

Original Research

Tenectomy of the Supracoracoideus Muscle to Deflight Pigeons (*Columba livia*) and Cockatiels (*Nymphicus hollandicus*)

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Abstract: Most of the methods used to deflight birds have one or more disadvantages, including impermanence, poor cosmetic appearance, or impairment of breeding function. We hypothesized that transection of the tendon of the supracoracoideus muscle at its insertion on the proximal humerus would impair a bird's ability to raise the affected wing and thus result in flightlessness. The purpose of this project was to evaluate the effectiveness of unilateral or bilateral surgical tenectomy of the supracoracoideus muscle in deflighting cockatiels and pigeons. Six pigeons (*Columba livia*) and 9 cockatiels (*Nymphicus hollandicus*) were included in the study. Three cockatiels were included in a sham group, and 3 birds of each species were included in a unilateral or bilateral tenectomy group. The birds in the sham group did not have flight difficulties at any time after surgery. Three cockatiels and 1 pigeon in the unilateral tenectomy group were flying within 3–6 weeks, respectively, after surgery. A ligament instead of a tendon was inadvertently transected in 2 of the pigeons in the unilateral group. These pigeons were able to fly the day after surgery. We did not euthanize these birds to confirm this suspicion. In the bilateral tenectomy groups, 1 of 2 cockatiels and 2 of 3 pigeons were eventually able to fly short distances within 4 to 6 months after surgery. In the same groups, 1 cockatiel died several hours after surgery and 1 pigeon was euthanized 6 weeks after surgery. The pigeon never regained its ability to right itself when placed on its back. Gross necropsies in both birds confirmed that the tendons of the supracoracoideus muscles had been transected. None of the birds undergoing unilateral or bilateral tenectomy had normal dorsal extension of the affected wing, but each was able to fly well enough to escape if taken outdoors. We concluded that neither unilateral nor bilateral supracoracoideus tenectomy is an effective technique for deflighting cockatiels or pigeons.

Key words: supracoracoideus muscle, tenectomy, deflighting, cockatiel, *Nymphicus hollandicus*, pigeon, *Columba livia*

Introduction

Birds are unique among vertebrates in having extraordinarily large flight muscles located on the keeled sternum with a center of gravity ventral to the wings. In order to maintain this low center of gravity, the supracoracoideus muscles, involved in the recovery stroke of flight (uplift) and high-velocity humeral rotation, are also located along the keel deep to the pectoralis muscles.¹ In order to produce a pulley effect to elevate the wing, the tendon

of the supracoracoideus muscle must pass through a triosseal canal (formed by the clavicle, scapula, and coracoid) to eventually attach to the dorsal tubercle of the proximal humerus.^{2,3}

The purpose of this study was to investigate the effectiveness of unilateral or bilateral tenectomy of the supracoracoideus muscle in achieving flightlessness in 2 species of strong-flying birds, pigeons (*Columba livia*) and cockatiels (*Nymphicus hollandicus*). Although this surgical procedure has been performed experimentally in the past,⁴ it has not been evaluated adequately as a surgical means of deflighting captive birds. Our hypothesis, based on the flight architecture of birds, was that tenectomy of the supracoracoideus muscle would cause flight impairment. We anticipated that this simple surgical

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procedure could be used to deflight companion birds and birds housed in zoological or avicultural collections in order to prevent accidental escape or injury. If effective, the procedure would be more cosmetic than pinioning or patagiectomy and more permanent than wing clipping.

Materials and Methods

Birds

Six pigeons and 9 cockatiels were used in this study. All birds were acquired from commercial breeding sources and housed separately by species in flight pens in the Laboratory Animal Resources facility at North Carolina State University. All birds had been housed in this facility for at least 1 year and were determined to be healthy and fully flighted based upon results of physical examination, test flights, fecal flotation tests, fecal Gram stains, and cloacal cultures (cultures in cockatiels only).

Preoperative flight capability of the cockatiels was determined by observation in their indoor flight cage (1.2 m wide \times 2.4 m long \times 2.1 m high). The pigeons were flown outside on a creance in an open grassy area, using techniques adapted from falconry and raptor rehabilitation.⁵ In each case, small leather jesses were attached to their tarsometatarsi and connected with a small metal clip to a 3-mm-diameter \times 30-m-long braided nylon cord. Postoperative flight was evaluated by assessing each bird's ability to fly from the floor of the flight pen to a perch located 1 m above the floor. The pigeons were flown outside on a creance in a large grassy area at 3, 6, 9, and 26 weeks after surgery. The cockatiels were free flown in a 2.5 \times 4 \times 2.5-m room to assess their flight abilities at 3, 6, and 16 weeks after surgery.

Study design

The pigeons used in this study were part of a pilot study to develop the surgical approach and evaluate the effectiveness of the surgical technique used for tenectomy. Three pigeons were assigned to each of 2 groups: 1 group underwent unilateral supracoracoideus tenectomy, and the other underwent an identical procedure performed bilaterally. Seven months later, 9 cockatiels were randomly assigned to each of 3 groups: 3 of the birds underwent unilateral supracoracoideus tenectomy, 3 birds underwent bilateral supracoracoideus tenectomy, and 3 birds served as controls in the sham group. The cockatiels in the sham group underwent a unilateral surgical approach to the supracoracoideus tendon, but the tendon was not transected.

Surgery

All birds were individually caged and fasted 8 hours before surgery. Each bird was anesthetized with isoflurane delivered via face mask then was placed in sternal recumbency. A small rolled towel was placed under the wing to elevate the shoulder on the side of the surgical approach. Feathers were plucked over the dorsal shoulder and proximal humerus (unilateral or bilateral), masking tape was applied to the feathered margins, and the skin was aseptically prepared. A sterile transparent drape with an adhesive, fenestrated opening was used to drape the surgical site (Avian/Research Animal Drape, Surgical Resources, Inc, Darlington, MD, USA). A 1- to 1.5-cm skin incision was made over the shoulder dorsally, parallel to the long axis between the distal coracoid bone and the proximal humerus (Fig 1A and B). A small indentation could be palpated at this location to mark the space between the proximal humerus, distal coracoid, and proximal scapula. The muscle fibers of the tensor propatagialis pars brevis muscle were bluntly dissected (Fig 1C). The muscle fibers were retracted to either side to expose a section of the tendon of the supracoracoideus muscle after it passed through the foramen of the triosseal canal. A sharp curved probe was used to bluntly dissect under the tendon and free it from the tendon sheath. The tendon was transected at its insertion on the dorsal tubercle of the proximal humerus, and a 4- to 5-mm segment of the tendon was removed (Fig 1C). The muscle fascia and skin were closed separately, each with a simple continuous pattern using 4-0 polyglactin 910 suture. A transparent adhesive dressing (Tegaderm, 3M Company, St Paul, MN, USA) was applied over the skin incision and left in place for 3 days. No postoperative medications were administered to any of the birds. Each unilateral surgical procedure was performed on the right side and required approximately 15 minutes of combined anesthesia and surgery time. Bilateral procedures required an additional 12–15 minutes. This study was approved by the NCSU Institutional Animal Care and Use Committee.

Results

All of the pigeons and cockatiels survived anesthesia and surgery. However, 1 cockatiel in the bilateral tenectomy group died during the night after surgery. No cause of death was determined at gross necropsy, and tissues were not submitted for histopathology. Results of the study are summarized in Table 1.

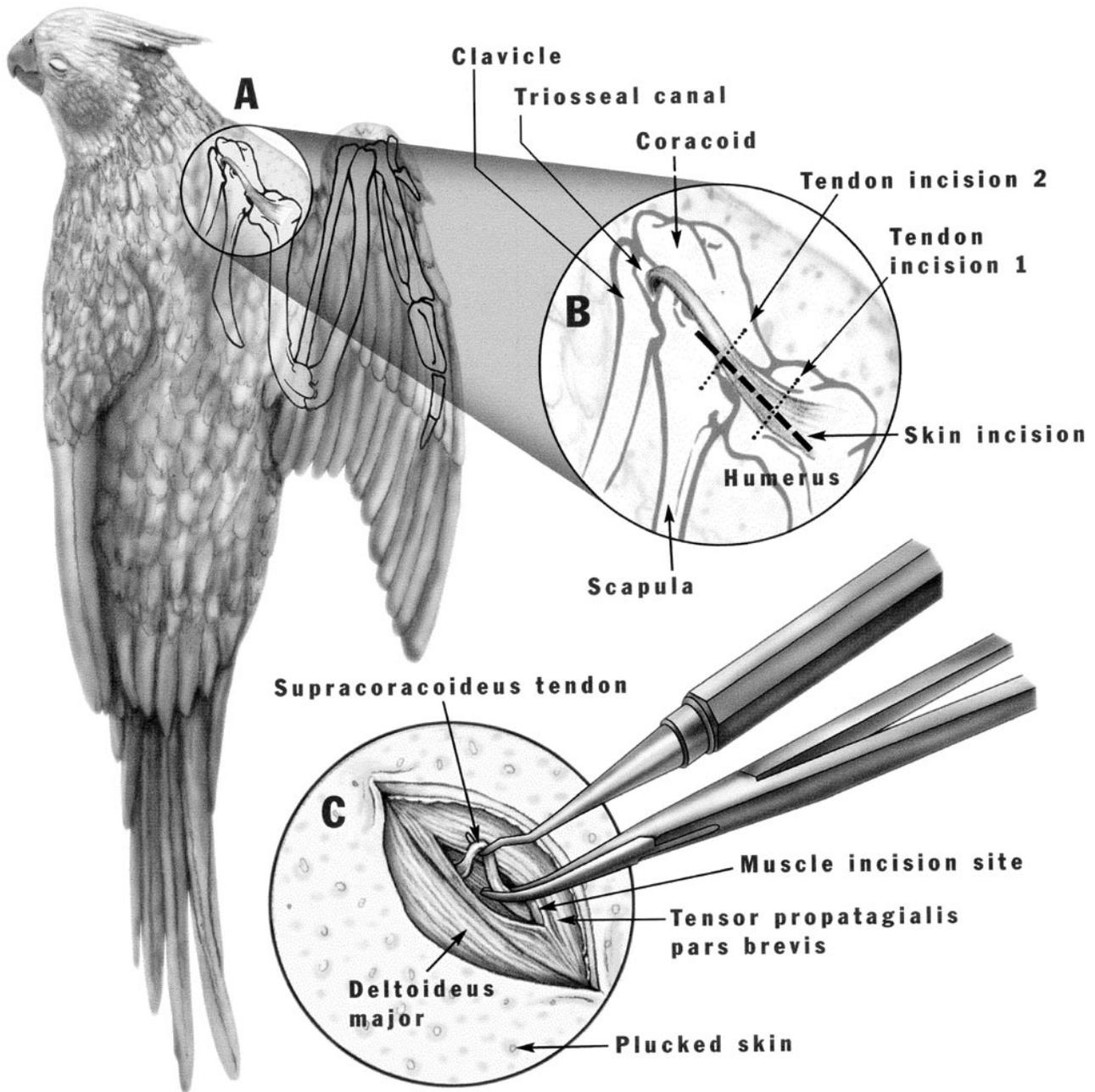


Figure 1. (A) Overview of the anatomic landmarks in the shoulder area for surgical tenectomy of the supracoracoideus muscle in a cockatiel positioned in sternal recumbency. (B) Orthopedic anatomy of the dorsal shoulder joint in a cockatiel, showing the tendon of the supracoracoideus muscle passing through the triosseal canal and inserting on the dorsal tubercle of the proximal humerus. A dashed line illustrates the location of the skin incision, and 2 dotted lines indicate the transection sites for removal of a segment of the supracoracoideus tendon. (C) Muscular anatomy of the dorsal shoulder of a cockatiel, demonstrating the partially elevated proximal segment of the tendon of the supracoracoideus muscle under the bluntly dissected muscle fibers of the tensor propatagialis pars brevis. The location of the first incision of the tendon of the supracoracoideus muscle is proximal to the dissection hook and the second incision is made proximal to the clamped tendon.

Table 1. Summary of supracoracoideus tenectomy surgery results in pigeons and cockatiels.

Bird no.	No. tendons cut ^a	Comments and observations
Pigeon 1	2	3 wk after surgery: able to right itself when lying on back 6 wk after surgery: flew to floor from 1 m height 9 wk after surgery: flew level 7 m 26 wk after surgery: flew 15 m and gained 1–2 m elevation
Pigeon 2	2	3 wk after surgery: able to right itself when lying on back 6 wk after surgery: flew to floor from 1 m height 9 wk after surgery: flew level 10 m 26 wk after surgery: flew 15 m and gained 1–2 m elevation
Pigeon 3	2	Euthanized at 6 wk, unable to fly or to right itself when lying on back; necropsy confirmed both supracoracoideus tendons were transected
Pigeon 4	1	3 wk after surgery: flew to floor from 1 m height 6 wk after surgery: flew 10 m and gained 1 m elevation 26 wk after surgery: flew 30 m and gained 2 m elevation
Pigeon 5	1	1 d after surgery: flew from floor to 1-m-high perch; surgery done incorrectly ^b
Pigeon 6	1	1 d after surgery: flew from floor to 1-m-high perch; surgery done incorrectly ^b
Cockatiel 1	2	1 wk after surgery: able to right itself when lying on back 3 wk after surgery: flew 2 m, with difficulty, within flight cage 6, 9, 16 wk, and 1 y after surgery: no changes or improvements
Cockatiel 2	2	1 wk after surgery: able to right itself when lying on back 3 wk after surgery: flew (fluttered) to floor from 1 m height 6, 9, 16 wk, and 1 y after surgery: no changes or improvements
Cockatiel 3	2	Died within 12 h after surgery; necropsy confirmed both supracoracoideus tendons were transected
Cockatiel 4	1	1 d after surgery: flew from floor to 1-m-high perch 3 wk after surgery: flew 2 m in flight cage and able to maneuver within flight cage; 16 wk after surgery: flew and maneuvered well in a 2.5 × 4 × 2.5-m room
Cockatiel 5	1	Same as for cockatiel 4
Cockatiel 6	1	Same as for cockatiel 4
Cockatiel 7	0 (Sham)	Normal flight 24 h after surgery; no changes noted at any future observations
Cockatiel 8	0 (Sham)	Same as for cockatiel 7
Cockatiel 9	0 (Sham)	Same as for cockatiel 7

^a Number of supracoracoideus tendons transected.

^b Ligament between the proximal humerus and the distal coracoid was probably transected instead of the supracoracoideus tendon, but this was not confirmed with examination at necropsy.

Cockatiel unilateral sham group

The 3 birds in this group flew and maneuvered well within the flight cage 1 day after surgery. No wing drooping or alterations in flight capabilities were noted in any of these birds during the observation periods. The birds were fostered to private homes 6 weeks after surgery.

Cockatiel unilateral supracoracoideus tenectomy group

No balance problems were observed in any of the 3 unilaterally tenectomized birds after surgery. The day after surgery, the birds were able to fly up to a perch placed 1 m above the floor. Three weeks after surgery, all of the birds were able to maintain a level 2-m flight from perch to perch. The right wing in each of the 3 birds did not extend fully during

flight and drooped slightly after flight exertion at all times observed during the first 6 weeks after surgery. Sixteen weeks after surgery, all 3 birds were able to fly, gain elevation, and maneuver around the 2.5 × 4 × 2.5-m room in which they were test flown. The right wing in each bird still did not have full extension during flight and drooped slightly after flying. Subsequently, the flight feathers were clipped, and the birds were fostered to a private home.

Cockatiel bilateral supracoracoideus tenectomy group

A gross necropsy examination of the cockatiel that died after bilateral surgery confirmed that the tendon of the supracoracoideus muscle had been transected on both wings. The 2 surviving bilater-

ally tenectomized birds had difficulty righting themselves when placed on their backs the day after surgery but were able to right themselves within 1 week after surgery. These birds were caged in a smaller cage (0.5 × 0.5 × 1.0 m) for 3 weeks after surgery to prevent potential complications from falling to the floor from a high perch. By 3 weeks after surgery, 1 of the cockatiels was able to fly 2 m from perch to perch in the flight cage. The bird seemed to struggle during flight, had limited maneuverability, and drooped both wings slightly after flying. The other cockatiel was not able to fly on a level plane, had very poor maneuverability, and was barely able to flutter to the floor from a perch 1 m high. Little change or improvement occurred in the performance of these 2 birds when test flown in a room 16 weeks after surgery. Both birds were fostered to a private home but were not wing-clipped. The 2 birds were test flown 1 year after surgery, and their flight capabilities were unchanged from our observations made 16 weeks after surgery.

Pigeon unilateral supracoracoideus tenectomy group

No balance problems were observed with any of the pigeons after unilateral tenectomy. During 2 of the surgeries, we had difficulty identifying the tendon of the supracoracoideus muscle. One day after undergoing surgery, the pigeons were able to fly from the floor to the perch located approximately 1 m above. A detailed dissection of the musculoskeletal structures in the shoulder area of a pigeon that was not part of the study group revealed that the connective tissue transected during the surgeries described was probably a ligament between the proximal humerus and the distal coracoid. We did not euthanize these 2 birds to confirm this suspicion. These birds were able to fly farther than 25 m on a creance 3 and 6 weeks after surgery. No asymmetry of the tenectomized wing was noted during flight. These 2 birds were fostered to a private home 6 weeks after surgery and were not evaluated any further.

The remaining pigeon was unable to fly on a creance 3 weeks after surgery but was able to fly approximately 10 m and gain 1 m altitude 6 weeks after surgery. This bird was not able to extend its right wing as high as the left wing and seemed to tire easily. Twenty-six weeks after surgery, the pigeon was able to fly the length of the creance (~30 m) and gain more than 2 m elevation during flight. Wing motion during flight was asymmetric, with the left wing lifted higher than the right wing. This pi-

geon was fostered to a private home at the completion of the study.

Pigeon bilateral supracoracoideus tenectomy group

For 3 weeks after surgery, the 3 pigeons in the bilateral tenectomy group had difficulty getting up on low perches placed 15 cm from the cage floor and were unable to right themselves if they fell over on their sides or backs. These birds were housed in a smaller cage (0.5 × 0.5 × 1.0 m) with low perches for easier management. Three weeks after surgery, 2 of the 3 pigeons were able to right themselves when placed on their backs. However, the third bird was still unable to right itself when placed on its back 6 weeks after surgery, and it was euthanized. Necropsy findings revealed that the surgery site had healed well grossly, and bilateral resection of a portion of the supracoracoideus tendon was complete. Six weeks after surgery, the 2 remaining bilaterally tenectomized pigeons were able to flap their wings and flutter to the ground from a 1-m-high perch. Nine weeks after surgery, the 2 birds were able to maintain a level flight for approximately 7–10 m when flown outside on a creance. Twenty-six weeks after surgery, these birds were able to gain 1–2 m elevation during a flight of approximately 15 m. Both birds moved their wings symmetrically during all flight tests after surgery, but they struggled during flight and did not fly smoothly at any time. These pigeons were fostered to a private home at the completion of the study.

Discussion

Temporary flightlessness was achieved in the 2 surviving cockatiels and 3 pigeons that underwent bilateral tenectomy of the supracoracoideus muscle. However, 1 cockatiel and 2 pigeons eventually regained the partial ability to fly and maneuver. The 3 cockatiels and 1 pigeon in the unilateral tenectomized groups were capable of limited flight 3 and 6 weeks, respectively, after surgery. The birds were relatively strong, maneuverable flyers at 16 weeks (cockatiels) and 26 weeks (pigeon). In all cases, the dorsal wing extension of the tenectomized wing was lower than the untreated wing, and most of the birds had a slight wing droop in the tenectomized wing after exercise. This wing droop could have been related to fatigue from disuse muscle atrophy, pain, or the loss of function of the supracoracoideus muscle.

Confirmation that the tendon of the supracoracoideus muscle had been transected was only made in 1 pigeon and 1 cockatiel in the bilateral tenec-

tomy groups. Gross and microscopic examination of the surgery sites in the other birds, weeks to months after surgery, may have determined whether any scar tissue developed at the surgery site, which could have contributed to some return of flight function.

The birds in the unilateral tenectomy groups regained flight abilities earlier after surgery than those in the bilateral tenectomy groups. The smaller birds (cockatiels) were flightless for a shorter period of time than were the larger birds (pigeons) in the unilateral tenectomy groups. In the bilateral tenectomy groups, pigeons eventually regained more flight ability than cockatiels. However, the small group sizes ($n = 2-3$) made statistical comparisons between groups impossible.

The most common nonsurgical deflighting technique used in captive birds involves clipping flight feathers.⁶ This procedure has many variations. Advantages include low cost, minimal stress, lack of pain, and temporary flightlessness. Disadvantages include inconsistent flightlessness resulting from different techniques, accidental cutting of blood feathers, keel trauma subsequent to a severely wing-clipped bird attempting to fly and hitting the floor or other surfaces, and the necessity to trim the wings 1–3 times yearly to prevent flight as new feathers molt to replace old, clipped feathers.⁶ Brailing is another nonsurgical method used for temporarily deflighting fledglings or adults or for shipping birds.⁷ Wing immobilization is accomplished by looping a flexible plastic or leather strap around a wing between the base of the seventh and eighth primary feathers and the propatagium. Potential complications with this technique include damage to growing blood feathers in fledglings or joint stiffness after immobilization lasting more than 2 weeks.⁷

Pinioning is a common surgical technique used to deflight birds, whereby the metacarpals are amputated distal to the carpus.⁸⁻¹¹ This procedure is uncomplicated in chicks younger than 1 week of age but is more difficult in full-grown birds, requiring anesthesia and sterile operating conditions. Complications, although rare, can include excessive hemorrhage, osteomyelitis, myiasis, sepsis, and death.⁹ Pinioning results in an esthetically altered bird, especially when the wings are extended during preening or courtship behavior. Some aviculturists believe that pinioned males may have more difficulty maintaining balance while breeding.⁸

Other surgical techniques used to deflight birds include removal of a wedge of propatagium (pata-giectomy),¹² joint ankylosis,¹⁰ tenectomy or tenotomy of the extensor metacarpi radialis tendon at the

carpus,^{13,14} and tenectomy of the superficial⁸ or deep¹⁵ pectoral muscles at their insertion on the proximal humerus. Resulting limitations of these techniques may include unsatisfactory appearance or development of scar tissue that could allow a degree of return to function and limited flight, especially on windy days.

Unlike most vertebrates, anatomy of birds is organized around the basic theme of flight. The flight muscles, the superficial pectoral and supracoracoideus muscles, range in total body weight from 7.8% in the white-throated rail (*Laterallus albigularis*, a predominantly ground-dwelling bird) to 36.7% in Cassin's dove (*Leptotila rufinucha*, a strong-flighted bird), illustrating the overwhelming importance of these muscles in strong-flying birds.^{16,17} A commonly held view among ornithologists and anatomists is that the pectoral muscles are responsible for the power-, or down-, stroke of the wing, and the supracoracoideus muscle is the primary elevator of the wing effecting the recovery stroke.¹⁸ Recent biomechanical studies indicate that the primary role of the supracoracoideus muscle is to impart a high-velocity rotation around the longitudinal axis of the humerus.¹ This rapid humeral twisting coupled with humeral elevation positions the forearm and hand so that the subsequent extension orients the outstretched wing appropriately for the downstroke.

Little attention has been paid in the literature to tenectomy of the supracoracoideus muscle used to deflight birds. In 1936, the German investigator Maxheinz Sy performed experiments to evaluate the flight capabilities of crows and pigeons after transection of the tendon of the supracoracoideus muscle.⁴ His surgical procedures had very different results in the different taxa. In crows, transecting the tendon of the supracoracoideus muscle bilaterally did not have any effect on flying ability. After the procedure, the crows in the study were capable of achieving flight up from the ground at an angle of at least 60 degrees over the head of the investigator. Sy noted greater impairment of flight in the pigeons. After the surgical procedure, the pigeons could not take off from level ground, nor could they climb steeply, but the birds' ability to raise their wings actively was not impaired. However, this researcher stated only that the tendon of the supracoracoideus muscle was cut dorsally. He did not state whether the tendon was completely incised or a segment of it was removed.

In contrast to the results of Sy's study, the pigeons that underwent bilateral tenectomy of the supracoracoideus muscle in our study were eventually capable of taking off from the ground, gaining elevation, and flying level for a short distance. In our

opinion, these birds could not have been housed in an open outdoor aviary without the risk of escape. The bilaterally tenectomized cockatiels never regained as much flight ability as the pigeons, but 1 of the 2 surviving birds could have flown well enough to potentially escape from an open aviary. One pigeon and the 3 cockatiels in the unilaterally tenectomized groups were all capable of flight and maneuverability such that they could have easily escaped from an open enclosure.

Muscles other than the supracoracoideus are also involved in the upstroke of the wing, and these muscles may compensate for the loss of function of 1 or both supracoracoideus muscles. The deltoideus major muscle has been shown to be involved in elevating the wing,^{2,19} and this muscle may have been responsible for producing the upstroke necessary for flight in our tenectomized birds. *Archaeopteryx*, one of the earliest known birds capable of limited flight from the late Jurassic period, and *Confuciusornis*, a likely flyer from the early Cretaceous period, did not possess muscles equivalent to the modern bird's supracoracoideus muscle. It seems likely that the supracoracoideus muscle as well as an ossified sternum are not absolutely necessary to effect the recovery stroke of the wing.²⁰ This view is reinforced by studying the anatomy of flighted mammals, such as bats, that also lack the complex avian flight musculature. The supracoracoideus muscle is functionally more complex than previously thought, and we demonstrated that surgical tenectomy of this muscle may not prevent upstroke of the wing. We concluded from our study that unilateral and bilateral supracoracoideus tenectomy does not adequately prevent flight in strong-flying birds such as cockatiels and pigeons.

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