SUPERFICIAL TEMPORAL ARTERY FLAP: ITS DEVELOPMENT AND APPLICATION IN THE DOG AND CAT

by

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(ABSTRACT)

Cutaneous arterial blood supply to the temporal region was evaluated in 8 dogs and 8 cats. Dissection of 4 dog and 4 cat cadavers revealed the location of cutaneous branches of the superficial temporal artery supplying the frontalis muscle and skin of the temporal region. The frontalis muscle is a thin muscle dorsal to the temporalis muscle that extends cranially and rostrally from the rostral border of the scutulum to the forehead and upper eyelid. Microangiography and subtraction radiography of the external carotid and superficial temporal arteries were used in 4 dogs and 4 cats to determine arterial blood supply to the temporal region and frontalis muscle.

A superficial temporal artery (STA) flap was developed in 9 dogs [group A (n=5), group B (n=4)]. Ligation of the superficial temporal artery in the control dogs (n=5), rendered flaps dependent on the subdermal plexus. Dogs in group A (n=5) and the control group (n=5) had flap lengths that extended to the contralateral eye, while group B (n=4) flaps extended to the contralateral zygomatic arch. All flap widths were equivalent to the width of the zygomatic arch in the individual dog. Mean length of surviving tissue (mean survival length) (+/- SD) of control flaps was 7.0 (0.6) cm, compared with experimental flaps, group A 9.1 (0.8) cm and group B 10.4 (1.1) cm. Mean survival percentage area of control flaps was 73.5 (7.4) %, compared with experimental flaps, group A 93.1 (7.5) % and group B 69.1 (4.5) %. The mean survival length of control and experimental flaps
was significantly different (P < 0.05). There was no significant difference between survival lengths of the experimental groups.

A superficial temporal artery (STA) flap was developed in 5 cats. Flap dimensions were 2.0 x 7.0 cm in all cats, extending to the contralateral eye and equivalent to the width of the zygomatic arch. Ligation of the STA in control cats (n=5), rendered flaps dependent on the subdermal plexus. Mean survival length (+/- SD) of flaps based on the superficial temporal artery was 6.9 (0.2) cm. Mean survival length of control flaps dependent on the subdermal plexus was 4.4 (2.2) cm. Necrosis occurred in all control flaps (n=5), resulting in a mean survival percentage area (+/- SD) of 62.8 (11.7) %, compared with 98.6 (3.2) % mean survival percentage area in flaps incorporating the STA. The mean survival lengths of the two groups were significantly different (P < 0.05).

The results of these studies suggest that a flap based on the superficial temporal artery may be a source of skin for surgical reconstructive procedures of the head and neck of the dog and cat.
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LITERATURE REVIEW

Purpose

The purpose of this study was to assess the superficial temporal artery as a source of direct cutaneous blood supply to the temporal region skin and frontalis muscle in dogs and cats, and to determine surgical anatomic guidelines and survivability of a superficial temporal artery flap as a technique to augment reconstruction of maxillofacial defects.

Anatomy

Certain vascular features of dog and cat skin present an anatomic advantage for reconstructive surgery compared to human skin. The blood vessels to the dermis of the dog and cat consist of three interconnected vascularplexuses: the deep (subcutaneous), middle (cutaneous), and superficial (subpapillary) (Figure 1). Simple cutaneous arteries in the dog and cat emerge from fascial planes between underlying muscle masses to supply primarily the deep plexus. Direct cutaneous arteries travel parallel to the skin in subcutaneous tissue or superficial muscle and send branches to the dermis and epidermis (Figure 2). In the dog and cat, vessels exiting a muscle or exiting between muscles are both termed direct cutaneous arteries to the overlying skin. Capillary loops emanate from the superficial plexus and are arranged parallel to the skin surface, however they are poorly developed in fur bearing animals.\textsuperscript{1-3} Flaps elevated without inclusion of a direct cutaneous artery and vein in the dog and cat have been termed subdermal plexus flaps to avoid confusion with human random flaps based on musculocutaneous vessels.\textsuperscript{4} Due to the increased vascular supply provided by the direct cutaneous vessels in dog and cat skin, large axial pattern flaps created in these species are more likely to survive than in humans.\textsuperscript{5} Cutaneous arteries in the dog and cat which are used for axial pattern flaps with documented efficacy include the caudal auricular artery, the cervical branch of the omocervical artery, the superficial brachial artery, the thoracodorsal artery, the deep
circumflex iliac artery, the cranial and caudal superficial epigastric arteries, the lateral caudal artery and the descending genicular artery.\textsuperscript{6-9}

The primary function of muscle is for regulation of blood pressure and exercise.\textsuperscript{10} Muscle has greater blood flow and capillary density than skin.\textsuperscript{10} Myocutaneous flaps, such as those based on the cutaneous trunci, latissimus dorsi, gracilis, rectus abdominus, or platysma muscles, are also based on direct cutaneous arteries.\textsuperscript{11-15} The additional vascular contribution of the muscular component of a myocutaneous flap enhances survivability.\textsuperscript{13}

Other important dermal vascular anatomic structures are arteriovenous (AV) anastomoses or shunts, since they play a role in the vascular and nutrient supply of skin flaps. AV shunts are described in the human, pig, dog, rat, horse and rabbit.\textsuperscript{10,16} AV shunting may account for 70-80\% of blood flow in island skin flaps and 50\% of blood flow in myocutaneous island flaps.\textsuperscript{17} Similar values for dogs and cats are not reported. AV anastomoses are highly specialized cutaneous vessels that enable blood to bypass the capillary bed.\textsuperscript{10} There are no AV shunts in muscle.\textsuperscript{10} They have a very small lumen compared to 100 micron arterioles, 50-150 micron venules, and 4-10 micron capillaries. The walls of anastomoses are 2-3 times thicker than arterioles of similar outer diameter.\textsuperscript{10} There are two types of AV shunts in humans; those that connect the arterial side of circulation to the venous side proximal to the capillary bed (diameter 50-150 microns) and those that occur within the capillary bed (12-25 microns).\textsuperscript{17} AV shunting describes the bypassing of blood flow from the arterial system, past capillaries, through AV anastomoses, and into the venous system. This results in inadequate tissue nutrient supply normally provided by the capillaries, and it can affect skin flap survival deleteriously.\textsuperscript{16}
Circulatory Pathophysiology - Preoperatively

Circulatory regulation of the skin is controlled by humoral, metabolic, physical and neural factors. The mediators of humoral regulation are primarily epinephrine and norepinephrine, which both act on alpha adrenergic receptors to cause vasoconstriction, and histamine and prostaglandin E, which cause vasodilation. A study of sympathoadrenal activation on the human finger microcirculation found a discrepancy between total finger and capillary circulatory responses to epinephrine in both normotensive and hypertensive patients. The study suggests there may be different adrenoceptor populations and/or sensitivity in AV shunts compared with capillaries.  

A1-adenosine receptor stimulation by adenosine causes vasoconstriction in the human cutaneous microcirculation. A study of adenosine receptors determined that release of norepinephrine, serotonin, angiotensin, thromboxane or leukotrienes is not evoked by their stimulation. A negative interaction between alpha adrenergic and A1-adenosinergic receptors may exist. Vasopressin and angiotensin cause direct vasoconstriction of blood vessels in muscle, but have only minimal effects on blood flow in skin. Vasopressin administration was reported to be associated with reduced skin blood flow in the digit and forearm but not the trunk of human patients. The metabolic autoregulation of blood flow is not as prominent in the skin as in other organs with greater metabolic demand. Metabolic factors such as increased pCO₂, decreased pO₂, decreased pH, or decreased interstitial K⁺ favor increased blood flow, by acting as vasodilators. The physical regulation of blood flow is mainly dependent on temperature and pressure. Local hypothermia causes decreased blood flow, while hyperthermia results in vasodilation and increased blood flow. Increased perfusion pressure causes distension in an isolated cutaneous vessel, which triggers vasoconstriction. This inherent response results in maintenance of a constant capillary flow despite variations in arterial pressure. The most important system of circulatory control in the skin is neural
regulation, which consists of sympathetic (adrenergic) vasoconstrictor fibers that maintain a basal tone on vascular smooth muscle. These supply AV anastomoses, arteries and arterioles. Withdrawal of sympathetic tone causes vasodilation, especially in AV anastomoses.\textsuperscript{10,21}

In contrast to skin, where humoral control by sympathetic constrictors is the predominant regulatory mechanism of blood flow, sympathetic constriction has little significance in muscle circulation.\textsuperscript{10} Methods to assess perfusion of skeletal muscle intraoperatively currently only allow vessel identification and degree of patency, however contrast ultrasound is reported to successfully assess perfusion.\textsuperscript{22} Norepinephrine causes vasoconstriction in muscle, while epinephrine causes vasodilation, which directly contrasts its actions in skin.\textsuperscript{10} Compounds having only minimal effect on cutaneous blood flow, such as vasopressin, angiotensin, isoproterenol and acetylcholine, have a greater effect on blood vessels in muscle.\textsuperscript{10} Vasopressin and angiotensin cause vasoconstriction in muscle, while isoproterenol and acetylcholine cause vasodilation.\textsuperscript{10} The metabolic autoregulation of muscle blood flow is greater than that of the kidney, heart or brain, but less than that of skin.\textsuperscript{10} The predominant factor is hypercapnia, causing vasodilation.\textsuperscript{10} Myogenic tone is poorly developed in the smooth muscle of cutaneous vessels, but it plays an important role in muscle circulation. The physical regulation of muscle blood flow is minimal and consists of small responses to temperature changes.\textsuperscript{10} The significance of the neural component of muscle blood flow is not definitively determined, since it remains unclear whether sympathetic denervation significantly alters blood flow in the muscle vascular bed.\textsuperscript{10,21} The contribution of muscle and its vascular supply to overlying skin is the basis of the explanation for the increased survival of myocutaneous axial pattern flaps compared with cutaneous axial pattern flaps.\textsuperscript{10} In order to determine the contribution of muscle to a myocutaneous flap, angiographic studies performed on the individual skin and muscle
layers could document the location of vessels. Histologic analysis of the muscle of myocutaneous flaps having the pedicle vessel experimentally ligated compared with that of flaps based on the pedicle may provide additional pathophysiologic information.

**Circulatory Pathophysiology - Postoperatively**

Skin flap survival length is determined by blood supply and is not proportional to the width of the pedicle.\(^{10,23}\) The surviving length of a myocutaneous or arterial pedicle flap is about 50% greater than that of a random cutaneous flap not based on a specific vessel (Figure 3).\(^{10,24,25}\) When a pedicle cutaneous or myocutaneous flap is elevated, a state of vascular imbalance is established, disrupting capillary flow and the inherent vascular supply may be insufficient to support flap survival, leading to devascularization.\(^{10,26}\) Surgical incision of a flap causes partial denervation and devascularization and initiates the inflammatory reaction expected with normal wound healing.\(^{27}\) Denervation alone of a pedicle flap will decrease its survival.\(^{28}\) The surgical incision of peripheral vessels and nerves required to create these flaps causes “sympathectomy”. The resulting vasodilation can adversely affect vascular supply, especially in AV anastomoses.\(^{29}\) Blood flow to the acutely elevated flap may be decreased by catecholamine release from the incised cutaneous vessels and severed sympathetic nerve terminals causing vasodilation.\(^{10,29}\) Blood flow rate at the tip of the flap, measured by Cr\(^{51}\) radiolabelled red blood cells, is negligible, with pooling of red blood cells and an increase in intravascular hematocrit.\(^{26}\) Sympathetic innervation is lost, as demonstrated by loss of catecholamine staining and piloerection. It is essential that humoral, metabolic, physical and neural mechanisms reach a new equilibrium so that adequate nutrient circulation is ensured.\(^{10}\)
In human studies, flap elevation has been documented to increase the luminal size of small arteries of the subdermal plexus and venous channels of the dermis. In addition, there is an increase in the number of vessels at the flap base, confirmed by histologic evaluation, that persists for 2-3 weeks, presumably due to the inflammatory reaction induced by surgical trauma. Ingrowth of new vessels from tissue surrounding the flap begins 4-5 days postoperatively, followed by anastomoses with pre-existing vessels in the flap. Vascular ingrowth begins 3-4 days postoperatively in swine, 3-5 days postoperatively in rabbits, and 5-7 days postoperatively in rats. The rabbit and rat numbers must be extrapolated for dogs and cats, with similar fur-bearing mammalian cutaneous anatomy. Catecholamine disappearance as a result of denervation due to sympathectomy in rat flaps begins 18 hours postoperatively and is complete by 30 hours. Reaccumulation of catecholamines, which signifies reinnervation, begins 4-8 weeks postoperatively. The microangiographic hemodynamics of dog and cat skin flaps have not been studied in detail compared with documentation in rats, rabbits (fur-bearing animals) and pigs used as study models for humans.

The delay phenomenon is described as increased flap survival when flaps are surgically created and undermined from the donor site, then replaced in the same site for 4-14 days, depending on the particular flap, prior to transposition of the flap to the recipient site. The maximal augmentation of capillary blood flow occurs at 4 days, while angiogenesis is not noted until 14 days after the initial surgical procedure. The pathophysiology of the delay phenomenon is controversial, and has been theorized to result from one of three hypotheses:

1. conditioning of tissue to survive hypoxia resulting from ischemia,
2. AV shunt closure and improved nutrient capillary blood flow, and
3. improved skin blood flow due to sympathectomy and resultant vasodilation, angiogenesis and vascular reorganization, reactive hyperemia or inflammation.\textsuperscript{32-36} According to Reinisch,\textsuperscript{31} the delay phenomenon results from AV shunting, described as non-nutritive blood flow through the path of least resistance. Reinisch theorized that the increased survival resulting from the delay phenomenon is due to spontaneous closure of the AV shunts, discontinuing the non-nutritive blood flow and subsequently increasing nutritive blood flow to the flap. Another study substantiates this view.\textsuperscript{37} More recent studies\textsuperscript{10,30,38-40} discount this theory, and one based on more advanced radioisotope labelling techniques has shown primary capillary circulation present in the distal tip of the flap in addition to some blood flow through AV anastomoses. The delay phenomenon has not been studied extensively in the dog and cat as a method of survival enhancement. One case report used the delay procedure to enhance survival of a bipedicle subdermal plexus flap in the inguinal region used for preputial reconstruction in a dog.\textsuperscript{41} A retrospective study of axial pattern flaps in 19 dogs and cats records use of the delay procedure in 2 dogs with caudal auricular flaps for reconstruction of buccal defects.\textsuperscript{42} A disadvantage of the delay procedure, particularly in veterinary medicine, is the necessary increased hospitalization time and number of surgical procedures.\textsuperscript{43}

The contribution of the recipient bed to flap revascularization can be greater than that of the surrounding wound edges.\textsuperscript{26,30} The collateral blood supply is established within 6-10 days in rats.\textsuperscript{26,30} Flap survival in the recipient bed depends on functioning intravascular circulation, in contrast to plasmatic circulation of skin grafts.\textsuperscript{10} The survival of an arterial axial pattern flap can be directly related to its arterial supply, or can depend partially on its bed if flap failure occurs and a portion of the flap heals as a graft. A study of axial pattern flaps in rats concluded that the distal part of an arterial flap survives through dermal-subdermal plexi and is comparable to standard random cutaneous flaps.\textsuperscript{10} If flap
necrosis occurs, the main blood supply to the proximal 45% of the flap comes from its pedicle, while the distal 55% behaves similar to a graft, receiving blood supply from its bed.44 Histological analysis of rat axial pattern flaps confirmed this interpretation, showing the proximal 45% of the flap to have re-established all three vascular plexi (superficial, middle and deep) at 24 hours. By 8 days postoperatively, if flap necrosis occurred at the tip, the histologic appearance was that of sloughed epidermis with the deep dermis partially replaced by fat. In graft healing, the reestablishment of the vascular plexi occurs gradually over the first 96 hours postoperatively, until later than 8 days, when all dermal plexi are replaced.44 Grafts initially undergo an ischemic phase, in which nutrients are absorbed by “plasmatic imbibition” for the first 48 hours, followed by revascularization to the point of restoration within 4-7 days.45,46 Plasmatic imbibition occurs when tissue takes up wound exudate by absorption, diffusion and capillary action and becomes edematous.45

**Flap Failure Pathophysiology**

The overall average complication rate of human pedicled skin flaps due to vascular insufficiency is 14%.47 A similar number is not reported in the veterinary literature, however a retrospective study of axial pattern flaps in 19 dogs and cats reported a mean survival of 96%.42 Skin flap failure results from both extrinsic and intrinsic factors.48 Extrinsic factors include systemic conditions such as infection, hypotension or malnutrition, as well as local factors such as compression, tension, thrombosis or kinking of the vascular pedicle, or acidosis.26 Clinical evidence of the presence of an infection contributing to flap failure may be difficult to document, since previous studies indicate that aerobic and anaerobic qualitative cultures of the necrotic distal tip of rat flaps were either negative or identified skin contaminants.49-50 Ischemic tissue is more prone to infection, and endogenous flora may play a role in flap necrosis.25
There are three theories for the pathophysiology of hematoma-associated flap failure. The hematoma may be a source of red blood cells that contain substrates for free-radical formation leading to flap necrosis. There could be a direct toxic effect of the hematoma that is currently not identified. Alternatively, inadequate circulation to the overlying skin may result due to pressure from the hematoma.\textsuperscript{49-51}

Hypoxia develops once a skin flap becomes ischemic, such as from thrombosis or kinking of the vascular pedicle, and causes acidosis and a shift to anaerobic metabolism.\textsuperscript{26} Cell damage, cell death and an inflammatory response result, leading to vasodilation, increased capillary permeability, increased blood viscosity, stasis of blood flow, white blood cell adherence to endothelium and endothelial cell swelling.\textsuperscript{52} Pure arterial occlusion causes pale flaps, while pure venous occlusion would be expected to cause cyanosis.\textsuperscript{26} Histologically, if arterial occlusion develops, full-thickness necrosis follows with little or no edema. If venous occlusion develops, marked edema ensues in the dermis and subcutis, with necrosis more prominent and severe in the deeper layers. If the artery and vein are occluded, full-thickness necrosis takes place with no edema.\textsuperscript{53} Combined arterial and venous occlusion with arterial insufficiency is the most common cause of flap necrosis.\textsuperscript{26} Necrosis can be clearly demarcated clinically as early as 3 days postoperatively, but may not be established until 7 days.\textsuperscript{26} The critical ischemia time (CIT) is the maximum time tissue can tolerate complete ischemia.\textsuperscript{48,52} Knowledge of the particular CIT of the flap employed is necessary in order to therapeutically manage failure.\textsuperscript{52} During flap elevation, survival also depends on the cells' ability to withstand ischemic insult, not solely on flow.\textsuperscript{40}
The only known intrinsic factor critical to flap survival is inadequate nutrient flow, or arterial insufficiency, which leads to ischemic necrosis. Vascular spasm secondary to surgical incision can also be induced by ischemia. The microcirculation of the ischemic flap tip in a compromised flap is comparable to that of a patient in hypovolemic shock. Obstruction to blood reflow after anastomosis of the vascular pedicle of a “free flap” is called the “no-reflow phenomenon”, and may be due to narrowing of the capillary lumen by external pressure from edema, or by thrombus formation within the lumen of the vessel. The same effects could occur after occlusion of the vessels within the pedicle of an axial pattern flap after its rotation. The superficial temporal artery flap proposed in this study would be expected to have at least 180 degrees of rotation, without likelihood of kinking of the pedicle. “No-reflow” results in cell swelling, intravascular aggregation and leakage of intravascular fluid into the interstitial space.

Oxygen free radicals or reactive oxygen species (ROS) have also been incriminated in skin flap necrosis. They cause cell death by initiating chain reactions that lead to damaged cell membranes. The cell membranes have increased permeability, impaired response to signals, altered enzyme activity, reduced affinity of binding proteins and altered uptake of oxidized entities, as a result of lipid peroxidation, protein/hemoglobin adducts and protein thiol oxidation from reactive oxygen species (ROS). Lipid peroxidation can be monitored by measuring malonyldialdehyde (MDA) levels. With ischemia, cells become anoxic, anabolic functions reverse, gluconeogenesis increases and glycolysis leads to lactate production, resulting in intracellular and interstitial acidosis. Cell permeability increases and Na+/H2O enter the cells, causing swelling, microvascular occlusion and lysozyme rupture. Free radical toxicity may explain why ischemic tissue can be more prone to hematoma-induced necrosis.
Pharmacologic Manipulation of Flaps

In the management of clinical cases, understanding the pathophysiology of flap failure is important, so that knowledge may be applied in developing a therapeutic plan. Knowing that the greatest contributor to flap necrosis is arterial insufficiency, treatment to enhance flap survival should be based on increasing arterial flow or decreasing the effects of ischemia.\(^{29}\) It is also important to note that total occlusion of the flap vascular supply renders it very difficult to deliver therapeutic agents systemically.\(^{61}\) The goals of treatment of failed flaps are to increase vascular perfusion during initial ischemia, and to protect ischemic tissue against progressive deterioration.

In order to accurately assess the effect of a drug on the vascular supply of a flap, controlled studies are necessary. Suggested study guidelines include: measuring serum/tissue drug levels, initiating the drugs only after flap elevation, administering the drugs for an appropriate length of time based on the expected action and duration, establishing proper controls, double-blinding the study, and measuring blood flow changes.\(^{29}\) The underlying component of all suggestions is consistency among studies, and repeatability of results, which to date is either not available, or has not been studied for most drugs.

One experimental method of manipulating a skin flap is to alter the rheology of its vascular supply.\(^{29}\) Theoretically, if the blood viscosity is decreased, enhanced blood flow and increased flap survival will ensue. Low-molecular-weight dextrans and pentoxifylline have shown initial success, however the results have not been duplicated.\(^{26}\) Administration of dextran 70 to rabbits with small, severely traumatized veins resulted in significant antithrombotic effects.\(^{62}\) Recombinant hirudin is specific for thrombin inhibition, compared with the cofactor-mediated thrombin inhibition of heparin. This factor
may make hirudin beneficial for vascular surgeries.\textsuperscript{63} Low-molecular weight dextran,
which alter blood viscosity by increasing blood volume, were not successful in enhancing
flap survival in three studies performed in rats with intravenous intraoperative therapy.\textsuperscript{10,20}
Perhaps low-molecular weight dextran do not act effectively at the capillary level,
necessary to enhance flap vascular supply.\textsuperscript{64}

Pentoxifylline is a vasoactive agent that increases ATP in red blood cells, which
increases their deformability and therefore decreases blood viscosity.\textsuperscript{54} A German study
states that pentoxifylline inhibits platelet aggregation by increasing the level of cyclic AMP
(adenosine).\textsuperscript{43} The popular use of pentoxifylline is for cerebral vascular insufficiency,
however two studies of its use in rat pedicle flaps demonstrated enhanced survival
associated with increased red blood cell flexibility.\textsuperscript{54} The pentoxifylline was injected
intraperitoneally at a dosage of 12.5 mg/kg 1, 12 and 24 hours preoperatively, and every
12 hours postoperatively.\textsuperscript{54}

Severe protein depletion is detrimental to wound healing, therefore impaired flap
survival would be anticipated, however hypoproteinemia (4.67 gm\%: normal 6.11 gm\%) increased flap survival in a rat study, theoretically due to the decreased serum viscosity
which was documented by measurement of a sample of 10 cc of pooled rat serum with an
Ostwald viscometer.\textsuperscript{54} Serum protein levels less than 2 mg/dl usually inhibit wound
healing in the dog and cat.\textsuperscript{65} DL-methionine or cystine supplementation is critical to wound
healing in protein-deficient animals. Methionine is converted to cystine which may be
necessary for collagen synthesis.\textsuperscript{66-69} Protein depletion is attained experimentally by
feeding a diet totally deficient in protein for 6 weeks preoperatively.
Decreasing the serum hematocrit (14-33%, normal 41.5%) also increased flap survival in several studies, theoretically by decreasing serum viscosity since blood loss includes protein loss, although a relative hypoxia resulting in decreased oxygen carrying capacity is also induced by decreasing hematocrit and may be a contributing factor. Decreased serum hematocrit is attained experimentally by feeding a protein-depleted diet (anemia of chronic disease) or excessive blood sampling (blood-loss anemia). Methods of attaining protein depletion and decreasing serum hematocrit would not be considered acceptable therapeutic measures clinically.

Alteration of the environment of the flap has also been employed in attempts to enhance survival. Pressure bandages increased survival in two studies, but their use clinically is not widely accepted due to the concern of associated compromise of blood supply with compression. Moisture in the flap environment was thought to have increased survival in one study. A moist environment was created by using a dressing in 15 rats and by tunneling the flap underneath surrounding skin in another 15 rats. Potential factors contributing to the enhanced survival included moisture, compression and protection. Control groups, with no dressing or tunneling, eliminated the options of compression and protection, therefore moisture was concluded to be the factor responsible for the enhanced survival. This conclusion is also supported by another rat study using similar semi-permeable membrane dressings.

Intraoperative hypothermia (4 degrees Celsius) decreased the metabolism of rabbit skin flaps, increased the critical ischemia time (CIT) (from 8 to 72 hours), and decreased blood flow through AV shunts resulting in more nutritive flow. Cold exposure (2 hours, 4 degrees C) resulted in decreased skin circulation and increased muscle and adipose tissue
circulation in rats. Clinical documentation of this form of flap survival enhancement is not available.\textsuperscript{10,26}

If hypoxia causes local vasodilation, perhaps hyperoxia causes constriction and maintains tone in AV shunts, preventing shunting of blood lethal to the flap.\textsuperscript{10} In two studies of flap survival in rats, hyperbaric oxygen had a beneficial effect, while a study of canine skin grafts demonstrated a detrimental effect and a study in feline axial pattern flaps showed no significant difference between treated and nontreated cats.\textsuperscript{10,29,73,74} There is some suggestion that hyperbaric oxygen therapy improves reepithelialization in both normal and ischemic rat skin.\textsuperscript{75} Hyperbaric oxygen therapy may also be beneficial in chronic wound healing in humans.\textsuperscript{76} The equipment to apply hyperbaric oxygen precludes use of this technique in most clinical settings.\textsuperscript{10}

Since decreased vascular supply is the primary underlying cause of flap failure, vasodilating agents might be expected to increase vascular supply and enhance flap survival. The vascular response may be associated with angiotensin II levels in different systemic regions.\textsuperscript{26} Nifedipine increased axillary arterial blood flow in dogs.\textsuperscript{77} Diltiazem did not change peripheral blood flow in the digit or forearm in a human study.\textsuperscript{78} Research documenting clinical efficacy of calcium channel blockers such as nitrendipine, verapamil, diltiazem, and nifebidrine, with potent vasodilatory effects, provide conflicting results.\textsuperscript{26} The impact of calcium regulating substances (phosphorus, parathyroid hormone, and vitamin D3) on finger blood flow was studied in humans. There was no indication that calcium regulating factors were related to parameters of peripheral circulation in normotensive humans.\textsuperscript{79} These are the most promising drugs under human investigation for enhancement of skin flap survival.
Prostaglandins are released by blood vessels in response to many stimulants including trauma and inflammation expected during surgical elevation of a skin flap.\textsuperscript{80} Prostaglandin E (PGE) compounds cause vasodilation, while prostaglandin F (PGF) compounds produce vasoconstriction.\textsuperscript{80} PGE\textsubscript{2} (a vasodilator) given 2 days preoperatively and 7 days postoperatively increased flap survival in the pig.\textsuperscript{81} There was a strong correlation between increased red blood cell flexibility and enhanced flap survival.\textsuperscript{81} PGE\textsubscript{2} reduced ADP-induced platelet aggregation but there was no correlation between platelet aggregation and enhanced survival.\textsuperscript{81} PGE\textsubscript{2} (a vasodilator) and indomethacin (an inhibitor of vasoconstrictive prostaglandin compounds) were administered to rats with island skin flaps at a dosage of 2 mg/kg/day for 3 days preoperatively and postoperatively, and flap survival enhancement was documented.\textsuperscript{80} Elsewhere, prostaglandin inhibitors have also been reported as successful in some studies, and unsuccessful in others.\textsuperscript{29} Since prostaglandins have multiple actions as vasodilators and anti-inflammatory agents, assessment of which function is enhancing survival is difficult.

The prostaglandin endoperoxide, prostacyclin, causes platelet disaggregation, vasodilation, and cytoprotective activity.\textsuperscript{82} A prostacyclin analogue, iloprost, given at a low dosage of 10 ng/kg subcutaneously 30 minutes preoperatively significantly enhanced survival of axial pattern flaps in rats after ischemia-reperfusion.\textsuperscript{82}

Direct vasodilators such as dimethylsulfoxide (DMSO, which also has multiple action as an anti-inflammatory agent), histamine, and isoxsuprine (beta agonist) have been tested with conflicting results reported.\textsuperscript{10,29} DMSO is postulated to have histamine-like vasodilation effects.\textsuperscript{10} It has been shown to enhance flap survival in one study, however the results of that study have not been duplicated to date.\textsuperscript{10} Histamine causes vasodilation by acting at the histamine (H-1) receptor, and its use to enhance flap survival has been
successful in some cases, unsuccessful in others.\textsuperscript{10} It is theorized that histamine may cause selective dilation of AV shunts rather than the capillary bed, which would increase non-nutritive flow deleteriously.\textsuperscript{10}

The primary regulator of circulation in skeletal muscles is vascular smooth muscle.\textsuperscript{83} Therefore, beta agonists, such as isoxsuprino, should cause vasodilation and prolonged relaxation of the precapillary sphincter vascular smooth muscle in the vessel walls, and perhaps increase the blood supply to the myocutaneous flap.\textsuperscript{83} Isoxsuprino increases muscle blood flow, since it is a smooth muscle relaxant, however its effects may not be solely related to its beta agonist action.\textsuperscript{29} Isoxsuprino was administered to pigs with random flaps at a dose of 0.5 mg/kg intramuscularly every 8 hours for 5 days postoperatively, and no enhancement of survival was noted.\textsuperscript{29} In contrast, isoxsuprino did enhance flap survival in a study in which flaps underwent hematoma induced necrosis.\textsuperscript{21,51,83}

Corticosteroids stabilize cell membranes, reduce inflammation, cause marked vasodilation, and improve oxygen consumption. Variable beneficial effects on flap survival are reported following corticosteroid administration.\textsuperscript{26} In one study, prednisone administered postoperatively at a 25-30 mg/kg QD dosage resulted in a 30-40% improvement in flap survival.\textsuperscript{56} Another study of rat pedicle flaps demonstrated enhanced flap survival when dexamethasone was given intraperitoneally at 0.5-2 mg/kg.\textsuperscript{47} The reduction of edema and inflammation postoperatively due to corticosteroid administration contributes to flap survival enhancement.\textsuperscript{47,84} Corticosteroids may inhibit later phases of healing by delaying fibroblast proliferation. Clinically, only high dose therapy initiated prior to surgery or prolonged therapy postoperatively has a significant negative effect.\textsuperscript{85}
If blood flow to acutely elevated flaps is kept submaximal by vasoconstriction caused by catecholamine release from incised sympathetic nerves, then alpha antagonists should increase flow. Sympatholytic agents have been used to chemically denervate flaps preoperatively and thereby produce vasodilation. Studies using sympathomimetic agents such as epinephrine resulted in decreased flap survival, supporting the use of sympatholytic agents. Thymoxamine is an alpha antagonist and has been tested both systemically and locally to enhance flap survival. In one study, both systemic and local injections of thymoxamine increased radioisotope clearance, indicating increased blood flow, however there was no corresponding increase in flap survival.

Phenoxybenzamine is another alpha antagonist tested both systemically and locally. In one study, it enhanced flap survival, however in another experiment in pigs, it was administered systemically at 2 mg/kg intravenously once daily for 5 days postoperatively, and this dose was not effective to cause alpha blockade. A challenge injection of norepinephrine intravenously resulted in increased blood pressure, which should not occur if alpha receptors are effectively antagonized. Phenoxybenzamine showed no flap survival enhancement in that experiment, however it was not used at an appropriate dose to provide alpha blockade. Studies of this drug demonstrate one of the primary inconsistencies of drug experiments, since appropriate dosages and durations are often unknown to date.

Six-hydroxydopamine (6-OHDopa) selectively destroys sympathetic nerve terminals, resulting in “chemical sympathetectomy” and vasodilation. When 6-OHDopa was infiltrated subdermally at 1 mg/cc of flap tissue in 2 pigs, flap survival length was enhanced by 30%. The dosage was chosen arbitrarily, and the numbers in the study are inadequate for definitive conclusions concerning the effect of the drug.
Reserpine is an alkaloid that acts as a catecholamine depletor, to hasten
 catecholamine release from the incised sympathetic nerve. In a study of 5 pigs, reserpine
 was administered at 2.5 mg/kg intravenously and initially caused an increase in blood
 pressure, then later caused decreased blood pressure and peripheral vascular resistance.
 There was no enhancement of flap survival in the study, and the animals could not
 ambulate and were anorexic for 2-3 days postoperatively, precluding further consideration
 of its use in a clinical setting.

The hydroxyl radical (OH) is very toxic and is formed by catalysis of the
 superoxide radical (O$_2^-$) with iron. Protein-binding of iron is an attempt to decrease this
 catalyst reaction. Iron chelators such as desferoxamine similarly prevent the reaction.
 Xanthine oxidase is an enzyme source of free radicals in ischemic tissue, such as a failing
 skin flap. Allopurinol competitively inhibits xanthine oxidase. Both desferoxamine and
 allopurinol could potentially reduce free radical numbers and decrease their deleterious
 effects on flap survival. Studies of rat pedicle flaps have shown desferoxamine may have a
 beneficial effect on flap survival. Allopurinol acts as a metabolic depressant and must
 be administered prior to the occurrence of ischemia. It has only been beneficial at
 extremely high doses administered preoperatively, which would be prior to knowledge of a
 clinical problem. Superoxide dismutase is an oxygen free radical scavenger. There was
 significant enhancement of flap survival in a study of island flaps in rats when flap
 ischemia was created by vascular occlusion for 10-11 hours and flaps were perfused with
 3 cc of Ringer’s lactate solution with 9000 IU of superoxide dismutase. In order to
 monitor free radical levels experimentally, malonyldialdehyde (MDA) levels can be
 measured. An elevation in MDA indicates increased lipoperoxidation, which is closely
 related to the free radical mechanisms. MDA levels have been found to be elevated at the
 distal necrotic portion of flaps in rats. The amino acid, taurine, has an antioxidant effect
in tissues, however taurine supplementation did not enhance survival of rat subdermal plexus flaps.\textsuperscript{87} Although a loss of tissue taurine was detected in the necrotic distal tip of the flap.\textsuperscript{87}

A study of the effects of polypeptide growth factors including transforming growth factor beta (TGF), insulin-like growth factor-I (IGF-I), and growth hormone (GH) alone and in combination with dietary L-arginine HCL (ARG), found that IGF-I alone, and GH and TGF in combination with ARG significantly improved skin flap survival in rats, presumably due to augmented wound healing.\textsuperscript{88}

It is evident that the study guidelines to accurately assess drug effects on flap survival suggested in this section's introduction have not been attained. The primary problems relate to unknown drug dosages and duration for clinical use, and the prevalence of conflicting reported results.

**Monitoring Cutaneous Perfusion**

Determination of flap size is important in comparison studies of flap survival. One method to indirectly measure flap area involved weighing a template of the flap initially postoperatively, and comparing the weight of a template made once necrosis was established.\textsuperscript{80} Another study used the average of maximum, minimum and two intermediate values of flap survival length to calculate the surviving flap area when the flap necrosis was not necessarily a symmetrical rectangular pattern.\textsuperscript{56} The sonic digitizer and polar planimeter are methods to measure area more accurately, although the polar planimeter is only accurate for areas greater than 64.5 cm\textsuperscript{2}.\textsuperscript{89} A study comparing use of a sonic digitizer and a polar planimeter to measure area of flap survival found that the
digitizer was faster and more efficient with more reproducible results, but was not cost
effective.\textsuperscript{89}

The ideal monitor of cutaneous microcirculation is one that is harmless to both the
patient and the flap, accurate, reliable, rapid, simple, inexpensive, applicable to all flaps,
repeatable, objective, and recordable. Additional benefits include the capability of
prolonged constant monitoring which is rapidly responsive to circulatory change, and
equipped with a simple display to alert inexperienced personnel.\textsuperscript{90} The gold standard is a
test that is able to detect vascular compromise prior to obvious changes in clinical
assessment, so that appropriate intervention can be employed earlier, with a greater
likelihood of success.\textsuperscript{90} The definition of an accurate monitor is suggested in the human
literature to be one that predicts final flap survival within 3 cm, for cutaneous or
myocutaneous flaps.\textsuperscript{91} Four categories of such tests exist: clinical tests, chemical methods,
radioisotopic methods, and instrumental methods. The following summary presents
techniques which have been used to monitor and/or predict flap viability.

**Clinical tests:**

Skin color, temperature, sensation and bleeding are subjective indicators of flap
circulation which, by their subjective nature, can all be inaccurate.\textsuperscript{26} Assessment of skin
color can be complicated by major factors affecting color such as filling and state of
oxygenation of blood in the superficial (subpapillary) dermal vascular plexus, whereas
epidermal contributions are relatively constant.\textsuperscript{90} Assessing skin flap viability by skin
color is even more subjective if the environmental light is variable.\textsuperscript{90} One study suggests
use of a colorimeter (Minolta 200 or spectrophotometer) to assess skin color less
subjectively.\textsuperscript{92} The colorimeter indicates the degree of erythema and can assess the amount
of blood in the vascular plexus.\textsuperscript{92} Pigmented skin is difficult to assess, especially for early
subtle changes. Many dogs and cats have pigmented skin, especially in the temporal region where the flap employed in this study is located. If the flap is healing with adequate supply from its arterial pedicle, a diffuse relatively normal skin hue is to be expected. If a portion of the flap is healing as a graft, with nutrient absorption initially from the recipient bed, there may be a pink to reddish color at the tip, signifying initiation of the normal revascularization phase. Any cyanotic or black coloration noted only postoperatively signifies lack of vascular supply and necrosis.45

Skin temperature is subject to regional variations93 and is dynamic, which makes it a very imprecise predictor.53 Assessment of skin temperature is very subjective, unless a thermocouple is used, and its expense may outweigh any benefit. A thermocouple is a device for measuring slight changes in temperature and consists of two wires of different metals, with one in an area of known temperature and the other in the test area. Despite use of the thermocouple, problems with regional variation and the changing metabolic rate of underlying muscle remain. Temperature assessment should not be used as a sole indicator of tissue viability or flap circulation.90,91

Capillary refill time (CRT) is another non-invasive monitor of skin flap circulation.90 CRT should be less than 4 seconds if normal circulation is present.25 Swelling, edema or skin pigmentation could interfere with this test. Bleeding from the cut edge of a sharp puncture wound would be considered a last resort of clinical tests in monitoring since it is more invasive and could affect flap healing.90,94

Disadvantages of clinical tests include the requirement of experienced personnel for interpretation, the effect of ambient light on perception of color, and the fact that changes are often subtle clinically in the early stages postoperatively.90 Direct assessment by an
experienced observer is the gold standard of flap assessment since it is safe, simple and reliable. To be successful, early postoperative monitoring and a substantial time committment of the surgeon are necessary. To the author’s knowledge, there are no clinical studies in the literature comparing success of clinical tests versus chemical, radioisotopic or instrumental methods.

**Chemical methods:**

Chemical methods are slightly more invasive than clinical tests. However, they are a more accurate means of assessing cutaneous perfusion, therefore their potential benefit can outweigh any involved risks. Several methods are reported in the literature. The following summary presents the advantages and disadvantages of each, as well as their potential application to this study.

The Atropine Absorption Test is reported in the human literature as an easy, satisfactory method for qualitative and quantitative assessment of peripheral circulation. Atropine is injected into the flap and the patient is monitored for clinical signs such as tachycardia, xerostomia or mydriasis caused by systemic effects of atropine, indicating the drug was absorbed from the flap circulation into the systemic circulation. This test could not be used for continuous monitoring due to overdosage of atropine, and it would likely be difficult to assess animal patients as to whether the changes were associated with the drug or the stress of injection and/or restraint.

The Cutaneous Histamine Reaction is reported as a test of collateral circulation in peripheral vascular disease. Its use has been applied to assessment of skin flap circulation in human patients. After histamine injection into the flap, the flap is observed for a “flare reaction” in the form of a wheal. If a wheal forms within 8 minutes, circulation is
considered adequate. Wheals do not form readily in the thick skin of the head region, therefore use of this test in our study would be limited. This method also is not acceptable for continuous assessment.

Fluorescein (resorcinol phthalein) injection, first reported used in 1882, has long been considered the gold standard for cutaneous perfusion assessment. Many animal experimental and human studies recommend its use. In dogs, fluorescein is not considered an effective or accurate method of predicting survivability in research or clinical cases, perhaps due to the fact that dogs have a less well-developed capillary loop system compared with humans. Uses of fluorescein in veterinary medicine primarily include fluorescein labelled antibodies, or fluorescein dye to assess intraosseous or intestinal vascular supply and occasionally to assess skin flap perfusion. In a study of capillary perfusion following ischemia in hamsters, fluorescein isothiocyanate - dextran was administered and monitored by transillumination to determine that increased perfusion is a normal reaction to ischemia - reperfusion injury. Fluorescein isothiocyanate is also used in combination with other compounds, such as bovine serum albumin, to monitor capillary circulation within skeletal muscle. Muscle circulation may be better monitored by other techniques such as plethysmography, or scintigraphy. The intensity of skin fluorescence is an expression of extracellular fluorescein in the skin, rather than the amount of blood flow or intravascular fluorescein. Absence of fluorescence suggests no inflow, while prolonged fluorescence suggests venous obstruction. Fluorescein injection has very few reported side effects, including hypotension, nausea/vomiting, and a low incidence of allergic reactions (0.6%), which all may be related to the rate of administration. Anaphylaxis resulted after intravenous administration of fluorescein to a cat for angiography. The primary drawback of cutaneous perfusion assessment with systemic fluorescein injection is that the test cannot be repeated more frequently than every
8-12 hours due to the dose required for visual assessment. Since visual assessment is subjective, one study attempted to categorize the readings into grades. Lack of fluorescence was graded 0, patchy fluorescence 1, and good fluorescence 2. Visual assessment of fluorescence provides an incorrect prediction of flap survival 37-41% of the time, meaning a 37-41% chance that areas with no fluorescence in the first 24 hours will survive (false negative). In contrast, there is a 12-22% chance of necrosis despite good fluorescence (false positive) with visual assessment in the first 24 hours, meaning a 12-22% chance that a fluorescing area will not survive. After 24 hours, fluorescence is 88-100% accurate with visual assessment. However this is past the CIT when intervention becomes necessary if planning to re-explore the flap to salvage vascular supply or begin medical therapy. Some studies suggest the use of a Fluoroscan in order to reduce the number of false negative assessments. The Fluoroscan is a surface fluorometer monitoring device that is more sensitive than visual assessment, allowing a lower dosage of fluorescein, which is eliminated more quickly, and more frequent assessment. Despite use of the Fluoroscan, there remains a 9% incidence of false positive assessments. In studies of human patients, mottled areas of fluorescence usually survive, however that was not the case in a rat study. Some studies suggest the use of fluorescein in a hospital setting is difficult since darkness and an ultraviolet light are required. Fluorescein assessment may be unreliable in pigmented skin, and this, along with the subjective nature of visual assessment, may have contributed to the inaccuracies in reported studies.

**Radioisotopic methods:**

Measurement of the clearance of radioisotopes (²⁴ Na, ¹³¹ I, ⁹⁹ᵐ Tc, ¹³³ Xe) from skin can provide an accurate estimate of cutaneous perfusion. One study concluded intradermal radioisotope clearance is the most accurate measure of skin perfusion.
However, the following are many disadvantages associated with this technique.\textsuperscript{112} Unfortunately, radioisotope clearance is useful only in a comparative mode and only measures a particular instant in time.\textsuperscript{90} The intracutaneous injection of isotope alone can cause increased blood flow.\textsuperscript{113} Another considerable disadvantage with this technique is the radiation exposure to patients and personnel. For these reasons, this method is not an acceptable option for clinical monitoring of skin flap viability.

**Instrumental methods:**

**Transcutaneous oxygen:**

Gaseous exchange in tissues depends on satisfactory circulation.\textsuperscript{90} Transcutaneous oxygen levels can be monitored using a sensing probe and a device that creates a local hyperemia (42-44 degrees Celsius) in order to increase blood flow and increase monitored gas levels. In one study, there was an 89\% accuracy in assessing a problem with circulation, primarily venous occlusion, using this method.\textsuperscript{91} The advantages of transcutaneous oxygen monitoring include: non-invasive, continuous, quantitative, easy, and commercially available.\textsuperscript{114} Whether this test truly measures tissue pO\textsubscript{2} remains to be determined, and some investigators consider it to be best used as a trend recorder.\textsuperscript{90,92,97,115} Disadvantages include: skin condition is crucial (unreliable readings occur if an eschar forms, therefore skin must be smooth, soft and have no edema), expense and local hyperemia, sometimes resulting in iatrogenic thermal burns.\textsuperscript{93,97,116} For a patient receiving no supplemental oxygen, a zero reading does not necessarily correlate with necrosis, therefore an “Oxygen Challenge Test” can be performed to determine the increase in tcPO\textsubscript{2} after administration of 100\% O\textsubscript{2} and assess the values as trends to determine significance.\textsuperscript{90,115} Areas with no increase in their readings are ischemic or necrotic. In this study, placing the sensors required for this technique would be difficult due to minimal tissue depth in the temporal region. When used over bone, as in this study, readings will
be lower, possibly due to dermal blood supply occlusion by the weight of the sensor. However, this would not matter if the technique is being employed only as a trend monitor.\textsuperscript{114}

Pulse oximetry:

This technique measures the oxygen content of arterial blood and it is a simple, reliable assessment, best used in human patients to monitor replanted digits.\textsuperscript{93} This method would not easily apply to assessment of the superficial temporal artery flap, other than intraoperatively, since it would be difficult to place the probe in the temporal region.

Photoplethysmography:

This technique is based on the amount of light absorbed by blood and tissue that is measured when a light source is directed at the skin.\textsuperscript{90} The light absorbance measurement can record either volume of blood in the skin, or the systolic-diastolic variations in skin blood volume.\textsuperscript{92} Photelectric plethysmography is a simple, non-invasive techniques to determine erythrocyte volume and oxygen saturation.\textsuperscript{117} Only two studies document its potential use in this field, one demonstrating successful assessment of viability of human tube pedicle flaps\textsuperscript{113}, and one specifically successfully assessing blood content and circulation in human maxillofacial defect reconstruction.\textsuperscript{118} One of the primary disadvantages with some types of equipment is the inability to distinguish arterial from venous flow.\textsuperscript{90} Other disadvantages of the technique include: changes with local cutaneous blood volume, motor artifacts, subjective interpretation, and expense.\textsuperscript{90,93} Previous studies conclude this technique cannot be used to successfully determine skin perfusion, since it provided only a 67\% accuracy with no false positives, 33\% false negatives, and a consistent underestimation of flap survival.\textsuperscript{91,112}
Laser Doppler:

Doppler ultrasound is a non-invasive method to measure the presence of blood flow, rather than its quantity.\textsuperscript{93} Color duplex imaging is recently reported for successful evaluation of fasciocutaneous flap perforator vessels, and may be used to determine more reliably the ideal donor site of such a flap.\textsuperscript{119} Laser doppler uses the same principle as doppler ultrasound, but measures frequency shifts of light (rather than of sound waves) calculated as the product of the number of red blood cells and their mean velocity.\textsuperscript{93,120} Laser doppler flowmetry was successfully used to assess skin circulation and detect impaired blood flow to skin overlying tissue expansion devices.\textsuperscript{121} Advantages of this technique include: the ability to measure flow in AV anastomoses as well as capillaries (in contrast to radioisotopes)\textsuperscript{113}, superiority compared to visual assessment alone\textsuperscript{53}, easy to measure, and non-invasive.\textsuperscript{112} Like some photoplethysmographs, laser doppler cannot distinguish arterial and venous flow.\textsuperscript{93} Other disadvantages of this technique include: pigmented skin affects readings\textsuperscript{122}, very wide variability in measurements between sites and individual patients from day to day\textsuperscript{122}, cannot be used on vessels larger than capillaries\textsuperscript{53,90,92,122}, movement artifact occurs when patients are conscious, and being the most misleading technique when tested on flaps (27\% false positives and 27\% false negatives).\textsuperscript{91} Based on the disadvantages listed, this technique would be unacceptable for assessment of the vascular perfusion of the superficial temporal artery flap.

Microdialysis:

In vivo estimation of endogenous and exogenous substances in the dermal extracellular space has been performed with microdialysis in humans.\textsuperscript{123} The presence of the microdialysis probe incites an inflammatory reaction which initially increases perfusion, however perfusion levels return to normal within 60 minutes. Microdialysis is a promising
new method in dermatologic research and may have an application in skin flap viability assessment.\textsuperscript{123}

**Summary**

Knowledge of the pathophysiology of flap healing and necrosis is essential in order to therapeutically manage a failing flap. Assessment of cutaneous perfusion is essential in early diagnosis of flap failure in order for successful therapeutic management. The risks of methods used to assess cutaneous perfusion must be outweighed by the potential benefit of such tests.
References


Figure 1 - Cutaneous vasculature of the dog (Reference #1)
(with publisher's permission)

Figure 2 - Schematic representation of the comparative vascular supply to the skin of animals (A) and humans (B) (Reference #1)
(with publisher's permission)
Figure 3 - Survival patterns of skin flaps (Reference #10)
(with publisher's permission)
INTRODUCTION

Excisional surgery for malignant tumors or traumatic wounds of the maxillofacial region including the eye, lip, ear, or nose may result in defects causing cosmetic and functional disturbances after wound healing. In our experience, most owners of veterinary patients with tumors elect surgical excision as the only treatment, while the patient may be best served by multimodality therapy.\textsuperscript{1,5} Surgical techniques which allow tumor-free margins would be optimal to maximize a successful outcome.\textsuperscript{4,5} Radiation therapy can be an effective therapeutic modality, however in some cases, secondary effects of radiation leave the patient with a significant wound which may require reconstructive surgical techniques.\textsuperscript{5,6}

The frontalis muscle is a thin muscle dorsal to the temporalis. It arises from the rostral border of the scutulum and extends cranially and rostrally to the forehead and upper eyelid (Figures 1,2).\textsuperscript{7} The rostral auricular plexus and palpebral branch of the auriculopalpebral nerve is ventral to the frontalis muscle and dorsal to the orbital rim (Figure 3).\textsuperscript{7} Myocutaneous flaps and axial pattern flaps have a vascular advantage compared to skin grafts and/or subdermal plexus or advancement flaps based on the direct arterial supply to the donor skin and the additional blood supply provided by the muscle, providing greater ultimate tissue viability.\textsuperscript{8-12} Myocutaneous flaps provide additional tissue bulk and vascularity, however the frontalis muscle is not substantial and it is unlikely that it contributes significantly to the blood supply or bulk, compared with other muscles such as gracilis or latissimus dorsi.\textsuperscript{8-12} Incorporating muscle with overlying skin can reduce the ability of the skin to advance and stretch into a defect.\textsuperscript{13} The improved vascularity of the donor flap tissue should promote healing and help resist infection.\textsuperscript{14} The superficial temporal artery flap may be a viable surgical technique for maxillofacial reconstruction in...
the dog and cat following resective oncologic surgery, trauma, radiation therapy, or after failure of other reconstructive techniques.\textsuperscript{5,15,16}

The purpose of the cadaver and vascular studies was to assess cutaneous blood supply to the temporal region and frontalis muscle in dogs and cats, and to determine the applicability of temporal region skin and frontalis muscle as an axial pattern flap to augment reconstruction of maxillofacial defects in dogs and cats.

The purpose of the surgical studies was to assess the superficial temporal artery and vein as a source of direct cutaneous blood supply to the temporal region and frontalis muscle, and to determine surgical guidelines and survivability of a flap based on the superficial temporal artery.
REFERENCES


Figure 1 - Lateral view of superficial muscles of the head. (Reference #7, p1112).

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Figure 2 - Dorsal view of superficial and deep muscles of the head. (Reference #7, p1113)

(with publisher's permission)
Figure 3. Lateral view of nerves of head region (Reference #7, p. 21).
Regional peripheral vascular supply based on the superficial temporal artery in dogs and cats.

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SUMMARY

Cutaneous arterial blood supply to the temporal region was evaluated in 8 dogs and 8 cats. Dissection of the temporal region in 4 dogs and 4 cats revealed the subcutaneous location of the superficial temporal artery as it continues rostrally from the caudal aspect of the zygomatic arch. The frontalis muscle is a thin muscle dorsal to the temporalis muscle that extends cranially and rostrally from the rostral border of the scutulum to the forehead and upper eyelid. Subtraction radiography and angiography of the carotid and superficial temporal arteries were used in 4 dogs and 4 cats to document arterial blood supply to the temporal region and frontalis muscle. An axial pattern flap based on the superficial temporal artery and frontalis muscle may be indicated for cosmetic reconstruction in dogs and cats following surgical resection of neoplastic lesions or traumatic wounds in the maxillofacial region.

MATERIALS & METHODS

Cutaneous and myocutaneous vascular supply to the temporal region was studied by dog (n=4) and cat (n=4) cadaver dissection and by angiographic studies of dogs (n=4) and cats (n=4). Observations were made in cadaver specimens of the origin of blood supply to the skin and frontalis muscle in the temporal region (Figures 1 and 2). Arterial catheterization was performed under aseptic surgical conditions in mixed-breed mesaticephalic dogs (n=4) and domestic shorthair cats (n=4) scheduled for euthanasia for conditions unrelated to the head. Prior to lethal injection, anesthesia was induced by IV injection of sodium thiamylal \(^a\) (16 mg/kg of body weight) and maintained by endotracheal administration of oxygen and halothane \(^b\) (1-2 %). In 2 dogs and 4 cats, carotid artery catheterization was performed and the catheter was advanced to the level of the maxillary
artery. In the remaining 2 dogs, the superficial temporal artery was directly catheterized. In all cases, radiopaque contrast solution was manually injected to visualize the superficial temporal artery and its branches (Figures 3 and 4). In one of the superficial temporal artery catheterized dogs, a frontalis myocutaneous axial pattern flap was surgically created. In this case, radiopaque contrast solution was manually injected before and after surgical ligation of the superficial temporal artery in order to document absent vascular supply post-ligation, based on the lack of visible contrast agent (Figure 5).

RESULTS

Results of cadaver and radiographic studies documented that the superficial temporal artery provides blood supply to the skin and frontalis muscle in the temporal region in dogs and cats. The superficial temporal artery originated at the base of the zygomatic arch in a subcutaneous position, and extended rostrally along the zygomatic arch in the dog and cat cadavers. Angiographic studies revealed small branches of the superficial temporal artery extending to the skin of the temporal region and the frontalis muscle (Figures 3, 4, 5). After surgical ligation of the superficial temporal artery, contrast agent was no longer visible within the surgically-created flap tissue.

DISCUSSION

There is less ample skin available in the maxillofacial region of the dog and cat compared with the trunk and occipital region, making cutaneous facial wounds not easily amenable to primary repair or second-intention wound management. Large cutaneous defects managed conservatively may heal with excessive scar tissue, leading to cosmetic and functional defects of the eye and mouth. Humans with maxillofacial defects have been successfully surgically managed using “forehead flaps” since as early as 700 BC. An
advantage in dogs and cats is that primary closure of the donor site is possible, whereas a free skin graft is necessary in humans. The scalping “forehead flap” or “galeal frontalis flap”, with the flap base ideally at the level of the zygomatic arch described for use in humans, is similar to the flap described in this study.\textsuperscript{3,4}

Reconstructive surgical techniques such as skin grafts would not be expected to provide a successful outcome in the maxillofacial region in dogs and cats due to the relative immobility of the skin and difficulty with wound management/bandaging necessary for a successful outcome, and the non-compliance of animal patients. Successful use of labial advancement flaps has been reported in some clinical cases.\textsuperscript{5} Axial pattern flaps have been developed in dogs and cats in various locations to increase treatment options for reconstruction of maxillofacial cutaneous defects.\textsuperscript{6-8} An axial pattern flap from the area investigated in this report may offer several advantages over previously described techniques. There is a large amount of available tissue to reconstruct defects in a one-stage surgical procedure with primary closure of the donor site. Flap pattern design, which would include direct cutaneous arteries and veins, described in this report should promote flap survival and permit an extended length of available tissue.\textsuperscript{6,8,9}

The superficial temporal artery is one of the terminal branches of the external carotid artery, arising rostral to the base of the auricular cartilage in the dog and cat.\textsuperscript{10,11} The course of the artery crosses the caudal aspect of the zygomatic arch, extends slightly dorsal to it, and then turns rostrally and roughly parallels the zygomatic arch. Two of its branches, the superficial temporal and rostral auricular arteries, supply the skin and muscle of the temporal region. Based on the cadaver and angiographic results of this study, these vascular structures are consistent in their location and distribution. Thus, a flap based on the region supplied by the superficial temporal artery and extending dorsally over the
cranium has potential clinical application in providing adequate skin for reconstruction of maxillofacial defects in dogs. Though previous reports\textsuperscript{12} of cat carotid artery angiography do not address the superficial temporal artery, cat cadaver and vascular studies performed in the present work show vascular features of this area to be similar in the dog and cat. Thus, clinical applicability of a superficial temporal artery flap in cats seems likely. Further studies are necessary to determine anatomic guidelines for flap development and estimates of expected flap survivability.
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a Bio-tal, Boehringer Ingelheim Animal Health Inc, St Joseph, Mo.
b Fluothane, Ayerst Laboratories Inc, New York, NY.
c Conray 400, ER Squibb & Sons Inc, Princeton, NJ.
Figure 1 - Representation from cadaver dissection of branch of superficial temporal artery supplying skin and frontalis muscle in the temporal region of the dog.

Figure 2 - Representation from cadaver dissection of branch of superficial temporal artery supplying skin and frontalis muscle in the temporal region of the cat.
Figure 3 - Angiography (subtraction view) via carotid artery catheterization demonstrating the superficial temporal artery (STA) and its branches supplying the temporal region of the dog. Note arrow demonstrating site of ligation of STA in control dogs.

Figure 4 - Angiography (standard view) via carotid artery catheterization demonstrating the superficial temporal artery (STA) and its branches supplying the temporal region of the cat. Note arrow demonstrating site of ligation of STA in control cats.
Figure 5 - Angiography via superficial temporal artery catheterization before ligation demonstrating a branch of the artery supplying the skin and frontalis muscle of the superficial temporal artery flap in the dog.
Superficial Temporal Artery Flap in Dogs

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SUMMARY

An axial pattern flap based on the superficial temporal artery (STA) was developed in 9 dogs. Dogs in the control group (n=5) and group A (n=5) had flaps that extended to the contralateral eye. Dogs in group B (n=4) had flaps extended to the contralateral zygomatic arch. In all cases, the width of the flap was equivalent to the width of the zygomatic arch. Dogs in the control group (n=5) had ligation of the superficial temporal artery and vein rendering flaps dependent solely on the subdermal plexus. Mean survival length (+/-SD) of control flaps [7.0 (0.6) cm], compared with experimental flaps [group A 9.1 (0.8) cm, group B 10.4 (1.1 cm)], was significantly different (P < 0.05). There was no significant difference between survival lengths of the experimental groups. Mean survival percentage area (+/-SD) of superficial temporal artery flaps (group A, 93.1 (7.5)%), compared with control flaps (73.5 (7.4)%), was significantly different (P < 0.05). On the basis of the results of this study, an axial pattern flap based on the superficial temporal artery may be a source of skin for reconstructive procedures of the head and neck in canine patients.
Excisional surgery for malignant tumors of the eye, lip, ear, and nose may result in cosmetic and functional disturbances after wound healing. In our experience, most owners of veterinary patients with tumors elect surgical excision as the only treatment, while the patient may be best served by multimodality therapy.\textsuperscript{1-5} Radiation therapy can be an effective alternative if the owner permits it, however in some cases, secondary effects of radiation leave the patient with a significant wound which may require reconstructive surgical techniques.\textsuperscript{5,6} Surgical techniques which allow tumor-free margins would be optimal to maximize a successful outcome.\textsuperscript{4,5}

The frontalis muscle is a thin muscle dorsal to the temporalis. It arises from the rostral border of the scutulum and extends cranially and rostrally to the forehead and upper eyelid.\textsuperscript{7} Myocutaneous axial pattern flaps have a vascular advantage compared to other reconstructive surgical techniques based on the additional circulation provided by the muscle, allowing potentially greater tissue viability.\textsuperscript{8-11} The improved vascularity of the donor flap tissue could promote healing and help resist infection.\textsuperscript{11} Single pedicle advancement flaps and transposition flaps performed after tissue expansion are successfully reported for reconstruction of defects in areas such as the antebrachium and crus where excess surrounding skin is not available.\textsuperscript{12} Perhaps this technique could also be applied to the maxillofacial region in dogs and cats. A 90 degree transposition flap based on the subdermal plexus in the frontal region, incorporating the frontalis muscle, has been successfully reported for reconstruction of a frontal defect after rhinotomy for aspergillosis. This flap is dependent solely on the subdermal plexus rather than a vascular pedicle for its blood supply.\textsuperscript{13} A similar type of flap based ventral to the ear and parallel to the mandible was used successfully to repair a maxillofacial defect resulting from neoplasia in a dog.\textsuperscript{14} Other maxillofacial reconstructive techniques could include the labial advancement flap\textsuperscript{15}, or the buccal rotation technique.\textsuperscript{16} The superficial temporal artery flap may be a viable
surgical technique for maxillofacial reconstruction following resective oncologic surgery, trauma, radiation dermatitis, or after failure of other reconstructive techniques.5,17

The purpose of the study reported here was to determine surgical anatomic guidelines and survivability of an axial pattern flap based on the superficial temporal artery as a source of direct cutaneous blood supply to the temporal region and frontalis muscle.

MATERIALS & METHODS

Fourteen mature, mesaticephalic mixed breed dogs were sedated with acepromazine (0.1 mg/kg SC) and butorphanol (0.2 mg/kg SC), then induced with sodium thiamylal (16 mg/kg IV) and maintained with oxygen and halothane (1-2%). Lactated ringer’s solution was administered at 10 ml/kg/hr IV. The dogs were placed in ventral recumbency and the temporal region was clipped and prepared for aseptic surgery. Guidelines for flap location were based on results of cadaver and vascular studies performed in dogs.13 The landmarks for the base of the superficial temporal artery flap were the caudal aspect of the zygomatic arch caudally and the lateral orbital rim rostrally (Figure 1). Flap dimensions were based on the feasibility of primary wound closure of the donor site and required length to transfer the flap to the maxillofacial area, including the nasal planum as the rostral extent. The width of the flap was equivalent to the width of the zygomatic arch in each dog. The length of the flap in the control dogs (n=5) and some experimental dogs (n=5) extended over the frontal region to the contralateral eye. In the remaining experimental dogs (n=4), the length extended to the contralateral zygomatic arch. The rostral auricular plexus and palpebral branch of the auriculopalpebral nerve was identified and partially incised at the cranial border of the flap over the eye ipsilateral to the flap base in order to enhance flap rotation.
The flaps were created randomly unilaterally using maximum dimensions to provide coverage of the maxillofacial area following rotation rostrally, yet allowing primary wound closure of the donor site. The skin was incised and the thin frontalis muscle was identified superficial to the fascia of the temporalis muscle. The flap was carefully elevated toward the base. In all cases, the superficial temporal artery and vein were identified by ventral extension of the incision at the caudal aspect of the flap base. Ligation of these vessels was performed with surgical clips in the five randomly assigned control dogs. All flaps were temporarily rotated rostrally to the nasal planum. The control and group A flaps could be rotated 90 degrees rostrally without apparent compromise to the vascular pedicle, based on continued presence of hemorrhage at the distal flap tip, and could extend at least to the area of the nasal planum in all dogs. The group B flaps could be similarly rotated, and extended 2-3 cm past the nasal planum. During temporary flap translocation, skin at the donor site was apposed using 3-0 nylon in a simple continuous pattern to assess feasibility and ease of donor site closure. After orthotopic placement of the superficial temporal artery flaps, they were sutured in place with 3-0 nylon in a simple continuous pattern. Latex drains were placed beneath the flap, exiting through a separate site caudoventral to the flap base, in a position not expected to influence circulation to the flap. A stent bandage was used to cover the drain exit site.

Postoperative care included daily wound cleansing and dressing changes. Latex drains were maintained until 48 hours postoperatively, when there was minimal drainage evident. Butorphanol tartrate (0.1 mg/kg SC) was administered twice daily for the duration of the study in conjunction with Animal Care Committee recommendations.

Flap viability was subjectively assessed in all dogs for seven days postoperatively on the basis of skin temperature, texture and color (Figure 2 A,B,C). Additionally,
perfusion and viability of the flaps based on cutaneous fluorescence following injection of fluorescein<sup>d</sup> (2%, 15 mg/kg IV) was performed immediately following surgery and on postoperative days 1 and 3. Flap examination was performed using ultraviolet light 15-20 minutes after fluorescein injection. Acetate sheets were placed over the flaps and used as templates to record areas of cutaneous fluorescence. The value of cutaneous fluorescence as a predictor of flap survival was determined based on comparison of template recorded cutaneous fluorescence with the amount of viable flap remaining 7 days postoperatively. The length of skin viability was determined as described previously with visual measurement of grossly devitalized tissue and geometric calculations and converted to a percentage of total flap area. Data were analyzed by use of the paired t test with P < 0.05 considered significant.

Clinical case - Surgery was performed on a 1-year-old Border terrier for reconstruction of a traumatic maxillofacial defect (Figure 3 A,B). A premaxillectomy was performed, removing the incisors but maintaining the palatal incisive papilla, to provide a mucosal surface for reconstruction of the nares. A 4.0 x 12.0 cm superficial temporal artery flap was created based on the left superficial temporal artery and vein and extending to the contralateral eye. A bridge incision was made beginning in the frontal region and bisecting the nasal region. The flap was rotated rostrally, and the distal tip was sutured to the palatal mucosa in the region of the nares (Figure 3 C,D). Primary closure of the donor site and the periphery of the flap was performed in a simple continuous pattern.
Mean width and length of flaps were: 3.2 +/- 0.8 X 9.9 +/- 0.5 cm for controls, 3.6 +/- 0.8 cm X 9.9 +/- 1.3 cm for group A, and 2.9 +/- 0.6 cm X 14.9 +/- 0.6 cm for group B. Mean survival length of flaps was: 7.0 +/- 0.6 cm for controls, 9.1 +/- 0.8 cm for group A, and 10.4 +/- 1.1 cm for group B (Table 1). Necrosis occurred in all control flaps (n=5) and in experimental group B (extended length) flaps, resulting in mean survival percentage areas of 73.5 +/- 7.4 % and 69.1 +/- 4.5 % respectively, compared with mean survival length of 93.1 +/- 7.5 % in experimental group A flaps incorporating vascular supply from the superficial temporal artery. Survival lengths of control and experimental (group A and B) flaps were significantly different. There was no significant difference between survival lengths of the experimental groups.

Complications included seroma development in one control dog and one experimental (group A) dog after self-trauma to the flap region and premature drain removal at 24 hours rather than 48 hours. One of those dogs required sedation in order to resuture the flap. Seromas were managed with intermittent drainage between sutures. Wound dehiscence occurred at areas of flap necrosis 7 days postoperatively and was not surgically managed. There were no abnormalities with blinking noted postoperatively.

Cutaneous fluorescence was a subjective assessment of vascular perfusion to the flap area. There were no adverse effects of fluorescein injection noted. The mean % fluorescence area immediately postoperatively was 17.2% for control dogs, 28.8% for group A, and 41.8% for group B. Postoperative day 1 mean % fluorescence area was 53.3% for control dogs, 66.4% for group A, and 46.6% for group B. Postoperative day 3 mean % fluorescence area was 66.3 % for control dogs, 95% for group A, and 48.9% for group B. The mean % survival area was 73.5% for control dogs, 93.1% for group A, and 69.1% for group B. There was a significant difference between the mean % fluorescence
area at postoperative day 0 and 1 for all groups compared with the mean % survival area at postoperative day 7. There was no significant difference between the mean % fluorescence area at postoperative day 3 compared with the mean % survival area at postoperative day 7 in any group. In five of the 14 dogs (35.8%), the area of non-fluorescence on day 3 was equivalent to the area that ultimately became non-viable. In eight of the 14 dogs (57.2%), the non-fluorescent area was larger on day 3 than the area that ultimately became non-viable, therefore it was a subjective overestimation of the amount of tissue that would ultimately become necrotic. In the remaining case (7%), the non-fluorescent area was smaller on day 3 than the ultimately non-viable area, therefore it was a subjective underestimation of the amount of tissue that would ultimately become necrotic. In all dogs, except three from experimental group B (extended length), there was a gradually increasing trend in the amount of fluorescence from postoperative day 0 to day 3.

Application of a superficial temporal artery flap in the clinical patient with the maxillofacial wound allowed primary wound reconstruction with 100 % flap survivability. Postoperatively, there was redundant tissue over the left eye due to rotation of the flap tissue, and mild tension over the right eye due to primary closure of the donor site (Figure 3 C,D), however there was no associated clinical problem with the palpebral response. At two months postoperatively, the tissue had redistributed providing an acceptable cosmetic result (Figure 3 E,F).

DISCUSSION

There is less ample skin in the canine maxillofacial region relative to the occipital region or trunk, making cutaneous wounds often not amenable to primary repair or second-intention wound management without resultant functional and cosmetic deficiencies. Human patients with maxillofacial defects have been successfully surgically
managed using "forehead flaps" since as early as 700 BC. The scalping "forehead flap", with the flap base at the level of the zygomatic arch, is similar to the flap described in this study.

The non-compliance of animal patients, combined with the difficulty in immobilizing the skin of the maxillofacial region, preclude reconstructive techniques such as skin grafts. Successful use of labial advancement flaps has been reported in some clinical cases. Axial pattern flaps have the advantage of better flap tissue survivability due to their vascular pedicle. Myocutaneous flaps have the advantage of additional bulk of tissue for cosmesis, as well as additional vascularity to enhance healing. In both cases, immediate tissue transfer and primary wound closure of the donor site is possible, resulting in a one-stage procedure to reconstruct the defect.

Our results were similar to survivability of other axial pattern flaps. The rationale for extending the length of the flap to the contralateral zygomatic arch was to determine the maximum feasible flap length that would reduce tension at the distal tip of the flap at the recipient site for larger wounds or dolicocephalic dogs. The human "forehead flap" is reported successfully extended to the contralateral zygomatic arch. Mean survival length was not significantly different for the experimental flaps, however, the percentage flap survival area of experimental group B was similar to the controls, indicating the extended length results in less tissue survivability at the distal tip. A length extending to the contralateral eye is therefore ideal, particularly considering the adequate amount of tissue available to reconstruct the maxillofacial region at this length.

Techniques to estimate skin blood flow including transcutaneous PO2 monitoring, photoplethysmography, laser Doppler flowmetry, and/or various heatmeasuring devices
may have provided a more accurate assessment of vascular perfusion during the monitoring period.\textsuperscript{24-27} Cutaneous fluorescence has been previously documented in the veterinary literature to have inconsistent accuracy in predicting survivability\textsuperscript{28}, while studies in humans advocate its use, based on the ease of the technique and its lack of invasiveness combined with predictive accuracy.\textsuperscript{29,30} Our results indicated a consistent accurate or slight underestimation of ultimate tissue viability, however the results were only significant at postoperative day 3, at which time visual assessment of the flap based on tissue temperature, texture and color was clearly indicative of ultimate tissue viability. Results of fluorescein studies would have more clinical applicability if they more accurately assessed perfusion within the first 24 hours postoperatively, in order that measures to enhance ultimate tissue viability could be taken prior to the development of tissue necrosis.\textsuperscript{31} In our study, cutaneous fluorescence at postoperative day 0 and day 1 was not an accurate predictor of flap survival.

In this study, inadequate blood flow in the control animals, with the superficial temporal artery and vein ligated, contributed to flap necrosis. An angiographic study concluded that no contrast agent was visible in flap tissue subsequent to ligation of the superficial temporal artery, therefore its ligation would preclude other blood supply.\textsuperscript{18} The primary factor contributing to flap necrosis in the experimental group is arterial insufficiency. However, the toxic effects of hematoma or free radicals cannot be excluded since they were not examined specifically. Since the flaps in this study were orthotopically placed, only temporary intraoperative assessment of the local extrinsic factors was possible. There was no evidence that infection contributed to flap death, although cultures of the necrotic areas were not performed. Since histologic analysis of the superficial temporal artery flap tissue was not performed, no conclusions can be drawn with respect to the timing or pattern of revascularization. Histologic analysis might have contributed to
this study by documenting full-thickness versus partial-thickness necrosis, and whether
graft healing occurred. There also may have been a histologic difference in the muscle
between the groups related to ligation of the superficial temporal artery. Histology was
used to identify neurogenic atrophy in muscle flaps in cats.\textsuperscript{33}

Despite incision of a portion of the rostral auricular plexus, including the palpebral
nerve, there were no adverse effects noted with palpebral function. The palpebral nerve
supplies the orbicularis oculi muscle, which is important to closure of the lid.\textsuperscript{32} Perhaps
only a portion of the plexus was affected, or adjacent muscle compensation occurred.

Clinical application of the superficial temporal artery flap demonstrated its viability.
The wound was not amenable to other reconstructive techniques such as skin grafting, due
to its location, or local advancement flaps, due to the size of the defect. The superficial
temporal artery flap provided single-staged wound reconstruction with an acceptable
esthetic result in this prominent region. Potential complications considered in the clinical
case included primary wound dehiscence secondary to self-trauma from licking, especially
due to irritation from the sutures in the region of the nares. A second reconstructive
procedure to redistribute the tissue over the eyes was anticipated, however by 2 months
postoperatively, the defect was no longer evident, eliminating the need for a second
surgery. Hair growth at the nares requires occasional trimming, however the dog receives
no additional care as a result of her surgery.

Based on the necrosis of the distal tip of the flaps extended to the contralateral
zygomatic arch, we recommend use of a superficial temporal artery flap which extends to
the contralateral eye and provides adequate tissue for rostral rotation to the nasal planum.
On the basis of the results of this study, the superficial temporal artery flap had a greater
surviving length compared with flaps dependent solely on the subdermal plexus. The superficial temporal artery flap may have application for maxillofacial reconstruction of traumatic wounds, or wounds resulting after excisional surgery or radiation therapy.
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b Dermalon, Davis & Geck, Wayne, NJ.
c Latex Penrose drain, Davol Inc (CR Bard), Cranston, RI.
d Fluorescein powder 10G, Sigma chemical, St. Louis, MI.
Figure 1 - Diagram showing location of the superficial temporal artery flap (broken lines) and the superficial temporal artery (STA) (black arrow) in relation to the zygomatic arch and orbital rim. Note arrow demonstrating location of ligation of the STA in control dogs.
Figure 2 - Day 7 postoperative photographs of control (A), group A (B), and group B (C) dogs.
Figure 3 - Preoperative lateral (A) and dorsal (B) views of a 1 year old Border terrier following maxillofacial trauma.
Figure 3 - Immediate postoperative lateral (C) and frontal (D) views show the superficial temporal artery flap used for reconstruction of the maxillofacial and nasal region.
Figure 3 - Two month postoperative lateral (E) and frontal (F) views show acceptable cosmesis. Note the incisive papilla (arrow).
Table 1 - Comparison of survival length of control and experimental (group A, group B) superficial temporal artery flaps.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>FLAP DIMENSIONS (cm)</th>
<th>SURVIVAL LENGTH (cm)</th>
<th>SURVIVAL PERCENTAGE</th>
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</thead>
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<tr>
<td>Control</td>
<td>4.5 x 10.0</td>
<td>7.0</td>
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<tr>
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<td>81</td>
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<tr>
<td>Control</td>
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<td></td>
<td>9.0 (0-5)</td>
<td></td>
<td></td>
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<tr>
<td>Group A</td>
<td>3.0 x 9.0</td>
<td>9.0</td>
<td>100</td>
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<tr>
<td>Group A</td>
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<td>95</td>
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<td>100</td>
</tr>
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<td>Group A</td>
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<td>Group A</td>
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<td>83</td>
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<td>MEAN (+/- SD)</td>
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<td>9.1 (0.8)</td>
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<td></td>
<td>9.9 (1-3)</td>
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<tr>
<td>Group B</td>
<td>3.5 x 15.0</td>
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<td>MEAN (+/- SD)</td>
<td>2.9 (0.6) x 14.9</td>
<td>10.4 (1.1)</td>
<td>69 (4.5)</td>
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</table>
Superficial Temporal Artery Flap in Cats

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SUMMARY

An axial pattern flap based on the superficial temporal artery (STA) was developed in 10 cats. Control flaps, which included ligation of the superficial temporal artery and vein, were developed in five cats. Flap dimensions were 2.0 cm x 7.0 cm in all cats. Mean survival length (+/- SD) of frontalis myocutaneous axial pattern flaps [6.9 (0.2) cm] compared with control flaps [4.4 (2.2) cm], was significantly different (P<0.05). Mean survival percentage area (+/- SD) of superficial temporal artery flaps was 98.6 (3.2) %, compared with control flaps 62.8 (11.7) %. On the basis of this study, a flap based on the superficial temporal artery may be a source of skin for reconstructive procedures of maxillofacial region in cats.

MATERIALS & METHODS

Cadaver & Vascular studies -

Surgical studies - Ten mature, domestic shorthair cats were sedated with acepromazine \(^a\) (0.1 mg/kg IM) and butorphanol \(^b\) (0.2 mg/kg IM), then induced with sodium thiopental \(^c\) (16 mg/kg IV) and maintained with oxygen and halothane \(^d\) (1-2 %). Lactated ringer’s solution \(^e\) was administered at 10 mg/kg/hr IV. The cats were placed in ventral recumbency and the temporal region was clipped and prepared for aseptic surgery. Guidelines for flap location were based on results of cadaver and vascular studies.\(^1\) The landmarks for the base of the superficial temporal artery flap were the caudal aspect of the zygomatic arch and the lateral orbital rim rostrally (Figure 1). Flap dimensions were based on the feasibility of primary wound closure of the donor site and required length to transfer the flap to the maxillofacial area. The flap length extended to the contralateral eye and the flap width was equivalent to the width of the zygomatic arch. The flaps were created
randomly unilaterally using maximum dimensions to provide coverage of the maxillofacial area following rotation rostrally, yet allowing primary wound closure of the donor site. The skin was incised and the thin frontalis muscle was identified superficial to the fascia of the temporal muscle. The flap was carefully elevated toward the base. In all cases, the superficial temporal artery and vein were identified by ventral extension of the incision at the caudal aspect of the flap base. Ligation of these vessels was performed with stainless steel clips in five randomly assigned cats. The rostral auricular plexus and palpebral branch of the auriculopalpebral nerve was identified and partially incised at the cranial border of the flap over the eye ipsilateral to the flap base in order to enhance flap rotation. The flaps could be rotated 90 degrees rostrally without apparent compromise of the vascular pedicle, and would extend to the nasal planum in all cats. After orthotopic placement of the superficial temporal artery flaps, they were sutured in place with 3-0 nylon in a simple continuous pattern. Flap size was determined by geometric calculations from acetate sheet templates created for each animal. Postoperative care included daily wound cleansing. Flap viability was subjectively assessed in all cats for seven days postoperatively on the basis of skin temperature, texture and color (Figures 2 and 3). The length of skin viability was determined as described previously (visual measurement of grossly devitalized tissue and geometric calculations) and converted to a percentage of total flap length. Histologic analysis of the superficial temporal artery flap tissue was not performed in either group. Data were analyzed by use of the paired \( t \)-test with \( P < 0.05 \) considered significant.

RESULTS

Results of the cadaver and vascular studies documented that the superficial temporal artery provides blood supply to the frontalis muscle and skin in the temporal region.\(^1\) Mean (+/- SD) width and length of flaps was 2.0 (0) x 7.0 (0) cm. Mean survival length of
superficial temporal artery flaps was 6.9 (0.2) cm. Mean survival length of control flaps was 4.4 (2.2) cm. Necrosis occurred in all control flaps (n=5), resulting in mean survival percentage areas of 62.8 (11.7) %, compared with the mean survival percentage area of 98.6 (3.2) % in flaps incorporating vascular supply from the superficial temporal artery. Survival length was significantly different.

Complications included serosanguinous drainage from the rostral border of the flap in four of the five control cats. Wound dehiscence occurred at areas of flap necrosis along the distal aspect of all control flaps. There were no abnormalities with blinking noted postoperatively.

DISCUSSION

Most cutaneous tumors in the cat are malignant, however if detected early, many can be managed successfully. Squamous cell carcinoma is the most common skin tumor in the head region of the cat and is reported to occur on the pinnae, eyelid margins or nasal planum. Other reported tumors include fibrosarcoma, melanoma or basal cell carcinoma. The treatment of choice for these tumors is early surgical excision, which may result in a large cutaneous defect with little local tissue available for reconstruction. An axial pattern flap such as the superficial temporal artery flap is an addition to the reconstructive surgeon’s armamentarium for the maxillofacial region. Other successful treatment modalities include radiation therapy, photosensitization and cryosurgery. If skin necrosis occurs secondary to those techniques, additional reconstructive surgery may be necessary. The superficial temporal artery flap is an adequate source of non-neoplastic, well-vascularized skin to provide optimal healing in those cases.
Our results for survival of the flap based on the superficial temporal artery were similar to survivability of other axial pattern flaps.\textsuperscript{8-10} Compared with the results of the superficial temporal artery flap in dogs, cats had an even greater mean flap survival length.\textsuperscript{11} Based on the preliminary vascular studies of the temporal region arterial supply in the dog and cat\textsuperscript{1}, there is no anatomic difference between the two species that might explain the increased flap survival length in the cat. Flaps in this study had a length extending over the frontal region to the contralateral eye, providing adequate tissue for reconstruction of the maxillofacial region as well as primary closure of the donor site without excessive tension. In dogs, the recommended length also extends over the frontal region to the contralateral eye.\textsuperscript{11}

In this study, inadequate blood flow in the control animals, with the superficial temporal artery and vein ligated, contributed to flap necrosis. The primary factor contributing to flap necrosis in the experimental group is arterial insufficiency. However, the toxic effects of hematoma or free radicals cannot be excluded since they were not examined specifically. Since the flaps in this study were orthotopically placed, only temporary intraoperative assessment of the local extrinsic factors was possible. There was no evidence that infection contributed to flap death, although cultures of the necrotic areas were not performed. Since histologic analysis of the superficial temporal artery flap tissue was not performed, no conclusions can be drawn with respect to the timing or pattern of revascularization. Histologic analysis might have contributed to this study by documenting full-thickness versus partial-thickness necrosis, and whether graft healing occurred. There also may have been a histologic difference in the muscle between the groups related to ligation of the superficial temporal artery.
Despite incision of a portion of the rostral auricular plexus, including the palpebral nerve, there were no adverse effects noted with palpebral function. The palpebral nerve supplies the orbicularis oculi muscle, which is important to closure of the lid.\textsuperscript{12} Perhaps only a portion of the plexus was affected, or adjacent muscle compensation occurred.

On the basis of the results of this study, the flap based on the superficial temporal artery has a greater surviving length compared with similar flaps dependent on the subdermal plexus alone. This flap may have application for maxillofacial reconstruction of traumatic wounds, or wounds resulting after excisional surgery or radiation therapy.
REFERENCES


a PromAce, Fort Dodge Lab Inc, Fort Dodge, IA.
b Torbutrol, Fort Dodge Lab Inc, Fort Dodge, IA.
c Bio-tal, Boehringer Ingelheim Animal Health Inc, St. Joseph, Mo.
d Fluothane, Ayerst Laboratories Inc, New York, NY.
e LRS, Baxter/Scientific Products Div, Charlotte, NC.
f Hemoclip, Solvay Veterinary Inc, Princeton, NJ.
g Dermalon, Davis & Geck, Wayne, NJ.
Figure 1 - Diagram demonstrating location of superficial temporal artery flap (broken lines) and the superficial temporal artery (STA) in relation to the zygomatic arch and orbital rim. Note arrow demonstrating site of ligation of STA in control cats.
Figure 2 - Day 7 postoperative photograph of a control cat (STA ligated).

Figure 3 - Day 7 postoperative photograph of cat from superficial temporal artery flap group (STA unligated).
Table 1 - Comparison of survival length of control (STA ligated, subdermal plexus) and experimental (STA unligated) superficial temporal artery flaps.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>FLAP DIMENSIONS (cm)</th>
<th>SURVIVAL LENGTH (cm)</th>
<th>SURVIVAL PERCENTAGE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STA ligated</td>
<td>2.0 x 7.0</td>
<td>4.0</td>
<td>57</td>
</tr>
<tr>
<td>STA ligated</td>
<td>2.0 x 7.0</td>
<td>3.5</td>
<td>50</td>
</tr>
<tr>
<td>STA ligated</td>
<td>2.0 x 7.0</td>
<td>4.0</td>
<td>57</td>
</tr>
<tr>
<td>STA ligated</td>
<td>2.0 x 7.0</td>
<td>5.0</td>
<td>71.4</td>
</tr>
<tr>
<td>STA ligated</td>
<td>2.0 x 7.0</td>
<td>5.5</td>
<td>78.5</td>
</tr>
<tr>
<td>MEAN (+/- SD)</td>
<td></td>
<td>4.4 (2.2)</td>
<td>62.8 (11.7)</td>
</tr>
<tr>
<td>STA unligated</td>
<td>2.0 x 7.0</td>
<td>6.5</td>
<td>92.8</td>
</tr>
<tr>
<td>STA unligated</td>
<td>2.0 x 7.0</td>
<td>7.0</td>
<td>100</td>
</tr>
<tr>
<td>STA unligated</td>
<td>2.0 x 7.0</td>
<td>7.0</td>
<td>100</td>
</tr>
<tr>
<td>STA unligated</td>
<td>2.0 x 7.0</td>
<td>7.0</td>
<td>100</td>
</tr>
<tr>
<td>MEAN (+/- SD)</td>
<td></td>
<td>6.9 (0.2)</td>
<td>98.6 (3.2)</td>
</tr>
</tbody>
</table>
VITA

On March 15, 1965, Maria Aline Fahie (née: Doherty) was born to Brian and Mabel Doherty in St. John's, Newfoundland. At the age of 4, the family moved to "The Big Brown Doghouse" in Dartmouth, Nova Scotia, where Maria grew up. Her earliest sign of dexterity was playing the piano. She advanced to the Grade 5 level of the Royal Conservatory of Music. Maria attended Dartmouth High School, where she met Daniel Fahie, who became her best friend and mentor, and who always encouraged her to pursue her career despite the separation that would be necessary. Hobbies are an important part of Maria and Danny's life and include hiking, mountain biking, motorcycling and weight lifting.

Maria attended Dalhousie University, obtaining a Bachelor of Science degree in April 1986. During university, she began working in a private veterinary practice as a technician/veterinary assistant for six years. This helped confirm her belief in her dream to be a veterinarian. Maria was admitted to the Atlantic Veterinary College in September 1989 and graduated in May 1992 with the American Animal Hospital Association Senior Student Award for excellence and proficiency in the practice of small animal clinical medicine and surgery.

Maria began her internship program at the Virginia-Maryland Regional College of Veterinary Medicine in July 1992. She received her Certificate of Internship in June 1993 and began a surgical residency the following month. Maria was honored with membership into the National Honor Society of Veterinary Medicine, Phi Zeta, on April 17, 1995. She received the D.C. Academy Clinical Resident Teaching Award in October 1995. At the end of her second residency year, on April 18, 1995, Maria happily married Danny.

Maria successfully defended her Master's thesis on April 15, 1996. The vascular portion of her master's research manuscript was accepted for publication in Anatomia Embryologia Histologia (Journal of the World Association of Veterinary Anatomists) in October 1995. The canine portion is pending acceptance by the American Journal of Veterinary Research, and the feline portion is pending acceptance by Veterinary Surgery. Maria plans to move with Dave the dog and Critter & Barney the cats, to the same city as Danny permanently to continue to develop surgical skills in private practice.

Maria A. Fahie, DVM