especially when the distance to be covered is large, resulting in compression, kinking, and eventual flap loss.

For this purpose, a flow-through flap is more reliable as the vascular pedicle is well protected with a reliable soft tissue-skin envelope. Hence, it is not surprising that it has been widely reported in the literature as a lifeboat option when recipient vessel options are limited. In head and neck reconstruction, the flow-through flap has usually served a dual purpose. While the vascular axis supplies the second flap, the nonvascular constituents of the flap are used to reconstruct part of the usually extensive defect. The aim of this report is to present our experience with the radial forearm free flap (RFFF) used solely for the purpose of providing reliable vascular supply from the thoracoacromial or internal mammary vessels to a second "main" flap in the head and neck region in the unfavorable scenario of a scarred, vessel-depleted neck.

2 | PATIENTS AND METHODS

From March of 2005 to May of 2016, ten patients underwent a combination of a "vascular bridge" RFFF and a second "main" flap. There were 8 male and 2 female patients; the mean age at surgery was 54.2 years (range 39–74). Indications included mandibular, oral cavity, and pharyngoesophageal reconstruction in the setting of previous surgery and radiotherapy. Both flaps were harvested and transferred in the same sitting. The second "main" flaps used were anterolateral thigh ($n = 4$), jejunum ($n = 3$), and fibula flaps ($n = 3$). The retrospective review was conducted after approval by the research ethics committee and the Helsinki declarations were strictly adhered to in the course of this study. Informed consent was taken from all the patients for being included in the study and for publishing diagnostic studies and clinical images.

3 | SURGICAL TECHNIQUE

All procedures were performed under general anesthesia and previous surgical incisions were used for neck exploration. First, the thoracoacromial (TA) ($n = 6$) or internal mammary (IM) vessels ($n = 4$) were prepared for microanastomosis. The skin paddle of the RFFF was then planned with a width of 5–6 cm centered over the radial pedicle. The ends of the skin paddle were designed wider, in the shape of a "dog bone", to provide good coverage of both anastomotic sites. The length of the skin paddle was tailored to the individual case so as to bridge the gap between the second flap and the recipient pedicle. After the RFFF was harvested, one team proceeded to anastomose the proximal ends of radial artery and veins to the recipient pedicle. If the anatomy was suitable, we connected single big vein from the proximal RFFF to a matching size recipient vein (Figure 1). If two proximal RFFF venae comitantes were to be connected instead, we performed two vein anastomoses (proximal and distal internal mammary veins or thoracoacromial vein branches). The skin paddle of the RFFF was temporarily stapled to the surrounding skin. Whenever deemed necessary, contractures or scarred areas along the path of the RFFF were excised and resurfaced with the flap. In the meantime, a second team harvested the second "main" flap, dimensions of which were matched to the post excision defect. The flap was then inset into the defect followed by anastomosis of the artery and veins of the flap to the distal end of the RFFF pedicle. Double venous anastomosis was performed in all cases. In the case of anterolateral or fibula flaps, we dissected the venae comitantes on both the RFFF and second 'main" flap until we were able to achieve a good size match. However, in four cases, a large sized fibula vena comitans (Figure 1) or the main draining vein of the jejunum flap was anastomosed to an internal jugular vein branch. We still performed a second venous microanastomosis by connecting the smaller fibula vena comitans or jejunum flap venous side branch to one radial vena comitans. The definitive RFFF inset was the final step. Drains

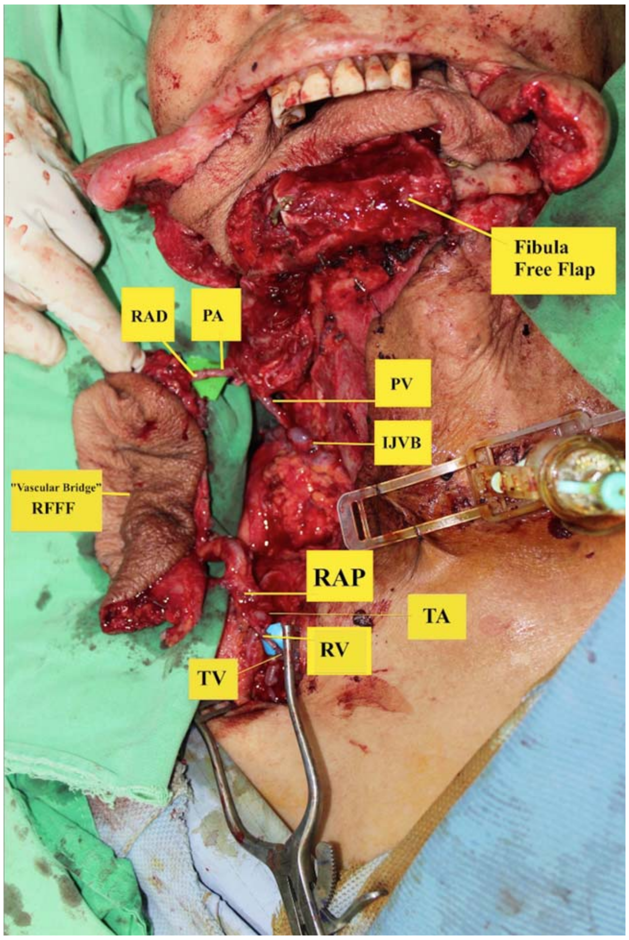

FIGURE 1 A radial forearm free flap (RFFF) serving as vascular bridge between the recipient vessels and the second "main" flap, a free fibula osteocutaenous flap in this case. The proximal pedicle of the RFFF (RAP/RV) was anastomosed to the thoracoacromial artery (TA) and vein (TV). The peroneal artery (PA) was then connected to the distal end of the radial artery (RAD). The larger of the paired peroneal veins (PV) was connected to an internal jugular vein branch (IJVB), whereas the smaller peroneal vein drained into one of the radial venae comintantes (this anastomosis is covered by the green microsurgical background sheet). TA, thoracoacromial artery; TV, thoracoacromial vein; RAP, radial artery proximal; RV, radial vein; RAD, radial artery distal; PA, peroneal artery; PV, peroneal vein; IJVB, internal jugular vein branch)

were kept near both anastomotic sites. Patients were monitored in the intensive care unit for 24 h. Postoperative follow-up was done at 2 weeks, 3, 6 months and annually thereafter (Table 1).

4 | RESULTS

The average RFFF dimensions were 13.8 cm (length) by 5.8 cm (width) with a range of 12–16 cm (length) and 5–6 cm (width), respectively. In all cases, the RFFF donor site was closed with a split thickness skin graft (STSG). The artery of the second "main" flap was anastomosed to the distal radial artery. The venous drainage of the second "main" flap was accomplished through the venae comitantes of the RFFF only ($n = 6$) or a combination of a radial vena comitans and an internal jugular vein branch ($n = 4$, one fibula and three jejunum flaps). The mean period of hospitalization was 17.4 days (range 14–21) and all flaps survived. Mean follow-up duration was 18.4 months (range 8–29).

In four cases, soft tissue reconstruction was required for intraoral mucosal defect and/or external skin defect. The reconstruction was completed with a free anterolateral thigh (ALT) flap. In one of the patients where the ALT flap was used, there was intraoperative arterial vasospasm which was managed with adventitiectomy and lidocaine irrigation. The patient had minimal epidermal loss at the edge of the skin paddle that led to delayed wound healing in the early post-operative period. This was managed conservatively without a need for secondary procedure. Three patients underwent debulking/flap revision procedures 4–10 months after the initial procedure to improve facial appearance.

There were three cases of mandible reconstruction with a free osteo-cutaneous fibula flap. Two of these cases were done for recurrent buccal cancer, whereas the third one was for mandibular osteoradionecrosis. On follow-up, there was complete survival of both the osseous and cutaneous components of the flaps with reestablishment of stable mandibular continuity. Lastly, three cases of hypopharyngeal cancer with a resultant esophageal defect were reconstructed with jejunal flaps. Two patients needed split thickness skin grafting to cover part of the jejunal flap. One patient developed an enterocutaneous fistula that necessitated a deltopectoral (DP) flap for closure in the third postoperative month. All patients had resumed regular diet at the time of the last follow-up.

5 | CASE REPORTS

5.1 | Case 1

A 50-year-old male was first diagnosed with left buccal cancer 5 years ago. Due to recurrences and failure of flaps, he underwent a total of 19 operations over the next 4 years. Prior to presentation to our clinic with a left upper gingival cancer invading the maxillary sinus floor and left cheek, the following flaps/grafts had already been used: bilateral free fibula flaps, free left composite latissimus dorsi/serratus anterior/7th rib flap, pedicled left pectoralis major flap, rib bone graft, pedicled left deltopectoral flap, free right composite osteomyocutaneous scapular flap (Figure 2A). After resection of the left buccal cancer, there was a large soft tissue defect extending from the left nasal cavity to the left maxillary roof, the left buccal area and left lower gingiva. Upon exploration, the left internal mammary area was the closest recipient site with reliable vessels (Figure 2B). The distance from the cranial aspect of the mucosal defect to the recipient site exceeded the reach of the planned left ALT flap. Therefore, a 16 cm by 6 cm RFFF flap with wider skin ends proximally and distally ("dog bone configuration") was harvested based on the radial artery and its venae comitantes. In the meantime, the second team harvested a 30 cm by 15 cm ALT flap. First, the RFFF was revascularized with proximal radial artery to IM artery and dual venae comitantes anastomoses to the IM veins. The ALT flap was then inset and revascularized by end-to-end anastomoses to the distal radial artery, one radial vena comitante, and an internal jugular vein branch (Figure 2C,D). Both flaps survived completely with no donor site morbidity (Figure 2E,F). The flap was then gradually inset with partitioning of the flap in stages to cover multiple defects in the orofacial region.

5.2 | Case 2

A 59-year-old male with metachronous oral and hypopharyngeal cancer underwent chemoradiation and a total of 26 operations (including bilateral neck dissections, free ALT, RFFF, latissimus dorsi, and pedicled pectoralis major flaps) prior to presenting to our clinic with a residual large left cheek soft tissue defect and lower lip cleft. Extensive release of oral mucosa and large resection of cheek/neck skin and fibrotic mucosa was required. Given the paucity of recipient vessels in the neck along with the left neck contracture from previous skin grafting, a "vascular bridge" RFFF/ALT combination was offered. (Figure 3A,B) A RFFF measuring 15 cm by 6 cm was interposed as vascular bridge between the free ALT flap pedicle and the recipient thoracoacromial vessels. The ALT flap (23 cm $\times$ 10 cm) was anastomosed with the recipient radial artery, venae comitans and superficial vein from the transferred RFFF. The second "main" flap (right ALT) was used to resurface the mucosal defect and provide soft tissue bulk and coverage for the cheek. Both flaps survived completely and the patient had an uneventful recovery. At a second procedure, the patient underwent pharyngoesophageal reconstruction with a free pedicled ileocolon flap placed on right side of the neck. Postoperatively, the patient was satisfied with the mouth opening and range of motion of the neck (Figure 3C,D). At 10 month follow-up, the ALT flap was revised to improve oral incontinence and cosmetic appearance. Eventually, the patient was able to resume oral diet.

6 | DISCUSSION

Despite rapid strides in microsurgery, recipient vessel issues continue to be a vexing problem in secondary head and neck reconstruction (Yazar et al., 2005). History of previous surgery and radiotherapy can further complicate the issue (Hanasono et al., 2009; Head et al., 2002). Vascular events are the most common reasons for re-exploration and flap failure, especially in secondary reconstruction. An ideal recipient vessel should have a reasonable diameter, adequate length, good spurt test and a scar free milieu. Some or all of these parameters are absent

TABLE 1 Demographic data, clinical information, intraoperative details, and outcomes

				RFFF (Vascular bridge)			Second (Main) flap							
Age	Sex	Pathology	Procedure	Dimensions (cm)	Donor site closure/ outcome	Recipientvessels	Type	Skin paddle dimensions (cm)	Recipient vessels	Flap survival (%)	Complications	Hospitalization time (days)	Follow-up (months)	Final outcome
42	Female	Hypopharyngeal cancer	Esophageal reconstruction	14 × 6	STSG/ 100% take	IMA/V	Jejunum	–	RA RVs	100	Fistula	17	18	Resumption of oral diet
65	Male	Recurrent buccal cancer	Mandible reconstruction	12 × 5	STSG 98% take	TA/V	Osteo-cutaneous Fibula	14 × 8	RA RV + IJVB	100	None	18	12	Stable mandibular continuity with good form
59	Male	Recurrent buccal cancer	Oral cavity reconstruction	15 × 6	STSG 99% take	TA/V	ALT	23 × 10	RA RVs	100	None	14	28	Reconstruction of the cheek defect achieved
68	Male	Mandibular osteoradio-necrosis	Mandible reconstruction	12 × 6	STSG 100% take	IMA/Vs	Osteo-cutaneous Fibula	18 × 7	RA RVs	100	Intraoperative vasospasm Delayed wound heling	18	15	Stable mandibular continuity with good form
50	Male	Hypopharyngeal cancer	Esophageal reconstruction	13 × 6	STSG 98% take	TA/V	Jejunum	–	RA RV + IJVB	100	None	17	23	Resumption of oral diet
50	Male	Recurrent buccal cancer	Oral cavity reconstruction	16 × 6	STSG 100% take	IMA/Vs	ALT	30 × 15	RA RVs	100	None	18	8	Coverage of multiple intraoral defects achieved
39	Male	Recurrent buccal cancer	Oral cavity reconstruction	13 × 6	STSG 100% take	TA/V	ALT	18 × 10	RA RVs	100	None	19	18	Successful reconstruction of oral cavity defect
74	Male	Recurrent buccal cancer	Mandible reconstruction	15 × 5	STSG 99% take	TA/V	Osteo-cutaneous Fibula	16 × 8	RA RVs	100	None	21	29	Stable mandibular continuity with good form
50	Female	Hypopharyngeal cancer	Esophageal reconstruction	14 × 6	STSG 100% take	IMA/V	Jejunum	–	RA RV + IJVB	100	None	18	18	Resumption of oral diet
45	Male	Recurrent buccal cancer	Oral cavity reconstruction	14 × 6	STSG 100% take	TA/V	ALT	22 × 9	RA RVs	100	None	14	15	Reconstruction of oral cavity defect achieved

STSG, split thickness skin graft; TA/V, thoracoacromial artery/vein; IMA/V, internal mammary artery/vein; ALT, anterolateral thigh flap; RA, radial artery; RV(s), radial vein(s); IJVB, internal jugular vein branch.

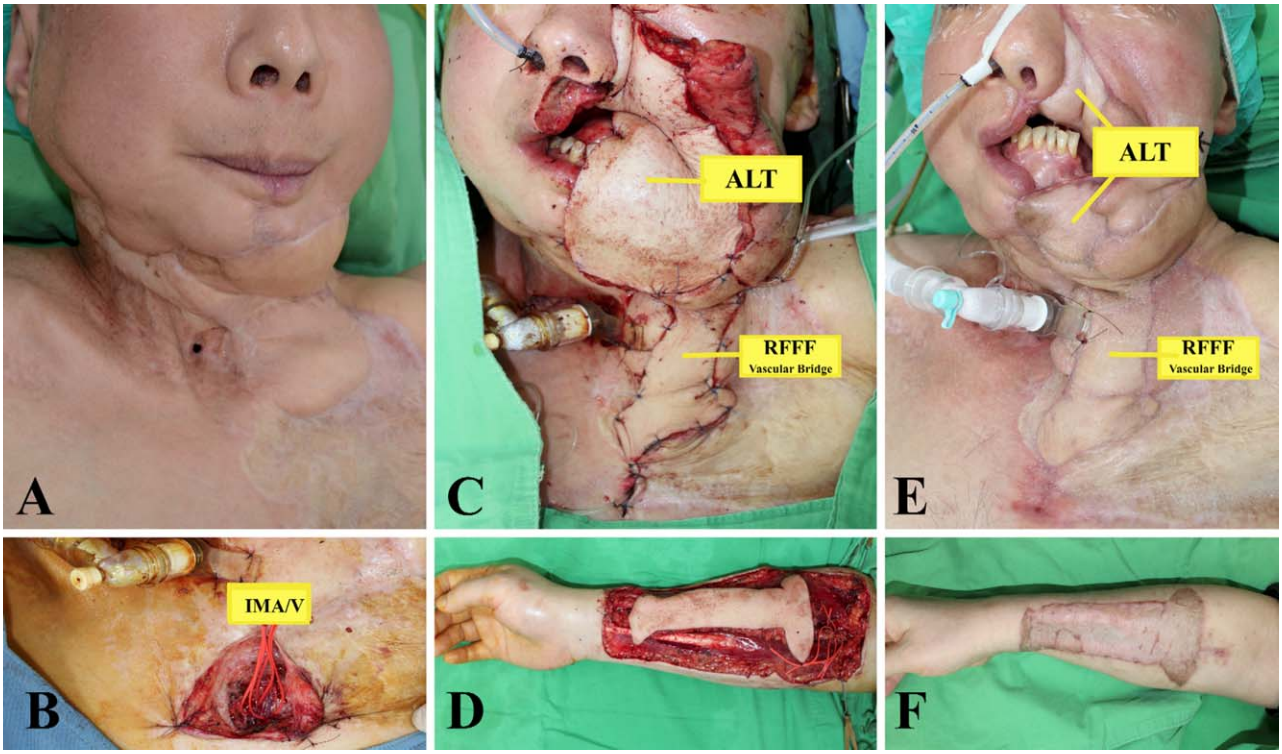

FIGURE 2 A, Preoperative view. B, Intraoperative exposure of the internal mammary artery and venae comitantes (IMA/V). C, Intraoperative view after revascularization and inset of both flaps. D, The RFFF prior to division of the pedicle (RFFF). E, Postoperative view at 6 months, the ALT flap skin paddle has been divided to cover the individual intraoral defects. F, Postoperative view of the RFFF donor site

when there is a history of radiation and previous surgical intervention, especially neck dissection. Identification of recipient vessels unaffected from the deleterious effects of previous surgeries and radiotherapy is paramount. The contralateral vessels are often equally affected by previous treatments and bear the same unfavorable characteristics of the most commonly used ipsilateral neck recipient vessels. The transverse cervical artery has been proposed as an alternative since by virtue of its location deep at the neck base many times it is spared from damage (Ciudad et al., 2017; Hanasono et al., 2009; Urken et al., 1989; Yu, 2005). Nevertheless, in certain patients who have undergone radiotherapy and multiple procedures, even this sanctuary site is violated.

In these challenging cases of head and neck reconstruction, more distant pedicles such as the thoracoacromial (TA) and internal mammary (IM) vessels have been used successfully (Harris et al., 2002; Jacobson et al., 2013). These pedicles have optimal dimensions for microvascular anastomosis but very often need a vascular conduit to bridge the distance to the flap pedicle. The TA and IM vessels are located in upper thoracic region and additional scars in this area are not as visible as facial scars, unlike in the case of superficial temporal vessels. The thoracoacromial system provides a reliable source of undisturbed vessels when cervical vessels are unusable or absent (Harris et al., 2002). Although the TA pedicle is more superficial and easier to dissect, its dimensions may be unsatisfactory in a small percentage of patients. For such patients, IM is the pedicle of choice. Jacobson et al. found IM artery to be an excellent recipient artery with a generous caliber and high-pressure arterial flow. They noted that its location, farther away from the neck, places it in a safe distance from previous surgical and radiation fields (Jacobson et al., 2013).

Such distant recipient sites often require a vascular conduit to bridge the distance to the flap pedicle. Both interposition vein grafts (IVG) and arterio-venous (A–V) loops have been attempted to surmount this challenge (Angel et al., 1993; Lin et al., 2004). Although, these help in bridging the vascular gap, the adverse local fibrotic conditions may render local skin flaps rigid and unable to provide good coverage leading to compression and/or kinking of the veins. For this reason, use of IVGs in head and neck reconstruction remains controversial (Kruse, Luebbers, Grätz, & Obwegeser, 2010). While free flap survival rates as high as 95% have been reported with their use in head and neck reconstruction, others have experienced free flap losses up to 24%, especially in salvage cases and when long vein segments are used (Furr et al., 2011; Nelson et al., 2015). A review on prevention and treatment of thrombosis in microvascular surgery suggested prophylactic use of antithrombotic agents when IVGs are used as it was considered an unfavorable condition (Hanasono & Butler, 2008). In challenging complex cases with multiple previous flap failures and depletion of reconstructive options, a more reliable alternative is necessary. At first glance, a flow-through flap mainly for the purpose of extending the reach of distant recipient sites to a second "main' flap may appear burdensome and unnecessary. However, when the precarious nature of IVGs in a hostile recipient bed is considered, the flow-

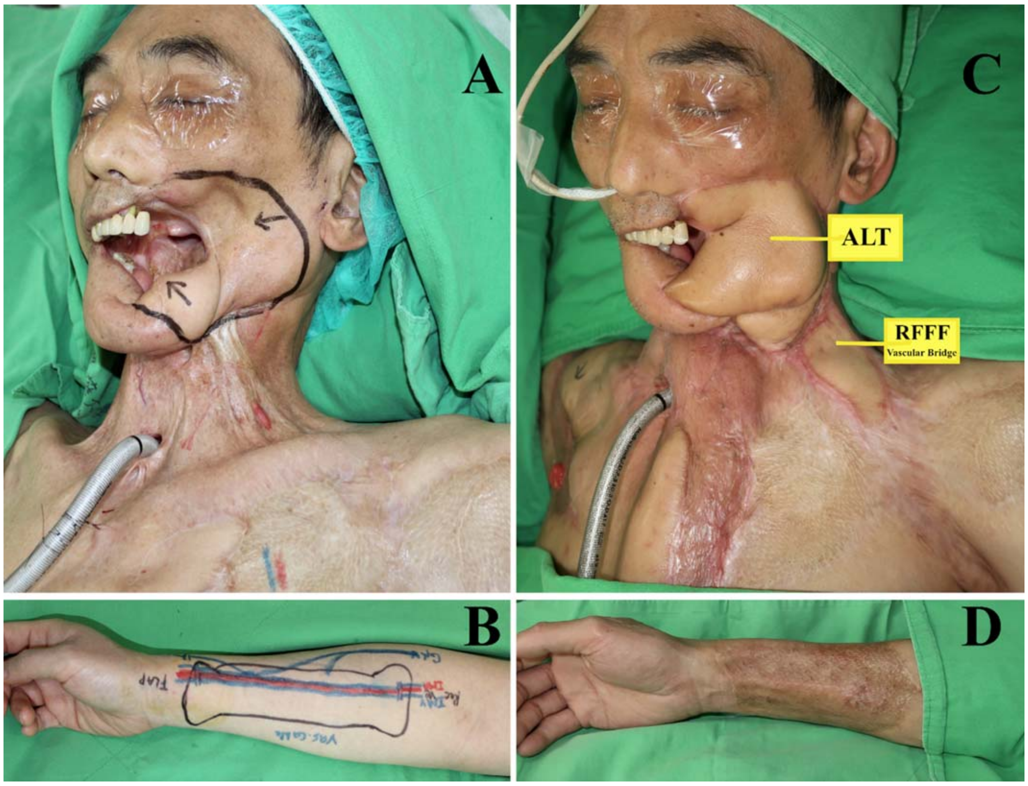

FIGURE 3 A, Preoperative picture showed patient with oral and hypopharyngeal cancer who underwent >26 operations. B, Design of the dog bone shaped "vascular bridge" RFFF. C, Postoperative view at 10 months. The RFFF was anastomosed to the thoracoacromial vessels and served as a flow-through flap to the second "main" flap (right ALT) used to resurface the mucosal defect and provide soft tissue bulk and coverage for the cheek. Of note, in the interim the patient also underwent pharyngoesophageal reconstruction with a free pedicled ileo-colon flap placed on right side of the neck. D, Postoperative view of the RFFF donor site

through flap emerges as a more dependable option. By using the reliable RFFF as a vascular bridge, were able to achieve survival of all flaps without any need for reexploration.

Soutar, Scheker, Tanner, and McGregor (1983) first introduced the concept of flow-through radial forearm flap by anastomosing both ends of the radial artery to maintain an unimpeded fast arterial flow through the flap. However, this was done to maintain the viability of the flap itself while preserving arterial flow continuity to distal native tissue and not to supply a second flap. The application of the RFFF as a flow-through flap to support a second flap was subsequently widely reported in upper and lower extremity reconstruction. In addition, various other flaps such as latissimus dorsi muscle, osteocutaneous fibula, rectus abdominis, anteromedial and anterolateral flaps have been utilized for the same purpose (Bullocks, Naik, Lee, & Hollier, 2006).

Specifically in head and neck reconstruction, the use a flow-through flap to vascularize a second flap was first reported by the senior author (H.C.C.) in 1989 (Chen, Tang, & Noordhoff, 1989). Since then, other authors have also presented their experience with radial forearm, fibula, rectus abdominis, anteromedial, and anterolateral thigh flaps (Ao et al., 1998; Ceulemans & Hofer, 2004; Koshima et al., 1997; Nakatsuka, Harii, Yamada, Ueda, & Ebihara, 1992, 1994; Nişanci, Türegün, Er, & Sengezer, 2003; Sanger, Matloub, & Yousif, 1990). In all instances, the flow-through flap did not only serve as a vascular conduit but also contributed to coverage of part of the tissue defect. To the contrary, in the current case series, the second "main" flap was enough to achieve the reconstructive goal by itself but fell short of reaching the distant recipient site; the RFFF was used to bridge this gap.

The RFFF has proved to be a workhorse flap for microvascular reconstructions in general and is an ideal follow-through flap when there is no need for additional coverage. The surgical anatomy is constant and a long pedicle with a large caliber is almost always available. Abundant skin paddle dimensions and ease of harvest are additional advantages. Not only does it allow safe use of distant pedicles in a single stage and but it also provides additional soft tissue coverage that can be used to cover the vascular conduit in scarred irradiated tissue. The RFFF skin paddle provides an ideal milieu that safeguards both microvascular anastomoses. By eliminating the need for tunneling, they prevent the risk of pedicle compression and/or kinking. The ability to provide double venous drainage through the paired venae comitantes is another potential benefit. Finally, arterial conduits are far superior to vein grafts with respect to patency rates and incidence of spasm (Suma, 1999). They match the flap artery in terms of hemodynamic characteristics and biochemical environment. The second "main" flap was always harvested with a large skin paddle to comprehensively resurface the large soft tissue defects. In few cases, with extensive scarring along the path of the RFFF vascular bridge, a RFFF with a slightly larger skin paddle than usual was harvested allow excision of scars and creation of favorable milieu for the conduit.

Possible drawbacks of this technique include need of harvesting two free flaps, therefore increased operative time and possibility of loss of two flaps in cases of thrombosis in the RFFF pedicle. The clearly visible donor site in the forearm might be another concern. However, the elevation of a RFFF is relatively straightforward and can be done expeditiously. With a two-team approach the operative time can be significantly reduced. None of our patients desired revision of the forearm donor site, possibly due to the relatively narrow nature of the defect that contracts even more after skin grafting. If required, the donor site appearance can be improved with partial or total excision of the skin graft at a second stage. In addition, in cases with a low RFFF skin paddle width-to-forearm circumference ratio, primary closure can be achieved. One criticism to our study could be the potential selection bias by excluding smokers and subjects with severe comorbidities. However, we felt that to evaluate the efficacy of our strategy, it was important to eliminate any confounding factors. Future randomized trials may possibly shade some light on the effect of these two factors on the outcome of RFFF flow-through flap in head and neck reconstruction.

To the best of our knowledge, flow-through RFFF has not been reported solely for the purpose vascular pedicle lengthening in complex secondary head and neck reconstruction. The authors are fully aware of the complexity of the technique, however, when applied in selected challenging scenarios, it represents a reliable and safer alternative in comparison to IVGs or A–V loops.

7 | CONCLUSION

The application of the "vascular bridge" RFFF for head and neck reconstruction is feasible and may provide a valuable alternative in selected cases, when commonly used recipient arteries are not readily available.

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CONFLICT OF INTEREST

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