Assessment of a caudal external thoracic artery axial pattern flap for treatment of sternal cutaneous wounds in birds

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Objective—To assess the use of a caudal external thoracic artery axial pattern flap to treat sternal cutaneous wounds in birds.

Animals—16 adult Japanese quail.

Procedure—A cutaneous defect in the region of the mid-sternum was surgically created in all quail. In 6 quail (group I), an axial pattern flap was created from the skin of the lateral aspect of the thorax and advanced over the sternal defect. In 8 quail (group II), a flap was similarly created and advanced but the flap vasculature was ligated. All quail were euthanatized at 14 days after surgery and had necropsies performed. Sections of the flap and the surrounding tissue were examined histologically to assess flap viability.

Results—All axial pattern flaps in group-I quail had 100% survival. In group II, mean percentage area of flap survival was 62.5%; mean area of necrosis and dermal fibrosis of flaps were significantly greater than that detected in group I. In flaps of group-II quail, neovascularization in the deep dermis and profound necrosis of the vascular plexus in the superficial dermis were observed.

Conclusions and Clinical Relevance—Results indicated that the caudal external thoracic artery axial pattern flap could be used successfully in the treatment of surgically created sternal cutaneous defects in quail with no signs of tissue necrosis or adverse effects overall. Use of this technique to treat self-mutilation syndromes or application after surgical debulking of tumors or other masses might be beneficial in many avian species. (Am J Vet Res 2004;65:497–502)

Wildlife and companion avian species are commonly presented to veterinarians because of extensive cutaneous wounds secondary to trauma. In birds, conventional treatment of these wounds has paralleled treatment recommendations for similar wounds in mammals; however, birds have a number of evolutionary adaptations that make the application of techniques used in wound management in mammals impractical. To minimize body mass for flight, the evolution of birds has resulted in the elimination of loose redundant skin; this feature makes simple wound closure difficult.1 Compared with mammalian skin, avian skin is much thinner and more easily torn during manipulation.2,4 In addition, there are scant subcutaneous tissues in many regions of the body of birds, which negatively affects the ability to support granulation tissue formation for adequate healing of large cutaneous defects.3 Also, the presence of feathers in the dermis further complicates wound management because they are distributed in tracts called pterylae.3 If the pterylae are placed in aberrant positions during wound closure, the abnormal feather placements might interfere with flight or stimulate excessive preening that leads to feather removal.3 Finally, there are anatomic sites and skeletal structures where the underlying avian skin is under tension. In these areas, closure of skin defects can potentially result in both static and dynamic tensile forces.6 Because of all these factors, wound closure procedures that would be simple to perform in mammals are more complicated to perform in birds.

From a behavioral perspective, birds rarely tolerate bandages that could promote wound healing.7 In some species of raptors and waterfowl, simple bandages such as the figure-of-eight bandage can be successfully applied over the wings. However, psittacine species promptly remove most bandages. The use of chemically induced sedation or restraint to prevent bandage removal rarely achieves the desired level of behavioral adjustment without also altering other important feeding and grooming behaviors.7 The application of restraint collars to prevent bandage removal may result in inappetence, stress, and potentially metabolic decompensation from drastic and rapid weight loss. Interestingly, birds do not usually remove skin sutures but merely preen any exposed segments of suture. For these reasons, primary or delayed wound closure is usually preferred in most birds when feasible.5

In psittaciformes, the skin over the ventral aspect of the keel of the sternum is a common area of cutaneous trauma as a result of hitting the ground after leaving perches or self-mutilation.89 These injuries can occur after improper trimming of the wing feathers in adult birds and in fledgling birds that are learning flight skills. As a result of such trauma, a chronic, infected, large laceration over the sternum usually develops that is not amenable to primary closure. In mammals, cutaneous flaps and grafting techniques have been developed to cover large skin defects or to...
mobilize skin in regions with excessive tension. In birds, skin grafting has been used with moderate success but is considered an advanced form of wound treatment that most clinicians and clients are unwilling to attempt for both financial and logistical reasons. However, the application of skin flaps for treatment of cutaneous defects in birds could be effective in resolving many chronic injuries and obviate the need for expensive hospitalization and bandaging. The use of single pedicle advancement flaps for closure of dorsal cervical wounds and antebrachial wounds in birds has been reported, but controlled studies to evaluate the use of skin flaps to cover cutaneous defects have not been performed in birds. To the authors’ knowledge, the use of an axial pattern cutaneous flap in any avian species has not been reported.

The purpose of the study reported here was to assess the use of a caudal external thoracic artery axial pattern flap to treat sternal cutaneous defects in adult Japanese quail (Coturnix coturnix japonica). Our hypothesis was that application of this flap would provide a reliable technique for closure of sternal wounds in avian species.

Materials and Methods

Sixteen adult Japanese quail (8 males and 8 females) were obtained from a commercial breeder. Health of the birds was assessed on the basis of results of physical examination and body weight (mean weight ± SEM, 121.4 ± 8.3 g). The quail were individually housed in an indoor, air-conditioned facility accredited by the Association for the Assessment and Accreditation of Laboratory Animal Care. Birds had access to fresh water and a commercial diet ad libitum. All surgeries were performed by the same surgeon (STF). This study was approved by the University of California Institutional Animal Care and Use Committee.

In a pilot effort, 2 of the 16 quail were used to investigate the extent of the external pectoral vasculature for creation of a well-vascularized flap. The birds were anesthetized via administration of medetomidine (100 µg/kg, IM) and ketamine (10 mg/kg, IM). After a light plane of anesthesia was achieved, heparin (3,000 U/kg, IV) was administered to prevent blood coagulation. Birds were euthanized with sodium pentobarbital (250 mg/kg, IV). The right subclavian artery was isolated via a surgical approach and ligated with 1 ligature of 3-0 nylon suture. Barium sulfate suspension (30 mL/kg, SC) was injected into the subclavian region. Notice that the contrast agent has filled the caudal external thoracic artery (white arrow) and the other branches of the pectoral artery.

In the remaining 14 quail, a cutaneous sternal defect was created surgically. Quail were randomly assigned to 1 of 2 groups. In group I (n = 6), an axial pattern flap was created and advanced over the defect in each bird; in group II (8), a similar flap was created and advanced in each bird but the flap vasculature was ligated at its base. The operation sequence was randomized to ensure that improvement in surgical skill and familiarity with the technique during the study did not influence the outcome.

Food was withheld from all quail for 3 hours prior to surgery to prevent regurgitation during anesthesia, but water was available to them until 1 hour prior to induction of anesthesia. The birds were premedicated with butorphanol (0.5 mg/kg, IM). Anesthesia was induced and maintained with isoflurane in 95% to 100% oxygen via a face mask. Fluid support consisted of warmed lactated Ringer’s solution (30 mL/kg, SC) administered in the inguinal region. Enrofloxacin (10 mg/kg, IM) was also administered at this time. Pulse rate via a Doppler flow detector and respiratory rate were monitored during anesthesia. As a corrective measure in birds that developed bradycardia (heart rate, < 160 beats/min), the isoflurane vaporizer concentration was decreased with or without the administration of glycopyrrolate (0.03 mg/kg, IM).

Axial pattern flap with routine advancement and closure (group I)—Quail were placed in dorsal recumbency. Feathers were removed to expose the ventral portion of the keel and the right lateral aspect of the thorax (from the clavicle to the pubis). The skin was routinely prepared for surgery. Surgical loupes

Figure 1—Right lateral whole body radiographic view of a Japanese quail (Coturnix coturnix japonica) obtained after injection of barium sulfate suspension into the right subclavian artery. Notice that the contrast agent has filled the caudal external thoracic artery (white arrow) and the other branches of the pectoral artery.

Figure 2—Schematic drawing of the arteries of the ventrolateral aspect of the pectoral limb of Japanese quail. a. = Artery (Reproduced with permission from Fitzgerald T. The Coturnix quail: anatomy and histology, Ames, Iowa: Iowa State University Press, 1969,71)
were used to perform every surgery. A sterile ruler and ink pen were used to delineate the margins of an area of skin (2 cm × 2 cm) to be removed from the ventral aspect of the keel, thereby creating the sternal defect. With a No. 15 scalpel blade, a full-thickness skin incision was made following the inked margins of the segment of skin. Minor hemostasis was needed and provided by direct pressure with cotton gauze. The skin segment was removed and discarded. The ruler and ink pen were used to delineate the borders of the flap to be created from the skin of the right lateral aspect of the thorax; the flap had a 3-cm cranial edge, a 4-cm caudal edge, and a 2-cm distal edge that was adjacent to the skin defect (Fig 3). The skin was elevated to ensure that the caudal external thoracic artery and its associated vein were included in the flap at its base. No undermining of subcutaneous tissues was needed because the artery and vein were closely apposed to the dermis. Bishop-Harmon forceps and a pair of small Metzenbaum scissors were used to create the lateral edges of the skin flap along the inked margins. The axial pattern flap was advanced forward with minimal tension to cover the skin defect (Fig 4). The cranial edge of the flap was sutured to the cranial left corner of the defect with 1 suture of 5-0 nylon on a reverse cutting needle. The caudal edge of the flap was sutured to the caudal left corner of the defect in a similar manner to that used at the cranial corner. Because the right caudal edge of the initial skin incision was in close approximation to the right inguinal fold in these quail, a flap with a 3-cm caudal edge would have caused excessive tension on the suture line; creation of a 4-cm caudal edge allowed for advancement of the flap and tensionless closure. The flap was completely attached to the adjacent skin with 5-0 nylon suture on a reverse cutting needle. The caudal edge of the flap was sutured to the caudal right portion of the flap base (1 cm) incorporating into the inguinal fold (Fig 3).

Axial pattern flap creation with vasculature ligation and closure (group II)—All quail underwent surgery in the same manner as described for group I, except that the caudal external thoracic artery and vein at the base of the flap were isolated and ligated by the use of 2 sutures of 6-0 nylon. The flap was then advanced over the sternal defect and secured in place, as described.

Care and assessment of quail after surgery—The quail were allowed to recover from anesthesia. Immediately after surgery, butorphanol (0.5 mg/kg, IM) was administered. Food and water were offered to the birds 3 hours after surgery. Consumption of food and water was subjectively assessed by observation of the food and water that were not consumed and estimation of volume of fecal output. To provide a more objective assessment of food and water intake, all quail were weighed daily until euthanatized. General alertness and level of activity were also subjectively monitored to detect signs of the development of complications secondary to the procedure. Daily assessments of the skin flaps included general appearance, as well as signs of dehiscence, necrosis, and infection. Measurements were made daily to determine the area (cm²) of flap necrosis present and thereby assess the duration of flap survival. Areas of necrosis were measured from the distal edge of the axial flap to the most proximal extent of the necrosis; the viable flap area (cm²) still present was then calculated by subtracting the area of necrosis from the total flap area. With exception of administration of butorphanol immediately after surgery, no medications were given to the birds during the course of the study.

Gross and histologic examination of postmortem specimens—Fourteen days after surgery, all quail were euthanatized with an overdose of sodium pentobarbital (250 mg/kg, IV). In each bird, the general appearance of the flap was evaluated but only final measurements as to the extent of flap necrosis were obtained. Complete gross necropsies were not performed; only the flap tissue with the adjacent skin (1-cm border) was collected by the surgeon (STF) for histologic examination. The tissue specimen was identified by a tag and stapled in a normal conformation to cardboard. The skin from each quail was placed in neutral-buffered 10% formalin for 24 hours.

After fixation, the flaps were carefully sectioned to ensure identification of the complete incision, flap, and adjacent skin. The sections were processed by routine methods to provide paraffin wax sections (4 µm) which were stained with H&E. Histologic examination of the flap, suture sites, and surrounding border of skin was performed to assess the degree and type of epithelial and dermal healing, neovascularization, and inflammatory reactions.

Histologic examination of the flaps was performed by the same pathologist (HEVD). Epithelialized regions of the skin flaps were defined as portions of the flap that had undergone necrosis, eschar formation, and fibrosis but did...
have an epithelium at the time of assessment; these were used for histologic evaluation. If a skin flap did not have any evidence of necrosis along its length, the flap was still considered epithelialized and a representative region was selected for histologic comparison. Nonepithelialized regions of the skin flaps were considered to be portions of the flap that had undergone necrosis, eschar formation, and dermal fibrosis but did not yet possess an epithelium at the time of assessment; these were also selected for histologic evaluation. The histologic characteristics of the flaps that were evaluated included epithelial cell hyperplasia; dermal fibrosis within the epithelialized and nonepithelialized skin of the flap, suture sites, and adjacent skin; inflammation surrounding the superficial vascular plexus, deep vascular plexus, and peril follicular regions of the flap, suture sites, and surrounding skin; and neovascularization in the layers of the dermis (ie, the stratum superficiale [a subepidermal layer] and the stratum laxum [a layer of loose connective tissue that supports large vessels, nerves, arterial muscles, and fat16]) of the skin of the flap and the suture sites. All of these aforementioned characteristics, except for epithelial hyperplasia, were graded subjectively by use of a numerical scale (ie, 0 = not present; 1 = mild; 2 = moderate; 3 = marked; 4 = severe; 5 = very severe; and 6 = necrosis). Epithelial hyperplasia was assessed by simply counting the numbers of epithelial cell layers present within the histologic section. Other characteristics, including superficial epidermal and dermal necrosis, the type of inflammation (involving lymphocytes, heterophils, or multinucleated giant cells) in the flap and surrounding skin, feather follicles in the flap, and large- and medium-sized blood vessels in the flap, were graded simply as present or absent in the histologic sections.

Statistical analyses—A Mann-Whitney U test or an exact χ2 test of homogeneity was used to compare gross flap survival and histologic findings between groups I and II. Computer software was used to perform the calculations; values of P < 0.05 were considered significant.

Results

Physical examination revealed no notable abnormalities in any quail. There were no anesthetic complications other than a single short duration of apnea in 1 bird. In group I, the mean ± SD anesthetic and surgical times were 76.6 ± 9.2 minutes and 52.8 ± 6.3 minutes, respectively. In group II, the mean anesthetic and surgical times were 86.6 ± 7.2 minutes and 59.1 ± 5.1 minutes, respectively. The median number of sutures needed to suture the flap in position in groups I and II was 9 (range, 8 to 10 sutures).

Clinical observations—No deaths occurred during any part of the study. All birds in group I appeared to behave normally within 4 to 6 hours after surgery; on the basis of visual assessment, food consumption in these birds appeared to be normal during the following day. In group II, food and water consumption and fecal output of the birds during the first 12 to 24 hours after surgery were assessed subjectively as less than normal but these variables increased to normal levels after 1 to 2 days. Group-II quail also appeared less active and were easier to catch for daily inspection than group-I birds.

The surgical flap area for all flaps was 6 cm2. All flaps appeared slightly erythematous and edematous immediately after anesthetic recovery. In group I, all birds had 100% flap survival with no evidence of necrosis on daily visual examination. Flaps in group-I birds retained normal skin coloration throughout the study period with no evidence of edema or erythema beyond that which developed immediately after surgery. However, the flaps in all 8 group-II birds became progressively edematous and discolored (purple) 4 to 6 hours after the birds recovered from anesthesia. During the next 12 hours, flaps in 5 birds became black. Within 24 hours, pronounced discoloration of the distal aspects of flaps in those 5 group-II birds was observed with dry necrotic zones of skin detected at 48 to 72 hours after surgery. Three group-II birds did not develop any gross evidence of flap necrosis, but they did have prolonged warmth, bruising, and edema in the flaps that resolved after 72 hours. In group II, the mean percentage area of flap survival was 62.5% (median, 63.0%; range, 16.7% to 100%); conversely, mean percentage area of flap necrosis was 37.5% (median, 37.0%; range, 0% to 83.3%). Mean width of flap necrosis was 1.3 cm (median, 2.0 cm; range, 0 to 2.0 cm) and mean length of flap necrosis was 1.1 cm (median, 1.1 cm; range, 0.2 to 2.5 cm). Mean area of flap necrosis was 2.3 cm2 (median, 2.2 cm2; range, 0.4 to 5.0 cm2); this value was significantly (P = 0.04) different from that of group I. Two group-II quail whose flaps had undergone necrosis developed a small zone of dehiscence along the suture line at the caudal right corner. These affected areas were monitored, but no medications were administered. No other appreciable dehiscence developed at suture lines in the quail of group II.

Approximately 10 days after surgery, the eschars associated with the skin flaps in group-II birds began to lift away from the underlying tissue to reveal granulation tissue with a thin epithelial covering at the proximal necrotic margins. At 14 days after surgery, only small remnants of the eschars remained in the 5 group-II flaps that had undergone necrosis.

On postmortem examination, all the flaps in the group-I birds had normal immature feathers emerging from the feather follicles. The pterylae that would normally have been on the lateral aspects of the thoracic region were immediately ventral or only slightly lateral to the keel. The birds did not disturb the emerging feathers. In the 5 flaps in group-II birds that had undergone some regional necrosis, there was little or no evidence of immature feather development in those previously necrotic regions.

Histologic findings—The skin was comprised of epidermis and dermis. The dermis was further subdivided (in accordance with the classification of Lucas16) from the superficial to deep aspects as the stratum superficiale, the stratum compactum, and the stratum laxum. The stratum superficiale contained the superficial vascular plexus, whereas the stratum laxum contained the larger blood vessels and feather follicles. There were no significant differences in the degree of epidermal hyperplasia in flaps between groups I and II. In the group II quail that had gross evidence of flap necrosis, only the stratum laxum survived in the nonepithelialized flap regions. Some degree of dermal fibrosis was evident in all the skin flaps of group-I quail.
and in the epithelialized flap regions of group-II quail; the degree of this dermal fibrosis was significantly 
\( P = 0.04 \) greater in the epithelialized flap regions of group-II quail, compared with that observed in flaps of group I. One of the 3 group-II quail that did not have evidence of gross necrosis in their flaps had a marked level of dermal fibrosis.

In groups I and II, the predominant inflammatory cells in the flaps were lymphocytes. Heterophils and multinucleated giant cells were also observed occasionally in both groups, but such cells were distributed in a localized pattern, usually associated with suture sites. In the skin surrounding the flap, inflammation was minimal and primarily lymphocytic; the inflammatory response surrounded the superficial vascular plexus. All quail had some evidence of neovascularization in the stratum superficiale of the epithelialized flap and at the suture site. Neovascularization was pronounced \( (P = 0.03) \) in the stratum laxum of the dermis in group-II quail, compared with that in the stratum laxum of group-I quail. The vascular plexus in the stratum superficiale had also undergone significant \( (P = 0.005) \) necrosis in group-II quail, compared with findings in group-I birds. In contrast to findings in group I, small, medium, and large arteries and veins in the deep dermis were not always associated with the feather follicles in group-II quail. However, these differences between groups were not significant.

Discussion

Results of the study reported here suggested that the caudal external thoracic artery axial pattern flap can be used successfully in the treatment of surgically created sternal cutaneous defects in birds; in our experience with the technique, there were no signs of flap necrosis or overt adverse effects on the general health of the birds. An axial pattern flap is defined as a pedicle flap with a cutaneous artery and vein included to ensure an adequate vascular supply after extensive mobilization and advancement. \(^{11} \) Results of research in canids have indicated the predominant type of cutaneous vasculature and the various axial patterns available for wound closure. \(^{11} \) The avian cutaneous vasculature pattern is diffuse and minute. \(^{27} \) In the skin of birds, arteries and veins lie beneath the cutaneous muscles at the base of the dermis and do not branch extensively prior to reaching the dermis. \(^{3} \) Minor branching is evident where these vessels pass through the cutaneous muscle with the primary arborization within the deep dermis. \(^{2} \) A superficial dermal vascular plexus is also present at the junction of the dermis and epidermis; this plexus is the only vascular supply to the overlying avascular epidermis.

In birds, the skin of the lateral aspect of the thorax has characteristics that suggest its suitability for creation of an axial pattern flap. Because birds have little redundant skin, the initial mobilization of an axial pattern flap would seem unlikely; however, the skin in the lateral region of the thorax is reasonably mobile, compared with skin in other anatomic locations. Furthermore, the skin flanking the ventral portion of the keel has a well-developed vascular supply that has evolved for 2 reasons. First, numerous contour feathers lie in pterylae near the keel, and each contour feather requires an individual arterial supply during development. \(^{13} \) Second, many species of birds possess a brood patch along the ventral aspect of the keel which is simply a featherless region of well-vascularized skin for the transfer of body heat to eggs during incubation. \(^{4} \) Thus, this area of skin appears to have an adequate vascular supply to support an axial flap.

Data regarding avian anatomic features identify the caudal external thoracic artery (a branch of the pectoral artery) as the predominant cutaneous artery to the skin lateral to the ventral portion of the keel. \(^{28} \) The vessel actually appears to be the primary blood supply to the pterylae on the lateral aspect of the thorax. It is not known whether this artery is present in all of the approximately 8,900 species of birds, and there is considerable controversy in regards to its correct nomenclature. \(^{29} \) However, regardless of its designation, a vessel or an artery with a very similar course to that of the caudal external thoracic artery has been identified by the primary author (STF) of this report in red-tailed hawks, doves, and some psittacines such as Amazon parrots (Amazona spp).

In the quail of group II, the caudal external thoracic artery was ligated to ascertain whether the caudal external thoracic artery was correctly identified as the predominant blood supply to the axial pattern flap. The degree of flap survival in group-II quail was similar to that of control animals used in axial pattern flap studies in mammals. \(^{11} \) In group-II birds, complete necrosis of the flaps did not develop probably as a result of collateral circulation from the deep dermal vascular plexi at the flap base, the considerable neovascularization capacity of those vascular plexi, and the thinness of avian skin that allowed the dermis to absorb sufficient nutrients from the underlying tissue bed. \(^{31} \) Three group-II quail had no gross evidence of necrosis of their flaps. However, histologic examination of the tissues of those flaps detected marked fibrosis and moderate neovascularization in the superficial dermis of 1 bird, which implied previous vascular compromise. This observation suggested that although overt necrosis of the flap tissue was not observed, sufficient ischemia developed to cause damage to deeper tissue layers. One explanation for the lack of flap necrosis in the other 2 group-II quail could be insufficient ligation of the vasculature at the flap base. All vessels were double-ligated with small-sized suture to minimize the risk of suture reaction. Because the artery and vein were ligated together, the ligatures might not have been sufficient to resist increased arterial hydrostatic pressures.

With the exception of fibrosis, there were no significant differences in the type and location of cellular inflammation between the 2 groups, which could mean the quickness of the acute inflammatory cascade in group-II quail by 14 days after surgery. Epidermal healing was similar in groups I and II at 14 days after surgery; in the flaps of the group-II birds, necrotic skin had been replaced with a bed of granulation tissue over which epithelial cells had migrated. Although a difference in epidermal hyperplasia between the groups was expected, this was not detected; the 14-day period between surgery and histologic assess-
ment may have been sufficient to allow normalization of the epidermal layers. Furthermore, the lack of any overt necrosis in flaps in 3 quail in group II combined with the small number of quail used in the study likely interfered with detection of significant differences.

In the study of this report, a surgical technique involving a caudal external thoracic artery axial pattern flap appeared to be useful in the treatment of cutaneous sternal defects in Japanese quail and might be applicable to the treatment of other avian species with similar wounds. However, before the procedure is applied to other avian species, the anatomic features of the cutaneous vasculature in the species of interest should be thoroughly investigated to avoid iatrogenic creation of a larger skin defect that might not be amenable to closure.

References