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Bill Injuries of the North Island Brown Kiwi (*Apteryx mantelli*)

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Abstract: Probing feeding behaviour and the delicate anatomy of the Apteryx spp. bill make it prone to injury. Types of bill injuries seen in the North Island Brown Kiwi (*Apteryx mantelli*) at a New Zealand wildlife hospital include keratin abnormalities, a variety of fractures and sequelae of previous trauma. The need for a fully functional bill and its unusual anatomy pose some unique difficulties in treating such injuries. This paper outlines some of the most common bill related conditions diagnosed and aims to highlight the major considerations in their treatment.

Introduction

Birds of the genus *Apteryx* are amongst the most unusual and admired of the unique avifauna of New Zealand. Endemic to the three main islands of New Zealand the genus currently consists of five recognised extant species, the North Island Brown (*Apteryx mantelli*), Okarito Brown (*Apteryx rowi*), Southern Brown (*Apteryx Australia*), Little Spotted (*Apteryx owenii*) and Great Spotted Kiwi (*Apteryx haastii*). The national conservation status of these species and their recognised local subspecies varies from Recovering, through Nationally Vulnerable to Critically Endangered (Robertson et al., 2017). The IUCN Red list™ has assessed the Little Spotted as Near-threatened and the remaining four species as Vulnerable or Endangered and consequently at risk of extinction (IUCN Red List of threatened species 2017-1). Extensive efforts have been made to attempt to mitigate threats to kiwi populations including creation and maintenance of predator-free mainland and island sanctuaries and intensive captive rearing programs.

This taxonomically isolated ratite genus is largely nocturnal, residing in burrows and hollows, large powerful legs, vestigial wings and unusual bill anatomy (Holzapfel et al., 2008). The bill of the kiwi is a highly specialised instrument for the detection, extraction and ingestion of food, manipulation of the environment and respiration through distally located nares (Holzapfel et al., 2008) . The probing feeding behaviour and somewhat delicate anatomy of the kiwi bill means that injuries to this structure are not uncommon. The fragile and complex anatomy of the kiwi bill means that treatment options are often limited and accompanied by some distinctive considerations. Additionally, a near-perfect restoration of bill function is required after injury for survival after release to the wild. After a brief outline of the structure and function of the normal Kiwi bill, this paper will cover some of the more common types of bill injuries and considerations in their veterinary management.

Anatomy and function of the Kiwi bill

The extraordinary kiwi bill a highly specialised elongate, curved and tapered instrument (Figure 1). Both the length and the degree of ventral curvature are more pronounced in the adult female (Holzapfel et al., 2008). The Apterygidae are the only extant group of birds that have the nares at the rostral tip of the bill, meaning that the open nasal passages extend the length of the premaxillia. The rostral tip of the upper bill bulges slightly and curves ventrally, rostral to the nares, overlapping the shorter mandible (Cunningham et al., 2007) (Figure 2). This "bull-nosed" tip of the upper bill presumably protects the nares from the incursion of soil and facilitates probing in the soil for the kiwi's largely invertebrate diet. Within the oral cavity there is a short triangular tongue that is largely fixed in position between the rami of the mandible. Rostral to the tongue both the upper and lower bills are dorsoventrally flattened with the opposing surfaces covered in oral mucosa used for crushing food items before swallowing (Holzapfel et al., 2008).

Figure 1: Normal adult kiwi bill

Figure 2: Close up of the bill tip showing the overlapping upper bill, distally located nares and plates of keratin.

Figure 3: Transverse histological section of the rostral bill tip of an adult kiwi showing the very thin layer of keratin and soft tissue overlying bone (bracket) and the density of Herbst corpuscles (arrows) within sensory pits. H&E 4x magnification. (M.Alley)

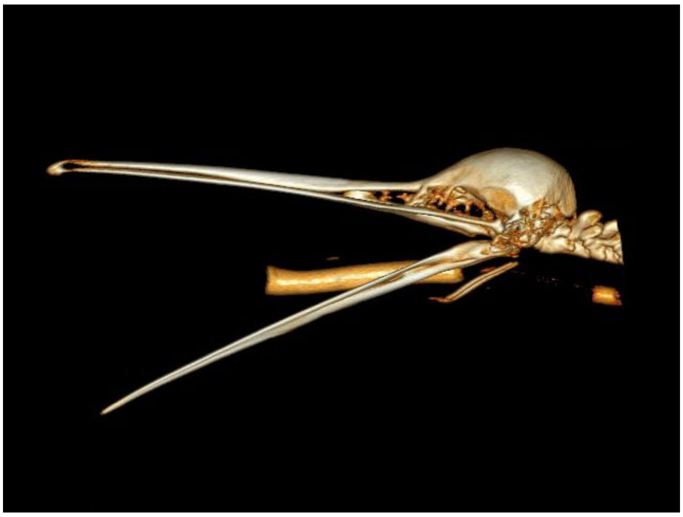

Figure 4: 3D reconstruction of kiwi skull (endotracheal tube within the oral cavity).

The external surface of the kiwi bill is composed of a series of harder keratin plates separated by junctions of apparently softer keratin (Figure 2). At the rostral tip these junctions have been found to demarcate distinct zones of morphology in the underlying bone and nervous tissue (Cunningham et al., 2013), the full significance of this is not currently understood. Current knowledge is also lacking in how the different keratin plates grow and wear in the normal bird. Anecdotally the germinal tissue of the largest plate over the dorsal surface of the bill appears to produce keratin outward and in a slightly rostral direction. The hard keratin on the lateral edges of the proximal premaxilla readily overgrows in a hospital setting where opportunities to wear the beak are limited. This overgrowth produces exaggerated ridges in this area extending laterally and slightly ventrally, possibly indicating the direction of growth of this area of keratin. From a clinical perspective a better understanding of the pattern of growth of different areas of keratin would assist in predicting the response to injury and likelihood of return to normal function. Additionally the keratin layer has also been used to attach external coaptation devices by various means. Covering the keratin in any impermeable substance, such as dental or nail acrylic, appears to soften it resulting in alterations in growth pattern or direct damage which can be temporary or permanent.

Deep to the keratin layer there is scant soft tissue covering the majority of the kiwi bill (Figure 3). This has clinical implications both in terms of most injuries communicating with bone and a limited blood supply that is easily compromised. The olfactory abilities of the kiwi are well developed playing a significant role in social interactions and territorial demarcations, but a less important role in foraging. The majority of prey detection appears to be via vibrotactile cues detected by a complex series of receptors within pits embedded deep within the bone (Cunningham et al., 2007). The distribution of these sensory pits varies across the bill being at highest density on the rostral premaxilla in an area termed the sensory pad located on the ventral surface of the rounded overlapping portion (Cunningham et al., 2007). The concentration of sensory tissue in the kiwi bill is consistent with the clinical impression that even minor injuries can be significantly painful and responsive to analgesics.

The bones of the upper bill including the nasal, vomer, pterygoid and short maxilla are fused to the cranium caudally and the markedly elongate premaxilla rostrally. Travelling within the premaxilla are the nasal passages forming dorsal and ventral layers of bone each with 2 cortices variably distinguishable on radiographs. Nasal turbinates do not extend beyond a 1/3rd the length of upper bill and particularly the caudal conchae are highly developed to increase the surface area of the olfactory mucosa (Baumel et al., 1993). A deep furrow rostral to the choanal opening on the roof of the mouth contains a significant vessel presumed to be a branch of the palatine artery. The rami of the kiwi mandible articulate with the tympanic bone of the skull caudally and rostrally fuse into the elongate, flat and broad mandibular symphysis (Cunningham et al., 2007). Clinically the dorsoventral flattening of the mandible and the presence of the nasal cavity within the premaxilla, leaves only a very small diameter of bone capable of holding orthopaedic implants. (Figure 4)

Injury types and their management

Annually ~30 kiwi, across all species, are presented to the Wildbase Hospital based at Massey University in Palmerston North. Individual birds have been presented from a diversity of captive, managed-wild and truly-wild origins with associated varying requirements for return to function. However, as described above a functioning bill is essential to kiwi survival even in the more supported captive environments. The most commonly seen bill injuries are discussed below.

Fractures

Kiwi bill fractures seen at Wildbase have varied from minimally displaced fissures involving only one cortex of the premaxilla to open severely comminuted fractures and have involved either the upper or lower jaw or both.

Initial evaluation must address the integrity of nerve and blood supply distal to the lesion, presence or risk of infection to bone and surrounding soft tissue and integrity of the surrounding keratin. There is rarely any effective way to temporarily stabilise bill fractures, therefore appropriate pain relief and supportive care should be followed by general anaesthetic and radiographic evaluation as soon as practicable. Radiographic examination should include the following views: Dorsoventral (DV) or ventrodorsal closed mouth views of the skull, with DV being easier to position given the domed shaped of the kiwi cranium and body; Lateral views with both open and closed mouth (a small piece of radiolucent plastic makes an effective oral gag); and lateral-oblique views again with an open mouth. During the general anaesthetic the overlying keratin can be closely assessed for damage that may require debridement and assessment of its ability to withstand the placement of external coaptation. Likewise samples can be collected from any areas of suspected infection and blood taken for complete blood count and plasma biochemistry. As the vast majority of bill fractures will be open broadspectrum antibiotics are recommended until repeat white cell counts suggest no active infection.

Fracture stabilisation has been attempted via a variety of techniques with variable success. Fractures of the caudal mandible have been stabilised with malleable metal splints attached by multiple sutures placed circumferentially around the ramus of the mandible (Figure 5) or in patients of sufficient size stabilisation can be attempted with Type I external fixateurs (Figure 6). More rostral fractures of the mandible rarely have bone fragments of sufficient cortical strength or thickness to allow placement of an external fixateur (type I or II if within the mandibular symphysis) except in the largest of kiwi. Such fractures in smaller birds can be somewhat stabilised by external coaptation with a material such as epoxy nail acrylic or dental acrylic to the surrounding intact keratin (Figure 7). The acrylic material can be supported by some type of splint bridging the fracture site. The adhesion of these impermeable materials to a permeable material like keratin results in softening and weakening of its integrity if it is left in place for more than a few weeks (Figure 8). The nail acrylic does not adhere as firmly to the keratin and usually exfoliates within a few weeks, while the dental acrylic is more rigid once set it is much more firmly adhered and can cause permanent alterations to the underlying keratin. Consequently it may be better to use repeated applications of a less permanent material in order to prevent some longer-term sequelae. Rostral fractures of the premaxilla are complicated by the presence of the nasal cavity which can be both an access point for infection and can be occluded by swelling or callus formation with temporary or permanent effect. The presence of the nasal cavity also largely precludes the placement of external fixateurs, leaving again splint type devices attached by adhesion to the keratin. This can involve the use of acrylic products with or without additional splints (as described previous for mandibular fractures) (Figure 9) or one attempt has been made to use a orthodontic-type device made of hooks attached to the keratin with superglue and suture material or rubber bands bridging the fracture site (Figure 10) While the later technique was successful this particular case had some callus formation prior to the application of this device and it remains to be tried on a less stable, more acute fracture.

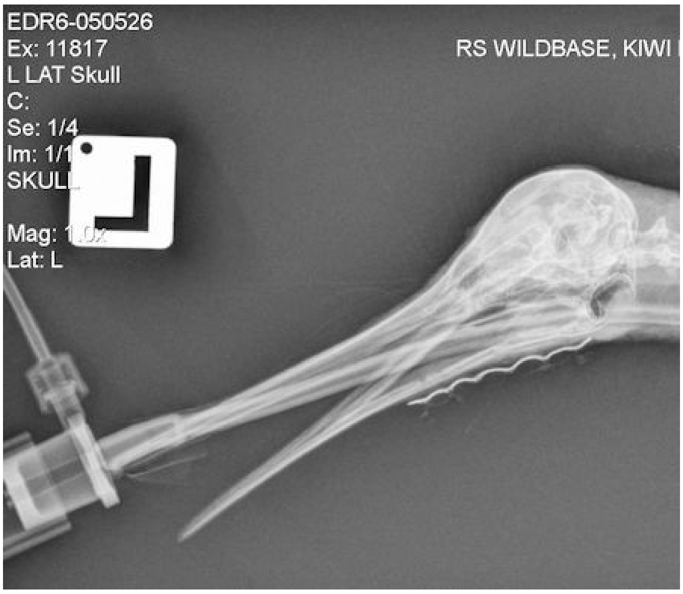

Figure 5: Left Lateral oblique radiograph with external splint device held in place with circumferential sutures

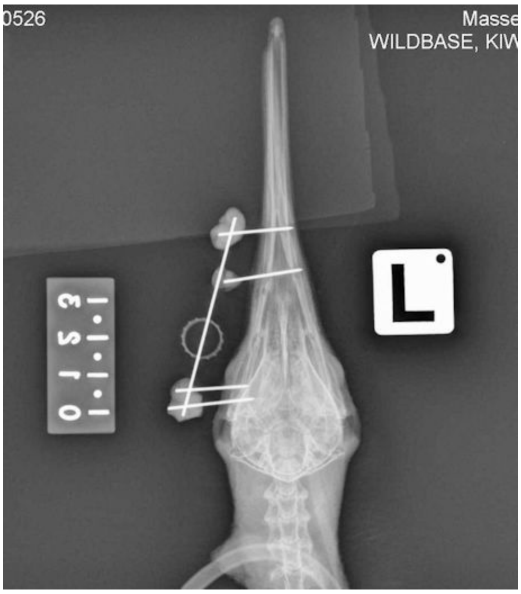

Figure 6: Radiograph with Type I external fixateur in place for caudal mandibular fracture (Note the presence of an oesophageal feeding tube in the lower part of the image).

Figure 7: Damaged keratin over a chronic fracture of the pre-maxilla reinforced with nail acrylic.

Figure 8: Keratin degradation after being covered in nail acrylic material for 2 weeks.

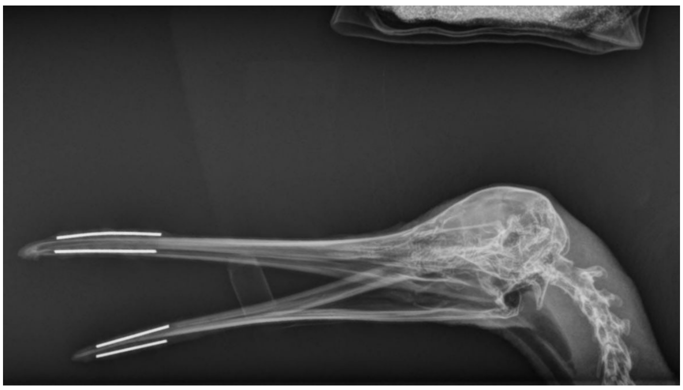

Figure 9: Premaxilla and mandibular fractures stabilised with curved K-wires applied externally with nail acrylic.

Figure 10: Premaxilla fracture with bridging tension device in place.

Pain relief post-stabilisation is critical, and we currently initially use butorphanol (4mg/kg IM BID to QID) and then move to meloxicam (0.5 to 1mg/kg PO BID), tramadol (30mg/kg PO BID) or a combination. Anecdotally tramadol appears to be very effective in kiwi with beak injuries, with food intake sharply declining when the medication was withdrawn and rebounding just as sharply when it was recommenced.

Nutritional support is essential to the healing of any injury and particularly in kiwi bill fractures where movement of the broken bones is required for eating. Appropriate nutrition, fluid therapy and medications will need to be administered which likely will require manipulation of the bill which risks both movement of the healing fracture site and causing significant pain to the bird. Also, as described above, few of the available stabilisation techniques will result in the degree of fracture site apposition and stabilisation that would be desired in other areas of the skeleton. Consequently the placement of an oesophageal feeding tube introduced to the level of the proventriculus should be considered at least initially. The small proventriculus and gizzard volume of the kiwi should also be remembered when formulating treatment plans to minimise the complication of volume overload, regurgitation and potential aspiration. If placed correctly a feeding tube can be maintained for an extended period and nutrition, fluids and medication can often be administered without handling or significantly disturbing the kiwi.

Avian pox infection

Avian pox viruses have been found to infect kiwi, causing the firm nodular cutaneous lesions seen in a variety of other bird genera (Ha et al., 2013). Areas of the skin exposed to abrasive forces are the most common sites of pox virus lesions, including the bill. Most infections have been not been associated with systemic illness and the lesions usually resolve spontaneously. However, pox lesions on the bill can be painful and temporarily disfiguring, therefore affecting the ability to forage leading to starvation. Additionally, the pox virus lesions can become secondarily infected with a variety of opportunistic bacteria and act as a conduit to infection of deeper tissues (Figures 11 and 12). Therefore management of avian pox infection with beak lesions in kiwi is centred around pain relief, nutritional support and antibiotics as indicated. Surgical debridement is recommended in severe cases if lesions are inhibiting eating or there is caseous material related to secondary bacterial infection. The highly contagious nature of avian pox also necessitates suspect and confirmed patients are isolated from all other birds. The route of infection between kiwi is not fully understood but likely involves biting parasites or direct contact between individuals, making it an important consideration in the intensive management and relocation of kiwi.

Osteomyelitis

The scant amount of soft tissue between the external keratin surface and the underlying bones of the premaxilla and mandible mean that any disruption to the external surface is likely to lead to contamination of the underlying bone. A likely compromise of the blood supply to affected areas of the bill and that distal to the lesion has implications in both the development of such osteomyeltic lesions and the delivery of medication to the area during treatment. All fractures and compression injuries should be considered contaminated until white cell count and serial radiographs discount an infectious process. Confirmed cases of osteomyelitis will require prolonged antibiotic administration, the selected drug determined by culture and sensitivity and altered as required by repeat testing.

Extensive osteomyelitis lesions can present an extended period of time after the original injury (Figure 13) and carry a guarded prognosis for either achieving control of the infection or the long-term return to function. If infection can be controlled and inflammatory material debrided

Figure 11: Pox lesion affecting the rostral bill tip

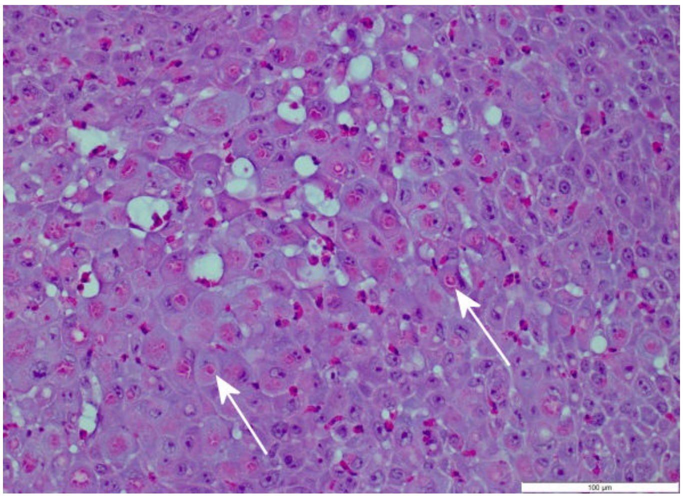

Figure 12: Hyperplasic epithelium with eosinophilic intracytoplasmic inclusion bodies (some marked by arrows) H&E x40 (S. Hunter)

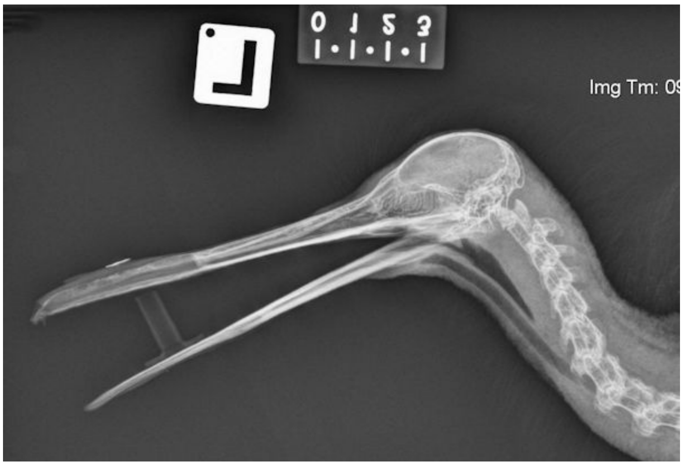

Figure 13: Lateral radiograph advanced osteomyelitis secondary to a crush injury of the bill 12 months previous.

Figure 14: Abnormal keratin regrowth several months after a transverse laceration of the distal bill tip.

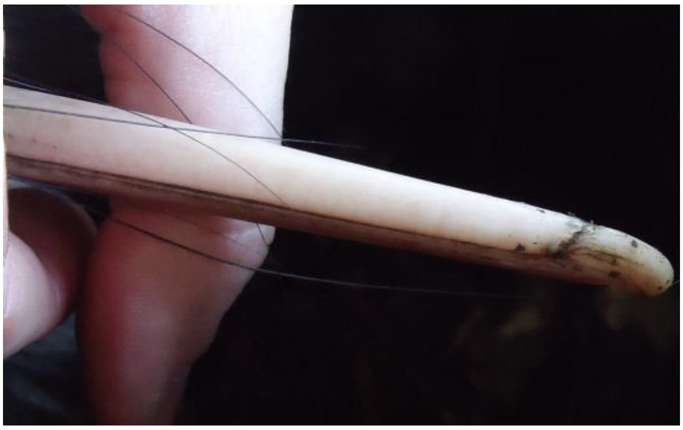

Figure 15: The same bird as Fig 14, 12 months post-admission after debridement and management of probing opportunities in a captive situation.

Figure16: Keratin regrowth 10days after the removal of a constricting rubber band from the tip of the bill.

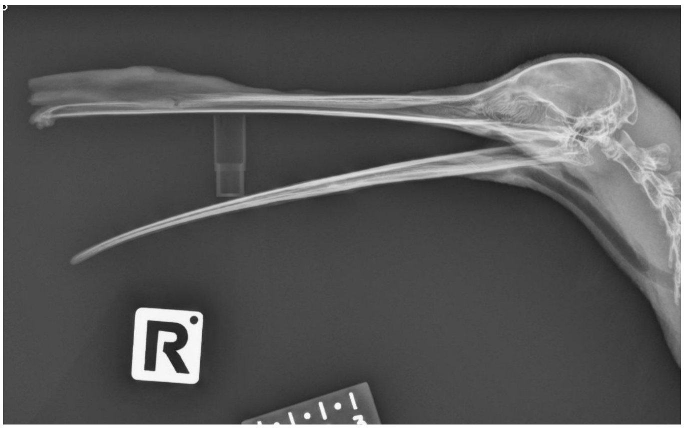

Figure 17: Open mouth lateral radiograph showing a chronic fracture of premaxilla and exuberant keratin growth dorso-rostral to the fracture site.

there will likely be considerable changes to the shape of the bill and growth/wear patterns of the overlying keratin, which may compromise bill function indefinitely.

Lacerations

A few cases of superficial injury to the keratin and soft tissue layers of the kiwi bill have been seen at Wildbase that do not involve the deeper bone structures. Once secondary infectious processes are successfully treated and pain relief initially to encourage feeding, such lacerations often heal rapidly. The subsequent regrowth of keratin over the laceration can be abnormal (Figures 14 and 15) and require management with repeated remodelling until probing behaviour and continued healing results in a functional if not always aesthetically normal bill. Permanent changes in the regrown keratin are presumed to be the result of damage to the germinal tissue forming the keratin structures. The pattern of keratin formation, growth and wear is not fully understood in kiwi and some Wildbase patients with keratin lacerations are contributing directly to our understanding of these growth patterns.

Crushing/strangulation/entrapment injuries

Entrapment or compression injuries without associated fractures have been seen sporadically in kiwi (Figure 16). This type of injury obviously inhibits or completely prevents normal foraging and drinking depending on weather the upper, lower or both jaws are entrapped. These types of injuries have only been identified so far in intensively managed birds, probably because any wild birds would succumb to dehydration and starvation before being found.

Removal of the entrapping material, pain management and assessment for underlying abrasions, fractures and compromised blood supply are the cornerstones of treatment. In uncomplicated cases the keratin returns to an apparently normal thickness and wear pattern within a few weeks. However, similar to lacerations mentioned previously, there may be ongoing abnormalities in keratin formation and wear that require monitoring and possibly intervention.

Exuberant keratin growth

A case of exuberant keratin overgrowth on the dorsal surface of the rhinotheca was seen in a Rowi kiwi (*Apteryx rowii*) and believed to be a possible long-term sequela to injury of the keratin germinal tissue. In this particular case there was an underlying non-displaced non-union fracture to the premaxilla and increased movement in the area of damage may have contributed to the apparent retention of keratin material that would normally have been abraded away (Figure 17). The exuberant keratin material would have prevented normal probing and foraging, however this bird had survived in a wild environment for what may have been months and presented to hospital in light body condition. While this was just one unusual case it is possible that this could be a long-term complication of a variety of kiwi bill injuries that alter the normal formation and wear of the keratin surface.

Treatment of exuberant keratin overgrowth will involve removal of excessive keratin material, addressing underlying contributing factors, such as fractures, and management of keratin wear as it returns to a more functional anatomy.

Amputation

Traumatic amputation of some portion of the upper, lower or both bills in kiwi do occur and are universally associated with a grave prognosis. The presence of nares at the tip of the bill and the adjacent sensory organ that is vital to the detecting food mean that the amputation of any portion of the rostral upper bill is not compatible with survival even in a captive situation where such birds have to be force-fed. Early triage and euthanasia is strongly recommended in cases of traumatic bill amputation in kiwi. Other situations may arise during the treatment of bill injuries, such as non-healing fractures or unresponsive osteomyelitis, where surgical amputation may be considered as a treatment option. Such a surgery would leave the patient with the same inability to self-feed as a traumatic amputation and would never result in a kiwi that was releasable into the wild. Treatment of all kiwi bill injuries should primarily aim to preserve the structure and function of the bill and euthanasia should be considered if that is not possible.

Conclusions

The kiwi bill is a unique anatomical structure, intricate and not fully described. The probing foraging behaviour of the kiwi makes damage to the bill an all too common reason for presentation to hospital. After an injury there is a need for a high level of return to bill function to survive, even in captivity. The preceding information aims to be a general guideline with each case requiring adaption of techniques and careful monitoring to achieve the best outcome possible.

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