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ORIGINAL ARTICLE

Outcome of superficial brachial axial pattern flaps used to close skin defects in dogs: 16 cases (1996-2019)

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Objectives: To report the complication rate, type of complications and outcome of the superficial brachial axial pattern flap when used for closure of skin defects in dogs.

Materials and Methods: Medical records of dogs treated with a superficial brachial axial pattern flap for closure of a skin defect were reviewed. Information regarding signalment, reason for axial pattern flap use, skin flap size, flap healing, postoperative complications and need for revision surgery was collected.

Results: Sixteen dogs were included in the study. Indications for the superficial brachial axial pattern flap included closure following tumour removal (15/16, 94%) and management of a non-healing wound on the olecranon (1/16, 6%). Postoperative complications occurred in all dogs and included partial dehiscence (7/16, 44%), partial flap necrosis (6/16. 38%), seroma formation (5/16, 31%), flap oedema (3/16, 19%) and complete flap necrosis (2/16, 13%). Eight flaps (50%) healed without open wound management or additional surgery. Five dogs required open wound management without additional surgery, and three dogs (19%) required revision surgery.

Clinical Significance: Use of the superficial brachial axial pattern flap was associated with a high rate of complications. Most complications were managed without additional surgery and all wounds eventually healed, in some cases after prolonged open wound management.

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INTRODUCTION

Axial pattern flaps are used in dogs and cats to close large skin defects resulting from trauma or surgical treatment of neoplasia, when simpler skin reconstruction techniques such as tension-relieving techniques or subdermal plexus skin flaps are not considered appropriate (Hunt 2018, Wardlaw & Lanz 2018). Axial pattern flaps are based on a direct cutaneous artery and vein, and allow closure of larger skin defects compared to other techniques due to their improved viability (Wardlaw & Lanz 2018). A variety of axial pattern flaps have been described in dogs and cats in experimental and clinical settings (Pavletic 1990, Field *et al.* 2015), but data on outcome and complication rates of individual flaps are limited, and prospective studies are mainly lacking.

For skin defects affecting the antebrachium, management options may include open wound management and second

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intention healing, tension-relieving techniques, tissue expanders, local (subdermal plexus) skin flaps, skin grafts or use of an axial pattern flap (Hunt 2018, Wardlaw & Lanz 2018). Second intention healing may lead to contracture and loss of function and therefore may not be appropriate in some cases. The superficial brachial axial pattern flap is based on the cutaneous branch of the superficial brachial artery, which is itself a branch of the brachial artery. In an experimental setting, Henney & Pavletic (1988) described this axial pattern flap as being centred over the dorsal third of the flexor surface of the elbow. The flap then runs dorsally and proximally, parallel to the humeral shaft, and ends at the level of the greater tubercle (Henney & Pavletic 1988, Wardlaw & Lanz 2018). This flap has been used in dogs to cover defects of the cranial antebrachium or elbow in experimental studies (Henney & Pavletic 1988, Pavletic 1990) and in clinical cases (Field *et al*. 2015, Shafiuzama *et al*. 2017). The skin defects covered by the superficial brachial axial pattern flap extended down to 2 to 3 cm proximal to the carpus in experimental studies (Henney & Pavletic 1988). Although flap survival has been reported to be over 90% in experimental conditions (Henney & Pavletic 1988), this flap is usually considered less robust compared to other axial pattern flaps (Wardlaw & Lanz 2018).

There is limited information regarding the clinical use of the superficial brachial axial pattern flap, with only four clinical cases being reported in the literature. Reported complications comprise seroma formation, flap dehiscence and distal flap necrosis; however, a detailed description of complications and flap survival rate is lacking for clinical cases (Henney & Pavletic 1988, Field *et al*. 2015, Shafiuzama *et al*. 2017).

The aim of this study was to describe the complications rate, revision rate and outcome of superficial brachial axial pattern flaps when used to close skin defects in dogs.

MATERIALS AND METHODS

This study was approved by the Association for Veterinary Soft Tissue Surgery (AVSTS) Research Cooperative (ARC) and the Animal Health Trust (UK) Clinical Research Ethics Committee.

Members of AVSTS were invited to participate via the ARC mailing list and medical records were collected for dogs that were treated with a superficial brachial axial pattern flap for treatment of skin defects between 1996 and the end of the study. Animals were included in the study if the medical records were complete with sufficient descriptions of flap appearance to allow outcome to be reliably assessed for a minimum period of 2 weeks after surgery.

The following information was collected from the medical records: signalment, location of the skin defect, cause of the skin defect, histological diagnosis, time between injury and skin reconstruction (if applicable), surgery and anaesthesia times, local or regional anaesthesia techniques, flap dimensions (length and width), anatomic landmarks used, use of surgical drains or bandages, perioperative and postoperative antimicrobial administration, preoperative and postoperative chemotherapy administration, oncological outcome (if applicable), presence and type of complications, flap outcome and follow-up time. Flap outcome was defined as "optimal" (complete healing without wound dehiscence or necrosis), "partial flap dehiscence or necrosis not requiring revision surgery," or "flap dehiscence requiring revision surgery" (with or without flap necrosis).

RESULTS

Patient characteristics

Sixteen dogs met the inclusion criteria, with a median age of 102 months (range 7 to 156 months) at the time of surgery. Breeds included boxer (n=5), German shepherd dog (n=5), golden retriever (n=2), English Setter (n=2), crossbreed (n=2), Miniature schnauzer (n=1), Rhodesian Ridgeback (n=1) and Labrador (n=1) with a median weight of 28 kg (range 10 to 46.7 kg). Five dogs were entire males, six were neutered males, one was an entire female and four were neutered females.

Flap indications and characteristics

The superficial brachial axial pattern flap was used for wound closure after removal of a neoplastic mass (15/16 dogs, Fig. 1) or for management of a non-healing wound on the olecranon in one dog. Histological diagnoses included mast cell tumour in seven dogs, low-grade soft-tissue sarcoma in seven dogs (perivascular wall tumour in five dogs and peripheral nerve sheath tumour in two dogs) and high-grade soft-tissue sarcoma in one dog. One dog with a perivascular wall tumour on the left carpus underwent preoperative radiotherapy. None of the dogs received preoperative chemotherapy.

The location of the skin defect was reported in 15 dogs and included the proximal antebrachium in six dogs, the mid to distal

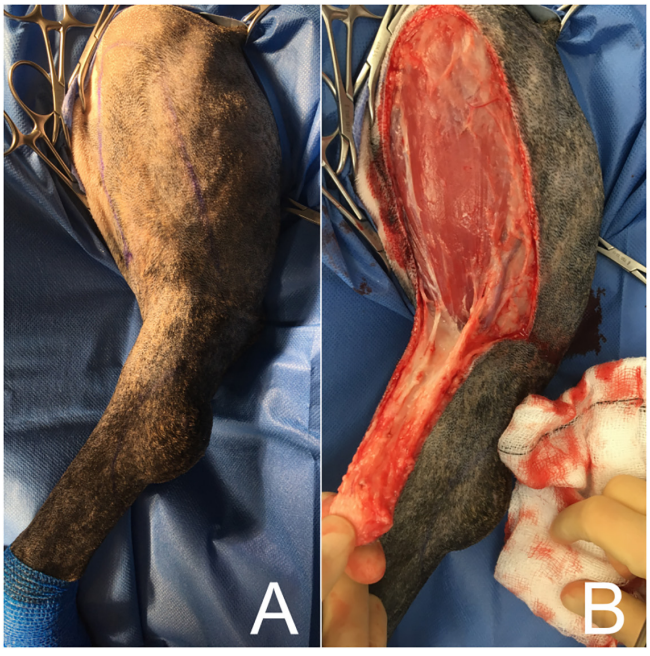

FIG 1. Photographs on dog 8 showing a soft tissue sarcoma on the proximal antebrachium preoperatively (A) and elevation of the superficial brachial axial pattern flap (B)

Table 1. Clinical features and flap outcome for the 16 dogs that underwent skin reconstruction using the superficial brachial axial pattern flap

	Breed	Age (in months)	Sex and neutering status	Weight (in kg)	Reason for reconstruction (and diagnosis)	Location of the defect	Surgery duration (minutes)	Postoperative antibiotics use	Drain placement	Complications	Revision surgery
1	Labrador	108	FN	24.9	Neoplasia (mast cell tumour)	Proximal antebrachium	40	N	N	Partial dehiscence (5%)	No
2	Boxer	108	MN	28.3	Neoplasia (mast cell tumour)	Distal antebrachium	Unknown	Y	Y (active)	Partial necrosis (2%), seroma	No
3	Boxer	108	MN	28	Neoplasia (mast cell tumour)	Unknown	Unknown	Y	Y (active)	Seroma	No
4	Miniature schnauzer	7	FN	10	Neoplasia (mast cell tumour)	Proximal antebrachium	45	N	N	Small area of ingrowing hair at base of flap	No
5	Boxer	7	MN	28	Neoplasia (mast cell tumour)	Proximal antebrachium	50	N	N	Prolonged wound discharge	No
6	Golden retriever	82	FN	29.5	Neoplasia (mast cell tumour)	Proximal antebrachium	150	Y	Y (active)	Partial dehiscence, partial necrosis (both 33%)	Yes
7	Boxer	75	MN	26	Neoplasia (mast cell tumour)	Distal antebrachium	90	N	Y (active)	Seroma	No
8	Boxer	101	FN	24.4	Neoplasia (soft tissue sarcoma)	Proximal antebrachium	75	Y	N	Partial dehiscence, partial necrosis (both 50%)	No
9	Rhodesian Ridgeback	104	MN	36	Neoplasia (perivascular wall tumour)	Proximal antebrachium	120	N	N	Partial necrosis (10%), seroma	Yes
10	Golden retriever	114	MN	32.4	Neoplasia (perivascular wall tumour)	Distal antebrachium	65	Y	N	Partial dehiscence (2%)	No
11	German shepherd dog	96	M	37	Neoplasia (perivascular wall tumour)	Carpus	80	N	N	Flap oedema, limb oedema	No
12	English Setter	120	M	19	Neoplasia (perivascular wall tumour)	Carpus	Unknown	Y	N	Complete flap failure (100% necrosis)	Yes
13	English Setter	156	F	17	Neoplasia (perivascular wall tumour)	Carpus	90	Y	N	Complete flap failure (100% necrosis)	No
14	Crossbreed	60	M	21	Neoplasia (peripheral nerve sheath tumour)	Distal antebrachium	75	N	N	Partial necrosis (10%)	No
15	Crossbreed	72	M	40	Neoplasia (high grade soft tissue sarcoma)	Distal antebrachium	70	Y	N	Partial dehiscence and necrosis (10%), seroma, oedema	No
16	German shepherd dog	108	M	46.7	Postoperative wound breakdown (non-neoplastic)	Olecranon	Unknown	Y	Y (active)	Infection, partial dehiscence and necrosis (5%), oedema, seroma	No

antebrachium in five dogs, the carpus in three dogs and the olecranon in one dog. The size of the defect as measured at the time of surgery was reported in 12 dogs and ranged from 22.4 to 96 cm^2 (median 48 cm^2).

The primary surgeon performing the superficial brachial axial pattern flap was an ECVS diplomate in 15 cases and an experienced veterinary surgeon in one case. The length of the harvested superficial brachial axial pattern flap was reported in 13 dogs and ranged from 14 to 19 cm (median 16 cm). This corresponded to 100% of the maximum angiosome described in the literature (Henney & Pavletic 1988) in nine dogs and 75%, 80%, 95% and 110% of the maximum angiosome in a crossbreed dog, a boxer, a crossbreed dog and an English Setter, respectively. The width of the superficial brachial axial pattern flap was reported in 10 dogs and was 100% of the maximum angiosome described in the literature (Henney & Pavletic 1988) in nine dogs and 90% of the maximum angiosome in the remaining dog.

Anaesthetic time was reported in nine dogs with a median of 140 minutes (range 105 to 225 minutes). Surgical time was reported in 12 dogs with a median of 75 minutes (range 40 to 150 minutes).

Preoperative and postoperative care

Local anaesthetic techniques were used in two dogs and included one brachial plexus nerve block using bupivacaine (Marcain; AstraZeneca) and one local instillation of ropivacaine (Ropivacaine Hydrochloride; Sandoz).

Thirteen dogs received perioperative antibiotics. Nine dogs received postoperative antibiotics for between 7 and 20 days. An active suction drain was placed at the time of the initial surgery in five dogs and remained in place for a median of 4 days (range 3 to 5 days). A bandage was used postoperatively in six dogs and remained in place for a median of 14.5 days (range 7 to 22 days).

Complications

Complications were reported in all dogs (Table 1) and included partial necrosis in seven dogs (Fig. 2), partial dehiscence in six dogs (Fig. 3), seroma or haematoma in five dogs, oedema in three dogs, wound infection in one dog, prolonged wound discharge in one dog, development of an area of ingrown hair at the base of the flap in one dog and complete flap failure with 100% necrosis in two dogs (Table 2). Seven dogs had more than one complication. In dogs with partial necrosis of the flap, necrosis involved between 2% and 50% of the flap (median 10%) and the median time from surgery to necrosis was 7 days (range 3 to 43 days). In dogs with partial dehiscence of the flap, dehiscence involved between 2% and 50% of the flap (median 10%).

Complications were managed conservatively in three dogs, including one dog with 5% partial dehiscence of the flap, one dog with flap oedema as the sole complication and one dog with prolonged wound discharge as the sole complication. In one dog that developed an area of ingrown hair at the base of the flap, the affected area was excised several months after the flap had healed. In four dogs, drainage of a postoperative seroma was performed as the sole postoperative treatment; all these dogs had an active suction drain placed postoperatively. In five dogs, a period of

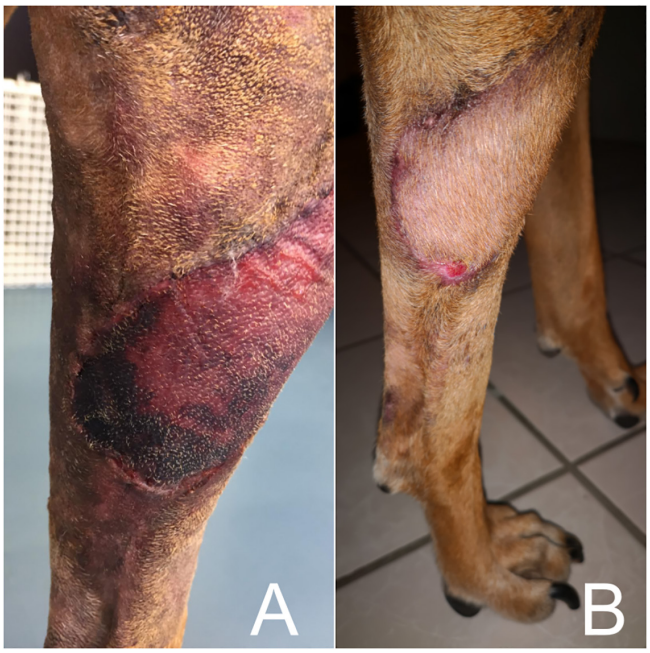

FIG 2. Photographs of dog 9 showing partial distal flap necrosis (A), which was treated with revision surgery (wound debridement and closure). Panel B shows the appearance of the wound 2 months after initial surgery

FIG 3. Photographs of dog 10 showing the appearance of the wound 4 days after surgery (A), and partial dehiscence of the axial pattern flap 1 week after initial surgery (B)

open wound management was necessary after partial dehiscence or necrosis (for four dogs) or complete necrosis (for one dog), but the wound eventually healed after a median of 20 days (range 16 to 72 days). In two dogs, surgical debridement and partial closure was required after partial flap necrosis or dehiscence, and the flap eventually healed after 45 and 58 days. In one dog with complete flap necrosis, revision surgery with a bipedicle flap was

Table 2. Summary of outcome and complications

Outcome and complications	Number
Uncomplicated wound healing	**0/16**
Complications not requiring further surgery	**13/16**
Partial dehiscence	5/16
Partial necrosis	5/16
Seroma	5/16
Oedema	3/16
Complete flap necrosis	1/16
Infection	1/16
Area of ingrown hair at base of flap	1/16
Prolonged wound discharge	1/16
Complications requiring further surgery	**3/16**
Partial dehiscence or necrosis	2/16
Complete flap necrosis	1/16

performed 150 days postoperatively, after a long period of open wound management.

Outcome

Overall, the superficial brachial axial pattern flap healed without further surgical intervention in eight dogs. The axial pattern flap healed after a period of open wound management in four dogs. In one dog, complete flap necrosis was treated with open wound management and second intention healing. Revision surgery was required in three dogs; in two of these dogs, revision surgery was limited to debridement and secondary closure, and a releasing incision was performed to allow wound closure after complete flap failure in the remaining dog. The time from surgery to complete healing was reported in 13 cases and ranged from 12 to 150 days (median 22 days); it was over 50 days in three cases.

In 12 of the 15 dogs treated for neoplasia, surgical excision was histologically confirmed to be complete. Three dogs had incomplete excision confirmed histologically. All three of these dogs had a perivascular wall tumour at the level of the carpus and the skin defects in these dogs were the largest (70 to 96 cm^2). One of these dogs received postoperative radiotherapy (protocol not specified). One dog received two postoperative doses of doxorubicin for treatment of a high-grade soft tissue sarcoma.

Local recurrence occurred in three dogs, two with incompletely excised perivascular wall tumours at the level of the carpus and one with a completely excised high-grade soft tissue sarcoma. Local recurrence in these cases occurred at 152, 282 and 125 days postoperatively.

DISCUSSION

In this report, we present 16 dogs that underwent reconstruction of antebrachial skin defects with a superficial brachial axial pattern flap. All dogs that underwent reconstruction with a superficial brachial axial pattern flap developed complications. However, only three required surgical revision and all wounds were determined to have healed within the inclusion period. The time from surgery to complete wound healing was over 50 days in three cases.

The skin defects reconstructed with the superficial brachial axial pattern flap were located on the proximal antebrachium, distal antebrachium or carpus in 15 dogs. The superficial brachial axial pattern flap has been primarily described to reconstruct skin defects affecting the antebrachium (Pavletic 1990) although the thoracodorsal axial pattern flap and latissimus dorsi myocutaneous flap may also be extended to cover defects of the antebrachium, depending on the conformation of the dog (Pavletic 1990, Wardlaw & Lanz 2018). However, these latter techniques involve a longer flap and a longer bridging incision between the base of the flap and the proximal aspect of the cutaneous defect.

In the initial experimental study describing the use of the superficial brachial axial pattern flap in five dogs (Henney & Pavletic 1988), the superficial axial pattern flap was elevated and transposed to the cranial antebrachium, and flap survival was 92 to 100%. Complications comprised seroma formation, minor distal flap necrosis (<10%), minor dehiscence (managed conservatively) and surgical site infection. Similarly, although all of the four clinical cases previously described in the literature showed minor complications, flap outcome was considered good to excellent in all cases (Field *et al.* 2015, Shafiuzama *et al.* 2017). This is in keeping with our findings, where 13 out of 16 superficial brachial axial pattern flaps healed without revision surgery, despite some requiring a prolonged period of open wound management.

The type of complications reported in this study was similar to other reports of axial pattern flaps (Trevor *et al.* 1992, Aper & Smeak 2003, Aper & Smeak 2005, Field *et al.* 2015, Emmerson *et al.* 2019, Proot *et al.* 2019) and most commonly included partial flap dehiscence, partial flap necrosis, seroma formation and oedema. However, at least one complication was reported in each dog leading to a complication rate of 100%, although 50% of these complications were considered minor as they did not require open wound management or revision surgery. Aper & Smeak (2005) also reported a complication rate of 100% for the caudal superficial epigastric axial pattern flap although 90% of the complications were also considered minor in this case series. The complication rate was reported to be lower in other axial pattern flaps with an 80% complication rate for the thoracodorsal axial pattern flap (Aper & Smeak 2003), a 63% complication rate for the caudal auricular axial pattern flap (Proot *et al.* 2019) and a 63% complication rate for the genicular axial pattern flap (Emmerson *et al.* 2019). The reason for the relatively high complication rate associated with the superficial brachial axial pattern flap is unknown, although Henney & Pavletic (1988) noted that the superficial brachial vessels were often hard to identify and may therefore be damaged during flap dissection. Due to the location of the skin defects, the superficial brachial axial pattern flap is also commonly transposed 180°, increasing the risk of twisting the direct cutaneous artery and vein. Due to the distal location of some defects, the flaps may also have been stretched rather than placed into position, which further increases the risk of vascular embarrassment. Finally, the flap is transposed over the flexor aspect of the elbow joint, which increases dynamic tension in the wound bed during limb movement.

Complete flap necrosis occurred in two dogs. Although the reason for complete necrosis was unknown, several factors may have contributed to this outcome. In both dogs, the skin defects extended to the carpus, and these were the largest skin defects in our report with areas of 78 and 96 cm^2. The length of the superficial

brachial axial pattern flaps used was 18 cm in both cases, and the flaps extended to the acromial region, which is beyond the landmark described by Henney & Pavletic (1988). Based on these findings, use of the superficial brachial axial pattern flap to cover skin defects over the carpus cannot be recommended. One of the two dogs also received preoperative radiotherapy, which may have led to decreased wound healing (Henry *et al*. 2003).

Only one dog in this report experienced a confirmed surgical site infection, although one other dog had prolonged wound discharge that may have been related to infection. Given the number of animals in the study and the low number of confirmed or suspected wound infections, it is not possible to comment on the possible utility of postoperative antibiotic therapy. Using an axial pattern flap to reconstruct a wound after excision of a non-ulcerated cutaneous mass is considered a clean procedure, albeit of potentially long duration, and therefore, all other things being equal, the use of postoperative antibiotics cannot be recommended based on current guidelines (Bratzler & Houck 2005).

In this report, three (19%) dogs underwent revision surgery to manage complications related to the axial pattern flap. Two of these revision surgeries were considered minor procedures involving secondary closure of the wound left by partial necrosis of the axial pattern flap. In the third dog, complete necrosis of the axial pattern flap occurred and was managed with open wound management for 5 months before a subdermal plexus skin flap was used to close the remaining defect. In all three dogs, the wounds eventually healed after revision surgery. The rate of revision surgery is similar to the revision rate of 13% reported for the genicular axial pattern flap (Emmerson *et al*. 2019), but lower than the rate of revision surgery of 31% reported by Field *et al*. (2015) for various axial pattern flaps. Higher revision rate was reported for the caudal auricular axial pattern flap (50%, Proot *et al*. 2019) and the thoracodorsal axial pattern flap (60%, Aper & Smeak 2003).

Use of the superficial brachial axial pattern flap allowed wide excision and clean histological margins to be obtained in 12 (80%) out of 15 dogs of the dogs treated for neoplasia in this study. The large skin defects created by wide surgical excision of these neoplasms may not have been amenable to simpler skin reconstruction methods.

The limitations of this study are inherent to its retrospective nature. The description of complications and flap outcome is based on the review of medical records, and the surgical technique, postoperative management and management of complications were not standardised. Despite these limitations, this study reports the largest series of dogs treated with a superficial brachial axial pattern flap to cover skin defects of the antebrachium. Surgeons and owners should be aware that the rate of complications is high. The majority of these complications appeared minor and could be managed without additional surgery, and all wounds healed within the inclusion period.

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Conflict of interest

No conflict of interest has been declared.

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