Coracoid Fractures and Dislocations

Brett Gartrell
Wildbase, Institute of Veterinary, Animal and Biomedical Sciences
Massey University, Palmerston North, New Zealand

ABSTRACT

The treatment of coracoid dislocations and fractures in the New Zealand native wood pigeon (kereru; *Hemiphaga novaeseelandiae*), undertaken at the Wildbase Hospital at Massey University from 2002-2012. After briefly reviewing the functional anatomy of the coracoid bones, the results of research on the nature of collisions that cause such injuries are reviewed. A comparative assessment of the relative force of collisions dependent on the body size of the bird is presented. The complications of coracoid fractures and dislocations including pulmonary haemorrhage, aspergillosis, cardiac contusions and rhythm disturbances is discussed. A new technique for the repair of coracoid dislocations from the keel and intramedullary pinning for repair of coracoid fractures are outlined. The merits of surgical versus conservative treatment of these injuries are discussed.

ANATOMY

The coracoid bones are essential to flight in birds and a reduced version of them is present in avian ancestors including *Archaeopteryx*, the earliest known flying bird from the Late Jurassic period (Figure 1) (Baier et al., 2007).

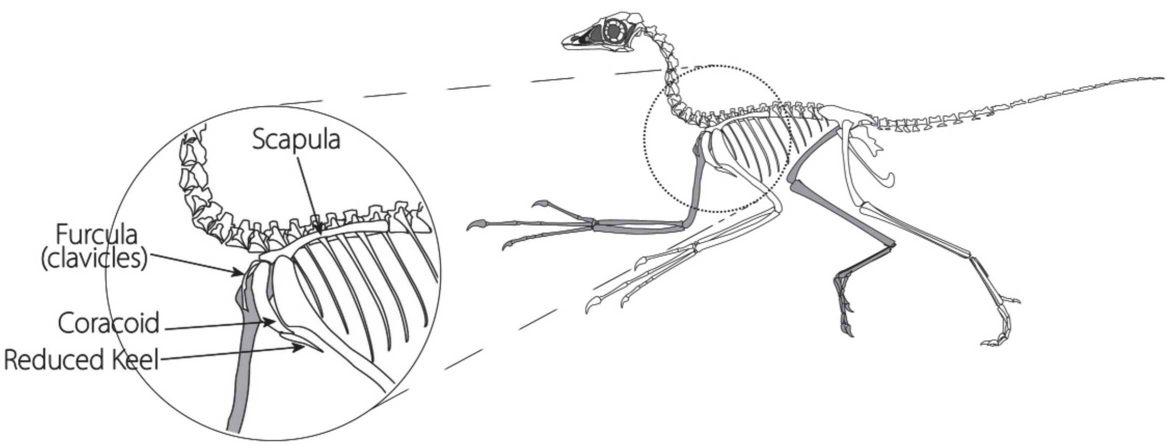

Figure 1. Diagrammatic reconstruction of *Archaeopteryx* skeleton showing the modified coracoid bone (arrow) attached to the limited keel. Image modified from (Rowe, 2011).

The function of the avian shoulder in flight is a complex interplay of forces from muscles, tendons and ligaments acting on the structural skeletal framework of coracoids, scapula, clavicles, humerus and keel. The coracoid bones are strut-like support bones running from the shoulder to the keel, whose function is to resist the compressive forces of the pectoral muscle contraction (Figure 2).

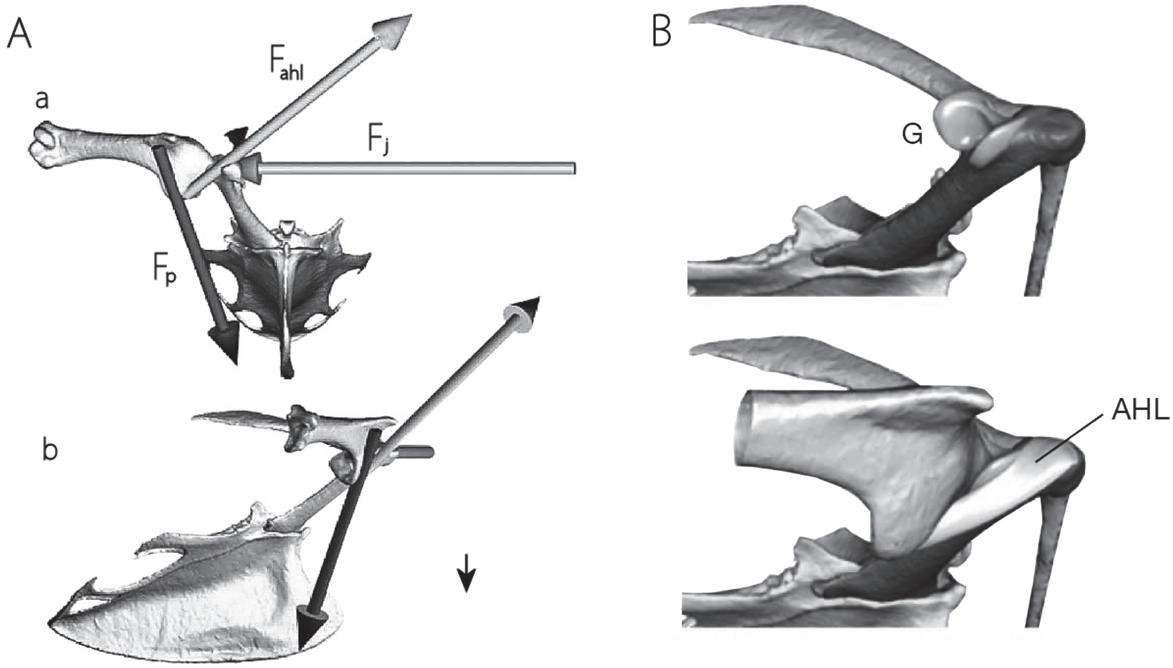

Figure 2A: Force balance diagram for the shoulder joint of a gliding pigeon, a) cranial and b) lateral views. The ventromedial force of the pectoralis (F_p) is resisted by the dorsomedial pull of the acrocoracohumeral ligament (F_{ahl}) and a lateral push from the glenoid (F_j).

Figure 2B. Lateral view of the shoulder joint showing the articular cartilage of the shoulder joint (G) and position of the acrocoracohumeral ligament (AHL). Modified from Baier et al. (2007).

The wing downstroke is driven by the contractile force from the pectoralis muscle. The acrocoracohumeral ligament (AHL), runs from the acrocoracoid process of the coracoid to the transverse sulcus of the humerus and provides a mechanism for transmitting the pectoralis force through the coracoid as a compressive strut, and prevents the shoulder from ventral dislocation (Baier et al., 2007). The wing upstroke is provided by the supracoracoideus muscle (Figure 3).

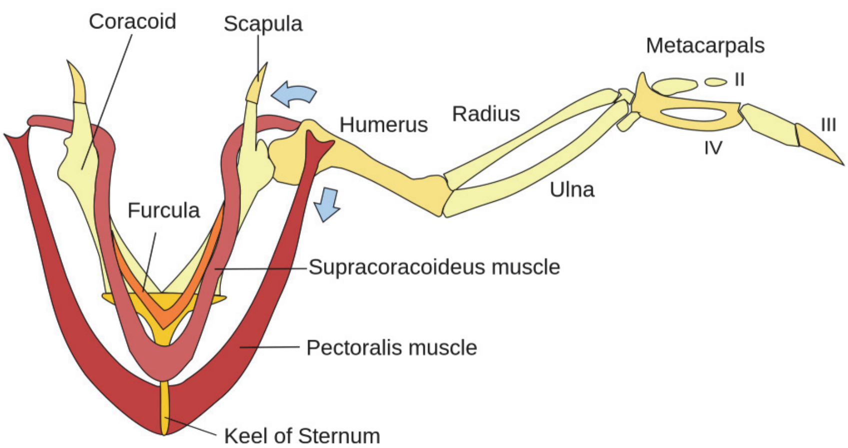

Figure 3. Diagrammatic representation of the major wing muscles of birds used in the upstroke and downstroke of the wing (Shyamal, 2007).

CAUSES OF CORACOID FRACTURES AND DISLOCATIONS

We recently published a study of the injuries sustained by kereru in collisions with vehicles or structures (Cousins et al., 2012). We assessed 146 kereru, including birds that died upon impact, birds that died during rehabilitation (or were euthanased after veterinary examination), and birds that survived and were either released back into the wild or retained in captivity (Table 1). Window collisions tend to result in a frontal impact with fanned wings, increasing the probability of a coracoid fracture or dislocation in comparison to motor vehicle collisions which are more likely to occur at an angle and result in leg or wing fractures. Twenty four of 40 (60 %) kereru that were known to have hit a window in flight sustained a coracoid fracture or dislocation. Dislocations from the keel represented 38% of all coracoid injuries. All remaining injuries were coracoid fractures. A comparison of immediate survival of the impact injury between birds with unilateral and bilateral coracoid fractures (Table 2) did not show a statistically significant difference (Fishers exact test, $p = 0.10$), however this should be interpreted with caution given the low sample sizes in the bilaterally affected group.

Table 1. Kereru skeletal injuries in relation to the type of infrastructure collided with. Data include multiple injuries per bird (Cousins et al., 2012).

		Type of injury						
Infrastructure	# birds	Coracoid	Clavicle	Wing	Leg	Keel	Head	No damage
Window	40	24	20	5	1	6	5	15
Vehicle	70	5	5	16	6	5	3	9
Fence	2	1	1	0	0	0	1	0
Unknown	34	7	9	5	1	4	5	10

Table 2. Coracoid injuries sustained by 37 kereru involved in collisions with infrastructure. Modified from Cousins et al. (2012).

Bone injuries	Location	Alive	Dead	Total
Coracoid	Left	10	4	14
	Right	5	10	15
	Bilateral	1	7	8

These findings contrast to other studies of window strike injuries elsewhere in the world. Small bird (<39g) casualties with towers and plate glass windows in America have shown little or no skeletal fractures, and more prevalent head trauma (>50%) (Veltri and Klem, 2005). A contributing factor is likely to be the force with which birds of different sizes collide with objects (Table 3). The impact force (in Newtons) for kereru and small passerine birds was calculated based on flight speeds calculated in the computer software programme Flight 1.11 (Pennycuick et al., 2011) using the formula:

$$F = 0.5 * m * \frac{V^2}{S}$$

where m=mass (kg), v=velocity (m s^{-1}) and s=slow-down distance during impact (assumed 25% of bird length).

Morphometric data suitable for input into this formula for kereru were collected from five of the study birds submitted (m=0.57 kg, wingspan=0.812m, wing area=0.115m^2) and data for the smaller passerine birds were taken from values loaded into Flight 1.11. In the case of the Kereru, the predicted collision forces are roughly 15–30 times higher than those of smallish passerine birds investigated. The difference in the force of collision in smaller birds would explain the lack of skeletal fractures reported in Veltri and Klem (2005).

Table 3. Flight impact forces for birds of various sizes. Minimum power and maximum range flight speeds were calculated using the *Flight* program (Pennycuick et al.,2011).

Species	Scientific name	Mass (kg)	Length (cm)	Minimum power Speed (ms^{-1})	Minimum power Impact force (N)	Minimum power Relative to Kereru	Maximum range Speed (ms^{-1})	Maximum range Impact force (N)	Maximum range Relative to Kereru
Kereru	*H. novaeseelandiae*	0.57	51	13.0	378	-	22.4	1122	-
Jackdaw	*Corvus monedula*	0.181	32	10.3	120	0.32	18.3	379	0.34
Starling	*Sturnus vulgaris*	0.082	18	9.9	89	0.24	17.8	288	0.26
Song thrush	*Turdus philomelos*	0.072	18	9.8	76	0.20	17.4	241	0.21
Chaffinch	*Fringilla coelebs*	0.023	15	7.8	19	0.05	14.7	66	0.06
Thrush nightingale	*Luscinia luscinia*	0.023	16	9.1	24	0.06	16.9	82	0.07
Garden warbler	*Sylvia borin*	0.022	10	8.7	33	0.09	16.2	115	0.10
Siskin	*Carduelis spinus*	0.011	15	6.9	7	0.02	13.2	26	0.02
Goldcrest	*Regulus regulus*	0.005	8	6.3	5	0.01	13.2	24	0.02

DIAGNOSIS OF CORACOID FRACTURES AND DISLOCATIONS

Clinical signs

Birds with a coracoid fracture or dislocation may appear clinically normal on physical examination and hold their wings evenly at rest. In my clinical experience, pain is usually elicited on manipulation of the wing and shoulder. Birds with coracoid fractures or dislocations may be able to fly in a downward arc but be unable to take off from the ground or gain height when flying. In some cases, bruising and crepitus may be palpated over the keel and shoulder. Clinical biochemistry changes are usually limited to elevations of plasma CK and AST levels as indicators of non-specific trauma.

Radiography

The standard method for confirming a coracoid fracture or dislocation is to take well-aligned lateral and ventrodorsal views of the shoulder girdle (Figures 4, 5 and 6). Both views must be examined to accurately diagnose the presence of fractures and the position of dislocations. As these birds are painful on manipulation of the wings, I strongly recommend general anaesthesia be used to position the birds for radiographs.

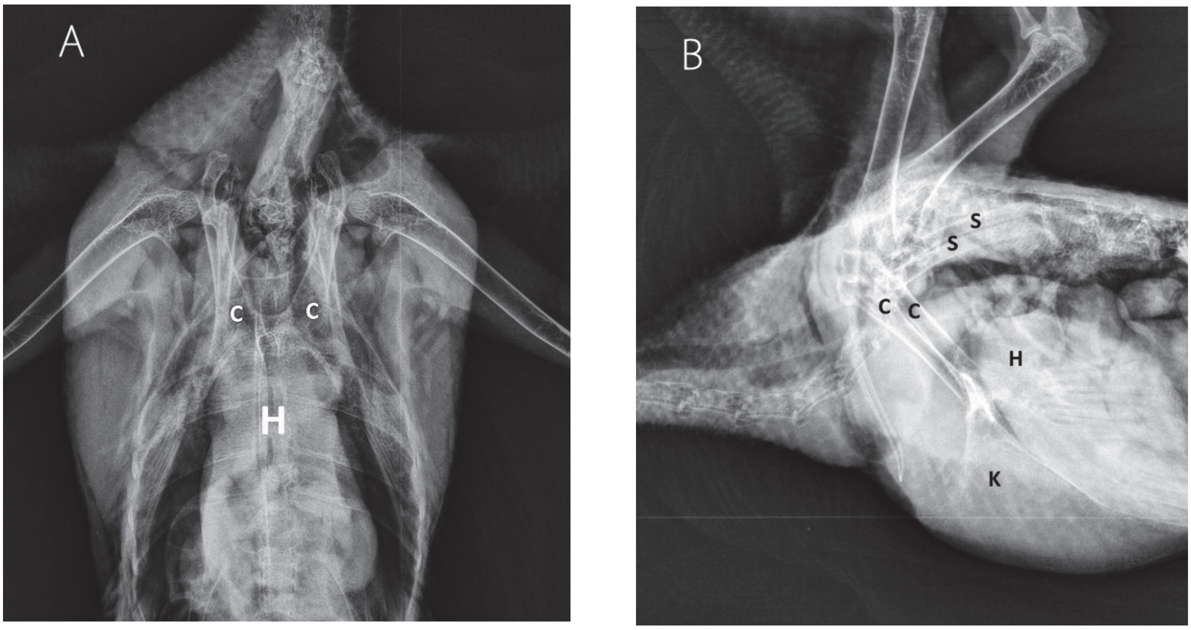

Figure 4. Normal radiographic anatomy of a kereru shoulder girdle with A) ventrodorsal and B) lateral positioning. The position of the coracoids (C), heart (H), scapula (S) and keel (K) is indicated.

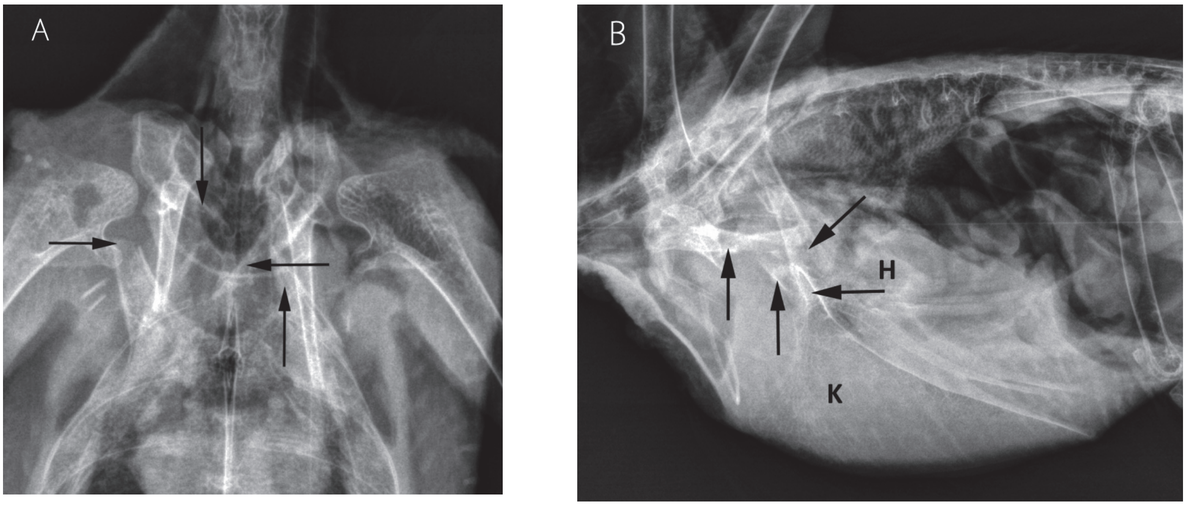

Figure 5. A) Ventrodorsal and B) lateral radiographs of a kereru shoulder girdle with bilateral coracoid fractures. The position of the fractured ends of the coracoids (multiple arrows), the heart (H), and keel (K) is indicated.

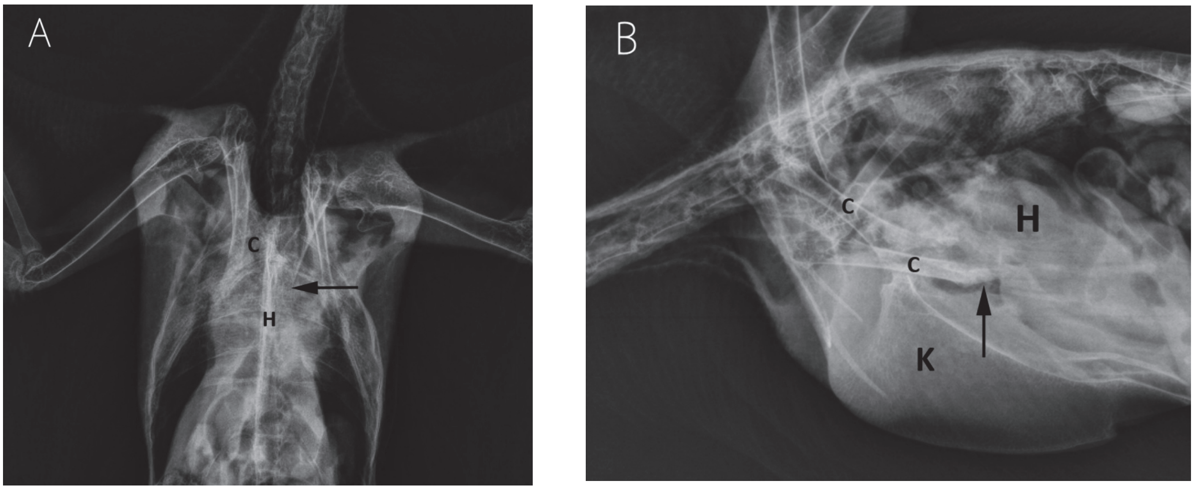

Figure 6. A) Ventrodorsal and B) lateral radiographs of a kereru shoulder girdle with a unilateral left caudo-medial coracoid dislocation. The position of the normal coracoid (C) and the end of the dislocated coracoid (arrows), the displaced heart (H), and keel (K) is indicated.

Computed tomography

We have previously reported a case of a subtle but clinically significant coracoid subluxation in a New Zealand falcon (*Falco novaeseelandiae*) that was not diagnosed by plain radiography but was detectable using computed tomography (Ward and Gartrell, 2009). The shoulder girdle is a complex structural area and computed tomography provides excellent advantages over conventional radiography in imaging this three-dimensional space. As the cost of computed tomography progressively reduces, this modality will become increasingly useful in defining coracoid injury.

OTHER INJURIES AND SEQUELAE ASSOCIATED WITH CORACOID TRAUMA

Post mortem examination of kereru that died with coracoid fractures from window strikes showed a high incidence of significant soft tissue injuries (Table 4). Cardiac trauma was present in 11/12 birds examined. Lacerations to the heart (10 of 12) were caused by a dislocated or fractured coracoid rupturing an atrium. In eight cases extensive damage to the heart from broken coracoids was considered to be the ultimate cause of death.

Table 4. Combinations of skeletal fractures and soft tissue injuries in Kereru that died from impacts with windows. Modified from Cousins et al. (2012).

		Soft tissue injury							
Skeletal injury	**Number of birds**	**Head**	**Breast**	**Heart**	**Lungs**	**Liver**	**Intestine**	**Major blood vessels**	**Neck**
Coracoid	3	1	1	3	2	1			
Coracoid/clavicle	6	1		5	3	2	1	1	
Coracoid/keel	1			1	1				

We have detected cardiac rhythm disturbances during anaesthesia and at rest in a number of kereru with coracoid injuries. During surgical repair of coracoid dislocations this seems to be directly related to pressure of the coracoids on the myocardium, based on an immediate improvement of the arrhythmias on surgical reduction of the coracoid dislocations. In conservatively treated cases, the cardiac rhythm disturbances are often transient and resolve with time. However, we have also seen several cases of permanent first and second degree heart block in kereru following window strike.

We have also seen several cases of pulmonary aspergillosis in kereru with coracoid injuries during rehabilitation. We speculate that the degree of pulmonary haemorrhage associated with these cases may provide a beneficial environment for *Aspergillus* spores to gain a foothold. Correspondingly, we routinely treat these cases with a prophylactic dose of 5mg/kg itraconazole PO SID for as long as the birds are housed indoors at the hospital. This is usually a period of 7-14 days.

A long term complication following treatment of the initial trauma and injury is permanent loss of flight due to patagial contracture or shoulder ankylosis. We attempt to circumvent these complications by carrying out physiotherapy on the affected wings as soon as the coracoid injury has healed sufficiently. The commencement of physiotherapy is usually four weeks after the injury, later than for other fractures. Initially passive range of motion (ROM) exercise is carried out under a general anaesthesia, but we quickly move to conscious exercises. Once an acceptable ROM is re-established in the wing, the birds are placed into circular nylon meshed flight aviaries to encourage safe exercise. Initial use of long straight flights with wire mesh resulted in some birds re-injuring themselves.

Another complication seen irregularly in these cases include crop stasis and delayed emptying associated with narrowing of the thoracic inlet after coracoid and clavicle trauma. These cases are usually difficult to treat successfully. We use a liquid slurried diet to provide nutrition, and treat with anti-inflammatories and bandaging support of fractures. Some cases resolve as the soft tissue trauma resolves but others continue to show delayed crop emptying and need to be euthanased.

TREATMENT OPTIONS

In preparing this paper I reviewed the radiographs of 116 adult kereru that had been admitted to the Wildbase wildlife hospital from February 2009 to June 2012. Of these 46 birds (39.7% of all kereru radiographed) had evidence of a coracoid fracture or dislocation (Table 5).

TABLE 5. Summary of the 46 kereru diagnosed with coracoid injuries by radiography at Wildbase, Massey University between February 2009-June 2012. The two birds in brackets are birds that had a fracture of one coracoid and a dislocation of the other.

Coracoid injury	Number affected	Unilateral: bilateral	Cranial: caudal dislocation
Fracture	17(+2)	17:2	N/A
Dislocation	27(+2)	16:13	11:18

a. Conservative management

External coaptation of coracoid injuries was our most commonly used treatment for these fractures in kereru, due to the low cost and reasonable success rate (Figure 7). Of 39 birds where treatment was attempted, 34 (87.2%) were treated with external coaptation and 5 were treated surgically. There was no significant difference in outcome between these two treatment methods (Fishers exact test, p=0.268) but caution should be used in interpreting these results due to the low number of surgical repairs attempted.

External coaptation consists of a unilateral or bilateral wing to body bandage. Medical support consists of analgesia (initially butorphanol IM at 4mg/kg bid 3-7 days, combined with meloxicam at 0.2mg/kg po sid once hydration established), oral fluid therapy, supplementary feeding, and 5mg/kg itraconazole po sid. Physiotherapy protocols have been previously discussed.

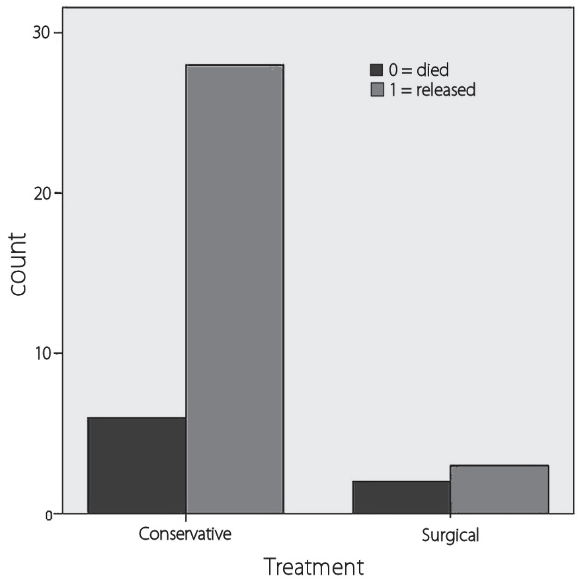

Figure 7. Outcome of response to conservative versus surgical treatment of coracoid injury in 39 kereru.

However, while conservative therapy gives a reasonable prognosis for survival in kereru, its use has been questioned in birds that require precision flight such as falcons. Other studies in a range of species with high wing loading have also shown better results with surgical treatment (Holz 2003). Recently, we have begun to question the use of conservative treatment in coracoid dislocations where there is evidence of impingement on the heart. Further, the compressive effect of the pectoralis muscles means that most coracoid fractures are over-ridden and displaced and I hypothesise that surgical correction may result in faster and more comfortable healing.

B. **Surgical repair - coracoid fractures**

Intramedullary pinning of coracoid fractures is a well described technique in birds (Holz, 2003). The bird is placed in dorsal recumbency and an incision is made along the line of the keel and clavicle through both skin and pectoral muscle. Haemorrhage is invariably encountered when reflecting the pectoral muscle from the keel and clavicle, and should be quickly controlled. The coracoid lies deep to the pectoral muscle and adequate visualisation of the fracture site is required so retractors are essential. The fracture ends are exposed and the intramedullary pin is placed retrograde, penetrating out through the shoulder, before being replaced into the caudal fragment and seating down near the keel. Care should be taken to measure the pin on insertion to ensure the keel is not breached and the heart punctured. Intra-operative radiographs or fluoroscopy can be useful in ensuring correct pin placement (Figure 8).

Figure 8. Intra-operative ventrodorsal radiograph of the surgical placement of an intramedullary pin to repair a coracoid fracture in a kereru.

Plate fixation of coracoid fractures has been successful in several eagles (Davidson et al., 2005; Guzman et al., 2007), but I would caution against their use in smaller birds due to the brittle nature of avian bone and the tendency of the bones to shatter when the torque of screws are applied.

c. **Surgical Repair - coracoid dislocations**

The surgical repair of coracoid dislocations has received little attention in the veterinary literature. Analysis of our records indicates that many of these dislocations will heal using conservative therapy but 4 out of 5 birds with significant cardiac arrhythmias had caudal dislocations of the coracoids that were impinging on the heart. The coracoids may dislocate cranially and lodge in the pectoral muscle and for these cases, stabilisation with external coaptation is likely to result in return to flight with minimal complications.

However, in 18/29 cases of coracoid dislocation in kereru in our files, the dislocation was caudal into the coelom and resulted in displacement of the heart. I suspect many of these cases do not survive the initial impact. Those that do survive often die early in care, or during anaesthesia for radiographs or surgery.

Based on our increasing recognition of the cardiac complications in these cases I have developed a surgical technique for repairing these dislocations. The surgical approach to the coracoid is the same as has previously been described for coracoid fractures, but more extensive retraction of the pectoral muscles is used to expose the cranial keel and confirm the dislocation. A set of towel clamps is used to grasp the dislocated coracoid taking care not to fragment the bone. A second set of towel clamps is placed in the blade of the keel and the dislocation is reduced by placing tension on the keel caudally and the coracoid cranially. Having reduced the dislocation, a non-absorbable suture or fine stainless steel wire is placed through the caudal diaphysis of the coracoid and insertion point of the keel. The keel suture is placed by lifting the keel away from the heart and using a curved needle to pass the suture from the coelomic surface of the keel outwards. The dislocated coracoid is then sutured or wired into position. The pectoral muscle and skin are then sutured back in place and a wing to body bandage is placed for three to four weeks before beginning physiotherapy. It is worth a note of caution that significant cardiac arrhythmias are encountered during the reduction of the dislocated coracoid from the coelom. This is an exciting surgery for anaesthetists.

As with all surgical repairs, this technique is easiest and of most benefit to the patient if carried out soon after the injury occurs. We have attempted this in older dislocations but encountered significant pectoral muscle fibrosis and adhesions between the dislocated coracoid and the pericardial surface.

CONCLUSIONS

Coracoid injuries are a common injury in window strikes in larger birds. A working knowledge of the functional anatomy of the coracoids can aid in the treatment of these injuries. Diagnosis is based on well positioned lateral and ventrodorsal radiographs. Conservative treatment shows good success rates but surgical treatment should be considered when there is displacement of fracture ends, caudal dislocations of the coracoids or where return to precision flight is essential. Complications of coracoid injuries include loss of flight, aspergillosis, cardiac arrhythmias and occasionally crop stasis.

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