Journal of Plastic, Reconstructive & Aesthetic Surgery (2019) 72, 181–187

JPRAS
An International Journal of Surgical Reconstruction
www.JPRASurg.com

Propeller flap reconstruction of irradiated sarcoma defects: A comparison☆

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Received 19 February 2018; accepted 28 October 2018

KEYWORDS
Sarcoma;
Perforator flap;
Plastic surgery;
Reconstruction

Summary *Introduction:* The treatment for soft tissue sarcomas has evolved to include radiotherapy, wide local excision and plastic surgical reconstruction. Goals for the reconstruction of these irradiated defects are the introduction of non-irradiated healthy tissue, tension-free closure and obliteration of potential dead space. Although many defects once required free tissue transfer for reconstruction, greater knowledge of anatomical vascular pattern has led to the increasing use of propeller perforator flaps, islanded and transposed into the defect. Propeller flap outcomes for the reconstruction of irradiated skin defects have only been reported in case reports. We evaluated the use of propeller perforator flaps at St Vincent's Hospital Melbourne in a series of patients for the reconstruction of irradiated sarcoma defects.
Methods: All patients who underwent sarcoma resection with plastic surgical reconstruction at St Vincent's Hospital from January 2009 to February 2017 were identified from unit audits and medical record data and compared depending on the type of reconstruction. Propeller perforator flaps were evaluated compared to other methods of reconstruction.
Results: Thirty-nine cases involved single perforator propeller flaps for reconstruction. The frequency of propeller flap reconstruction has greatly increased from 3 in their first year of use in 2013 to 12 in 2015. Most propeller flaps were used to reconstruct thigh defects (43.6%) followed by shoulder defects (17.9%). Generally the defects were smaller (138.7 cm^2) than free flaps (214.2 cm^2), and the usual composition of the defect was skin and subcutaneous tissue only. Patients who underwent propeller flap reconstruction had a significantly short length of inpatient stay ($p < 0.01$), and there were no total failures.

☆Parts of this article have been presented at the following meetings/conferences: 1. Plastic Surgery The Meeting, Boston, USA (October 2015). 2. Royal Australasian College of Surgeons 84th Annual Scientific Congress (May 2015).

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https://doi.org/10.1016/j.bjps.2018.10.011
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Conclusion: Propeller perforator flaps are useful for the reconstruction of irradiated defects in sarcoma reconstruction surgery, particularly small- to moderate-sized fasciocutaneous defects. They offer less morbidity, faster recovery and better aesthetic results than free or standard pedicle flaps. The success of propeller flaps has changed the algorithm for how we approach towards the reconstruction of irradiated sarcoma defects to consider their use as the first reconstructive option for superficial sarcoma defects.
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Introduction

Sarcomas are a heterogeneous group of rare tumours that arise predominantly from the mesoderm.[1] They present most commonly as an asymptomatic mass originating in an extremity but can occur anywhere in the body. Optimal management is often best carried out by an experienced multidisciplinary team in care of patients with sarcoma.[2] St Vincent's Hospital Melbourne is a tertiary referral centre for the management of patients with sarcoma in the states of Victoria and Tasmania, Australia.

During the past several decades, the management of soft-tissue sarcomas has evolved from surgery alone, often requiring amputation of the affected limb, to limb-saving procedures combined with neoadjuvant or adjuvant radiation, thereby providing equivalent outcomes.[3-6] This has the advantage of improved quality of life, and function, however, prompts challenges in the closure of irradiated defects following preoperative radiotherapy and subsequent excision.

Plastic surgical reconstruction is often integral to achieve optimal wound healing.[7] Principles of reconstruction in these irradiated defects are centred around introducing a healthy tissue from outside of the field of irradiation, tension-free closure, obliteration of potential dead space and optimisation of function.[8] Pedicled and free tissue transfers are most commonly used for successful wound closure.[9,10]

In recent years, greater understanding of vascular anatomy has led to more frequent use of propeller perforator flaps, completely islanded on a single vessel and transposed into the defect.[11,12] As reconstruction methods continue to advance, goals have currently emerged to include functional restoration and the best possible aesthetic result. Compared to free flaps, aesthetically, propeller perforator flaps can lead to optimal results, as they involve the like-with-like reconstruction concept with the use of donor tissues located near the defect. These flaps create less donor site morbidity, and as there are no microsurgical anastomoses, they eliminate associated complications and are a faster procedure that can be performed with less equipment than the free flaps.[13-15]

At St Vincent's Hospital Melbourne, typical management of sarcoma is neoadjuvant radiotherapy, excision by the orthopaedic surgery unit and reconstruction of the resulting defect by the plastic surgery department, using a range of reconstruction options including local, propeller and free flaps. This study reports the initial experience and comparison of the use of propeller perforator flaps in sarcoma reconstruction.

Methods

This retrospective study identified patients who underwent sarcoma resection with plastic surgical reconstruction at St Vincent's Hospital Melbourne between January 2009 and February 2017. Data were collected from medical records related to demographics and comorbidities (Table 1). Approval was obtained from St Vincent's Hospital Human Research Ethics Committee. Free and local flaps were previously standard reconstructive practice for these defects, and these groups were useful as a benchmark to compare propeller flap outcomes. The local flap group includes any pedicled or local random pattern flaps.

Operative details including the size, location and composition of defects were recorded and are summarised in Table 1. Table 2 depicts the various types of propeller flaps, their location and dominant source vessels. Post-operative outcomes, complications and length of stay are recorded in Table 3.

Surgical approach

Propeller flaps are defined as local fasciocutaneous flaps completely islanded on a single vessel and transposed or rotated like a propeller into the defect. Key considerations in flap design include perforator site/size and surrounding skin laxity and availability of the donor tissue. The surgical approach began by assessing the laxity of the surrounding tissue to determine whether a local flap is feasible and the direction of the donor tissue. We always aimed for direct closure of the donor site; hence, if the surrounding tissue laxity is insufficient to allow both defect coverage and direct donor site closure, this method of reconstruction will be abandoned.

In the general direction of the potential donor site, a subfascial dissection was performed from the edge of the defect without making any additional incisions to look for perforators. The ideal perforator is one that is closest to the defect, located typically within 2–3 cm from the defect edge. This is also the pivot point of the flap. Perforator size suitability is determined on the basis of visible pulsatility and by intraoperative handheld Doppler assessment. Once a suitable perforator was identified, the flap was then designed in the direction of maximal donor availability to include the adjacent non-irradiated tissue. The flap borders were then incised and the subfascial plane developed. The flap was then completely islanded on its perforator and freed from any restricting fascial fibres, which might compromise venous return, by bipolar diathermy. The flap was

Table 1 Demographics and sarcoma defect characteristics of the study population.

	Propeller	Free	Local	*P* value
Age (mean ± s.d., years)	50.5 ± 15.5	55.6 ± 17.7	53.6 ± 18.9	0.29
Gender (% male)	48.7	64.3	54.5	0.17
Diabetic	5.1%	8.0%	7.6%	0.94
Current smoker	0	8.9%	7.6%	0.15
Body mass index (mean ± s.d., kg/m^2)	25.8 ± 5.6	28.5 ± 5.3	29.4 ± 7.1	0.011*
Neoadjuvant radiotherapy	87.1%	91.0%	92.4%	0.66
Defect size (mean ± s.d., cm^2)	138.8 ± 89.0	214.2 ± 170.8	190.1 ± 158.2	0.03*
Defect composition	Fasciocutaneous 51.3% Myocutaneous 48.7%	Fasciocutaneous 21.3% Myocutaneous 63.9% Osseomyocutaneous 15.2%	Fasciocutaneous 37.9% Muscle 48.9% Osseomyocutaneous 13.6%	

* = $p < 0.05$.
** = $p < 0.01$.
s.d. = standard deviation.

Table 2 Location and type of vessels used for propeller flap reconstruction.

Defect site (number)	Flap perforator source vessel
Thigh - 17 (43.6%)	Descending lateral circumflex femoral: 6 Medial circumflex femoral: 3 Superficial femoral artery perforator: 2 Profunda femoris perforator: 6
Shoulder - 7 (17.9%)	Circumflex humeral (parascapular): 7
Back - 5 (12.8%)	Lumbar perforator: 2 Superficial gluteal artery perforator: 1 Posterior intercostal: 1 Circumflex humeral (parascapular): 1
Arm - 3 (7.7%)	Circumflex humeral (parascapular): 1 Brachial artery: 1 Thoracodorsal artery perforator: 1
Knee - 3 (7.7%)	Sural perforator: 1 Geniculate: 2
Forearm - 2 (5.1%)	Ulnar perforator: 2
Lower leg - 2 (5.1%)	Peroneal artery: 2

then transposed and 'propellered' into the defect and both the flap and the donor site were closed in 3 layers over a drain.

Statistical analysis

Analyses were performed using STATA (version 12, StataCorp LP, College Station, TX) software. ANOVA (Analysis of Variance) and chi-square tests were used to compare groups. A value of $p < 0.05$ was considered to indicate significant differences between groups.

Results

During the entire period, 39 propeller flaps were used for sarcoma reconstruction, all by a single surgeon (EM). Propeller perforator flap use also increased from 3 in their first year of use in 2013 (7.9% of reconstructions for the year) to 12 (25% of reconstructions for the year) in 2015. No propeller flaps were used before 2013. The results showed an increasing preference for the use of propeller flaps compared to other reconstructions. Although there were no smokers in the propeller flap group, this occurrence was coincidental and smoking was not considered to be a contraindication. Patients who underwent propeller flap reconstruction had significantly lower BMI ($p = 0.011$) than those in the other 2 groups (Table 1).

As expected, propeller flaps were smaller (mean size 138.8 cm^2) and used in more fasciocutaneous defects (51.3%) than free flaps (mean size 214.2 cm^2, 21.3% of fasciocutaneous defects) or local flaps (mean size 190.1 cm^2, 37.9% of fasciocutaneous defects). The size of defects reconstructed with propeller flaps ranged from 24 to 450 cm^2 with a mode of 135 cm^2. All propeller flap donor sites were amenable to direct closure, compared to 81.3% of free flap and 92.4% of local flap donor sites being directly closed, with the remainder requiring split skin grafts.

The utility of the propeller flap is evident in a wide range of defect sites (Table 2). There was a clear preponderance for sarcoma occurrence in the thigh region, which was also the most common site in our series of propeller flaps.

In terms of post-operative outcomes, propeller perforator flaps have low overall complication rates (18.5% compared with 42.0% for free flaps and 48.5% for local flaps, $p = 0.11$) and significantly short length of stay (7.4 days compared with 17.4 days for free flaps and 18.1 days for local flaps, $p < 0.01$) (Table 3). There have been no total failures of propeller flaps. There was 1 partial failure of a propeller flap: a parascapular flap to an arm defect, which required debridement of a necrotic distal portion.

Three propeller perforator flaps required early re-operation for the exploration of vascular compromise (8% of all propeller flaps): 1 case for a haematoma and 2 cases

Table 3 Post-operative outcomes based on the type of flap reconstruction.

	Propeller [$n = 39$]	Free [$n = 112$]	Local [$n = 66$]	P value
Length of stay (mean ± s.d., days)	7.4 ± 3.9	17.4 ± 11.2	18.1 ± 16.3	<0.01**
All complications	18.5%	42.0%	48.5%	<0.01**
Partial failure	1 [3.7%]	4 [3.8%]	2 [3.0%]	0.94
Total failure	0	3 [2.7%]	0	0.30
Haematoma	2 [7.4%]	8 [7.1%]	5 [7.8%]	0.88
Re-operation for exploration	3 [11.1%]	7 [6.3%]	1 [1.5%]	0.27
Dehiscence	0	14 [12.5%]	8 [12.0%]	0.04*
Infection	0	15 [13.4%]	12 [18.2%]	<0.01**

* $= p < 0.05$.
** $= p < 0.01$.

of veins being compressed requiring the release of fascial bands.

Discussion

The term 'propeller flap' was introduced in 1991 by Hyakusoku et al. to describe an adipocutaneous flap raised on a central pedicle and rotated 90° like a propeller.[16] Hallock and Teo have greatly contributed to the development of the surgical technique for these flaps, currently defined as a flap skeletonised on a perforating vessel and rotated 180°.[15,17] These flaps have been increasingly used for soft tissue defect reconstruction in different parts of the body, with surgical technique refined and described by several authors.[18-20]

One recent change in our approach towards reconstructing irradiated sarcoma defect with time has been the increasing consideration and use of propeller flaps as a first-line reconstruction option for small- to moderate-sized superficial defects. Our results demonstrate the success of propeller flaps with a shorter length of stay and faster recovery and lower complication rates than free or local flaps. The benefits of propeller flaps also include better aesthetic results replacing like-with-like tissue, less donor site morbidity, with all donor sites closed directly and eliminating microsurgery, thereby allowing a faster procedure.(Figures 1 and 2)

One critical goal of reconstructing irradiated defects is the introduction of a healthy non-irradiated tissue to avoid direct closure of both irradiated wound edges. By harvesting donor tissue away from the irradiated field and propeller into the defect, wound edge closure is entirely between the irradiated tissue on one side and the healthy dermis on the other side of the wound circumferentially, including the irradiated edge that formed part of the flap that is rotated away during inset (Figure 3(c)).

A number of methods are used to identify suitable perforators in the design of the propeller flap. First, they can be known local single perforators such as those used commonly for free flaps, e.g. anterolateral thigh flap perforators. Alternately, the tissue surrounding the defect can be explored subfascially looking for a suitable skin perforator as a 'freestyle' approach.[21] With increased anatomical knowledge and experience, it is the principal author's opinion that the site and the size of skin perforators are frequently predictable and reliable, thereby allowing more accurate preoperative planning and less 'freestyle'. With other less predictable perforators, adjuncts such as handheld Doppler or preoperative computed tomogram angiography (CTA) have also been useful.[12-15] CTA was not routinely used in our series; only 7 had a preoperative CTA, typically in areas where perforator anatomy is less well known.

In the design of our propeller flaps, the pivot point is the site of the perforator selected; therefore, the best perforator is one that is located close to the defect edge. This allows the shortest flap design possible and the maximum use of the flap in reconstructing the defect. The farther away the perforator is from the defect, the longer the flap needs to be to reach the distal end of the defect and more flap is 'wasted' in the transposition, i.e. not used in repairing the defect. The principal author's preference is a perforator located within 2–3 cm away from the defect edge, which means the perforator is usually either within or at the border of the irradiated field. Perforator size suitability is determined simply on the basis of visible pulsatility (without magnifying loupe) and by intraoperative handheld Doppler assessment.

Figure 1 (a) Lateral ankle defect with adjacent peroneal artery perforator, and (b) peroneal artery perforator flap inset.

Figure 2 (a) Central lower back defect, (b) superior gluteal artery perforator flap raised, and (c) flap inset.

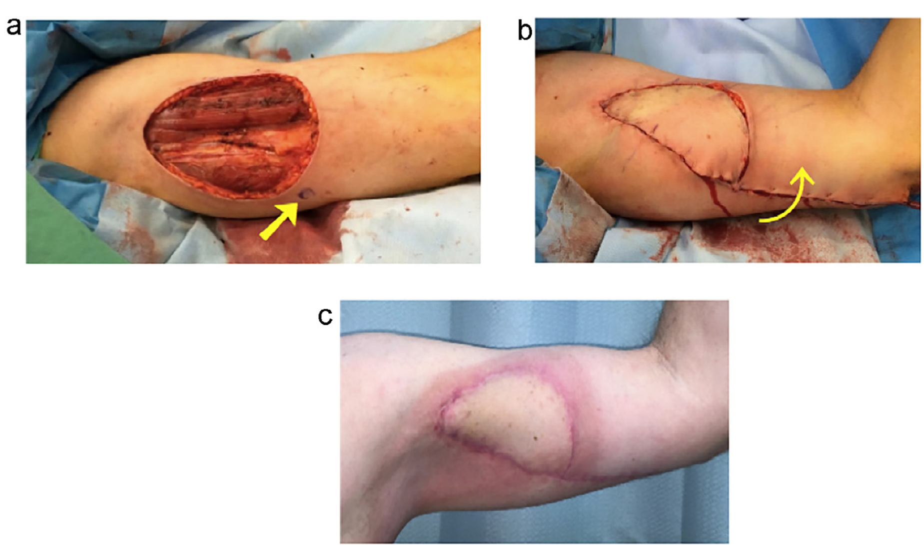

Figure 3 (a) Medial arm defect with brachial artery perforator identified adjacent to the defect (arrow), (b) propeller perforator flap inset to the defect, and (c) longer term post-operative result, healthy flap inset into the irradiated field.

It is also our preference to directly close the donor site, and this was successful in all our cases. This avoids skin grafts near or on irradiated sites, allows dermis to dermis healing and improves contour and aesthetics. If donor site direct closure is not possible or if the perforator is not found, we would proceed to another method of reconstruction, typically a free flap. This is in contrast with findings of the largest systematic review of 428 propeller flaps, used for lower limb reconstruction, by Bekara et al., which found that 30.3% of cases required split skin grafts for donor site closure.[22] Again, in contrast to the findings reported in this review, where 46.2% of propeller flaps were < 50 cm^2, the defect size for our series of propeller flaps are much larger, with only 14.8% being < 50 cm^2 and 48.1% of flaps ranging between 100 and 200 cm^2.

Our propeller flap series also appear to have better outcomes than those reported in other studies. Despite the flaps being larger than most flaps, we had no total failures, 1 (2.6%) partial failure and an 18.5% overall complication rate, compared to the results given in the review by Bekara et al., which found rates of total failure to be 3.5%, partial necrosis to be 10.2% and all complications to be 25.2%.[22]

We made an early observation that the direction of our donor site generally follows the axial line, where the maximal flap width can be harvested to allow direct closure. This element of the design is now integral because we believe it may contribute to the success of our larger flaps by capturing 'true' anastomoses between cutaneous perforators. Further, the closure of the donor site often assists in making the defect narrower.

Greater knowledge of cutaneous angiosomes has been the critical determinant in designing any cutaneous perforator flap, and the concept of the perforasome theory introduced during recent years reinforces the same message.[12] It has been widely acknowledged that adjacent angiosomes are connected by direct (true) and indirect (choke) linking vessels. Flap design and skin paddle orientation should be ideally placed along the direction of the linking vessels for maximal blood flow. These linking vessels make it possible to harvest large perforator flaps based on a single perforator. As emphasised by Taylor et al., 'true' anastomoses between adjacent angiosomes typically parallel cutaneous nerves and veins; hence, our axial design may be capturing cutaneous perforators connected with 'true' anastomoses, thereby successfully allowing larger flaps.[23]

Patients who underwent propeller flap reconstruction had a significantly lower BMI ($p = 0.011$) than those who underwent free or local flap reconstruction. Whilst BMI is not a selection criteria, patients with a lower BMI are more likely to have donor site amendable to direct closure than those with a higher BMI.

There are apparent limitations to the use of propeller perforator flaps. Not all superficial defects will have appropriate perforators nearby, and the relative redundancy and availability of the donor skin is frequently limited. Similarly, the need to obliterate dead space and any potential functional requirements are not addressed, as this is a skin-only reconstruction. Free flaps remain the standard reconstructive method for larger or more complex defects to achieve all the reconstructive goals such as whether bony reconstruction or innervated muscle is required.

Conclusion

Propeller perforator flaps are a useful reconstructive option in sarcoma reconstruction surgery. They are most effective for irradiated smaller fasciocutaneous defects in many regions of the body. From our experience in sarcoma reconstruction, there is a definite change in the approach, with an increasing use of propeller perforator flaps as the first reconstruction option. They are a faster procedure and allow reconstruction of wound with the local tissue, low donor site morbidity, faster recovery and a better aesthetic result. Our design, largely based along axial lines, may successfully enable larger propeller flaps to be performed with direct closure of the donor site. Nevertheless, the use of free flaps and standard pedicle flaps remains for larger defects or complex defects requiring composite flaps or innervation for functional reconstruction.

Conflicts of interest

None.

References

1. Cormier JN, Pollock RE. Soft tissue sarcomas. *CA Cancer J Clin* 2004;**54**:94–109.
2. Nystrom LM, Reimer NB, Reith JD, et al. Multidisciplinary management of soft tissue sarcoma. *Sci World J* 2013;**2013**:852462.
3. Parsons JT, Zlotecki RA, Reddy KA, et al. The role of radiotherapy and limb-conserving surgery in the management of soft-tissue sarcomas in adults. *Hematol Oncol Clin N Am* 2001;**15**:377–88 vii.
4. Rosenberg SA, Tepper J, Glatstein E, et al. The treatment of soft-tissue sarcomas of the extremities: prospective randomized evaluations of (1) limb-sparing surgery plus radiation therapy compared with amputation and (2) the role of adjuvant chemotherapy. *Ann Surg* 1982;**196**:305–15.
5. O'Sullivan B, Davis AM, Turcotte R, et al. Preoperative versus postoperative radiotherapy in soft-tissue sarcoma of the limbs: a randomised trial. *Lancet* 2002;**359**:2235–41.
6. Carlson GW. The evolution of extremity reconstruction for soft tissue sarcoma. *Ann Surg Oncol* 2006;**13**:610–11.
7. Tseng JF, Ballo MT, Langstein HN, et al. The effect of preoperative radiotherapy and reconstructive surgery on wound complications after resection of extremity soft-tissue sarcomas. *Ann Surg Oncol* 2006;**13**:1209–15.
8. Peat BG, Bell RS, Davis A, et al. Wound-healing complications after soft-tissue sarcoma surgery. *Plast Reconstr Surg* 1994;**93**:980–7.
9. Popov P, Tukiainen E, Asko-Seljaavaara S, et al. Soft tissue sarcomas of the lower extremity: surgical treatment and outcome. *Eur J Surg Oncol* 2000;**26**:679–85.
10. Barwick WJ, Goldberg JA, Scully SP, Harrelson JM. Vascularized tissue transfer for closure of irradiated wounds after soft tissue sarcoma resection. *Ann Surg* 1992;**216**:591–5.
11. Taylor GI. The angiosomes of the body and their supply to perforator flaps. *Clin Plast Surg* 2003;**30**:331–42 v.
12. Saint-Cyr M, Wong C, Schaverien M, Mojallal A, Rohrich RJ. The perforasome theory: vascular anatomy and clinical implications. *Plast Reconstr Surg* 2009;**124**:1529–44.
13. Teo TC. Perforator local flaps in lower limb reconstruction. *Cirugia Plastica Ibero-Latinoamericana* 2006;**32**:15–16.
14. Artiaco S, Battiston B, Colzani G, et al. Perforator based propeller flaps in limb reconstructive surgery: clinical application

and literature review. *BioMed Res Int* 2014;**2014**:5 690649. doi:10.1155/2014/690649.

15. D'Arpa S, Toia F, Pirrello R, Moschella F, Cordova A. Propeller flaps: a review of indications, technique, and results. *Biomed Res Int* 2014;**2014**:1–7.
16. Hyakusoku H, Yamamoto T, Fumiiri M. The propeller flap method. *Br J Plast Surg* 1991;**44**:53–4.
17. Hallock GG. The propeller flap version of the adductor muscle perforator flap for coverage of ischial or trochanteric pressure sores. *Ann Plast Surg* 2006;**56**:540–2.
18. Mateev MA, Kuokkanen HO. Reconstruction of soft tissue defects in the extremities with a pedicled perforator flap: series of 25 patients. *J Plast Surg Hand Surg* 2012;**46**:32–6.
19. Lecours C, Saint-Cyr M, Wong C, et al. Freestyle pedicle perforator flaps: clinical results and vascular anatomy. *Plast Reconstr Surg* 2010;**126**:1589–603.
20. Bravo FG, Schwarze HP. Free-style local perforator flaps: concept and classification system. *J Plast Reconstr Aesthet Surg* 2009;**62**:602–8 discussion 09.
21. D'Arpa S, Cordova A, Pignatti M, Moschella F. Freestyle pedicled perforator flaps: safety, prevention of complications, and management based on 85 consecutive cases. *Plast Reconstr Surg* 2011;**128**:892–906.
22. Bekara F, Herlin C, Mojallal A, et al. A systematic review and meta-analysis of perforator-pedicled propeller flaps in lower extremity defects: identification of risk factors for complications. *Plast Reconstr Surg* 2016;**137**:314–31.
23. Taylor GI, Chubb DP, Ashton MW. True and 'choke' anastomoses between perforator angiosomes: part i. anatomical location. *Plast Reconstr Surg* 2013;**132**:1447–56.