Case Report

Application of Sutures for Skull Stabilization: A Novel Technique for Cranioplasty in Fennec Fox (*Vulpes zerda*)

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Abstract

Skull fractures in fennec foxes (*Vulpes zerda*) are a serious issue that demands urgent intervention because of the species' fragile cranial structure. Compressed fractures can cause brain injury, bleeding within the skull, and neurological disability. Failure to promptly manage these complications can be fatal. A 1-month-old, 0.29 kg female fennec fox suffered a traumatic bite wound to its head from a skunk. Panalai Veterinary Hospital received a referral for the fennec fox, which showed signs of lethargy, ataxia, and left circling. The heart rate, respiratory rate, capillary refill time (CRT), and rectal temperature were within normal range. Diagnostic imaging, including a computed tomography (CT) scan, revealed collapse of the frontal and parietal bones, invading the left parietal-temporal lobe of the brain, and a fracture of the vertical ramus of the left mandible. Surgical interventions were performed with frontal and parietal bone decompression, as well as suturing the fractured skull using a tapered needle and a 4-0 polydioxanone suture in a simple interrupted pattern, without the use of skull mesh. Postoperative care included intensive monitoring, hyperbaric oxygen therapy, and acupuncture to promote brain healing, wound recovery, and neurological improvement. The fox was administered amoxicillin-clavulanic acid, followed by a switch to cefovecin sodium for infection control; pregabalin for neuropathic pain; meloxicam for inflammation management; vitamin B complex and Aktivait dog® for nerve function support; and dimenhydrinate to alleviate vestibular signs. The wound, appetite, ataxia, and left circling were gradually improving. The fox fully recovered within two months and returned to a normal daily life, although it continued to exhibit mild circling before eating. This case highlights the importance of prompt and comprehensive treatment for skull fractures in fragile species. The successful application of straightforward surgical techniques demonstrates their practicality and adaptability for managing complex cranial injuries in small animals. These methods could serve as a valuable reference for addressing similar challenges in other small exotic mammals with delicate skull structures.

Keywords: CT scan, Skull, Suturing, Treatment, Surgery

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การประยุกต์ใช้ไหมเย็บในการเชื่อมกะโหลก: เทคนิคใหม่สำหรับการผ่าตัดกะโหลกสุนัขจิ้งจอกเฟนเนก

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บทคัดย่อ

กะโหลกศีรษะแตกในสุนัขจิ้งจอกเฟนเนก (*Vulpes zerda*) นับเป็นปัญหารุนแรง ที่ควรได้รับการรักษา ให้ทันท่วงที เนื่องจากโครงสร้างกะโหลกศีรษะของสัตว์ชนิดนี้มีความเปราะบาง หากกะโหลกยุบตัวลงจะก่อให้เกิด ความเสียหายและการบาดเจ็บของสมอง รวมไปถึงเลือดออกในกะโหลกศีรษะ และทำให้เกิดความบกพร่องทาง ระบบประสาทหากไม่ได้รับการรักษาอย่างทันท่วงทีอาจส่งผลให้ถึงแก่ชีวิตได้ สุนัขจิ้งจอกเฟนเนกเพศเมียอายุ 1 เดือน น้ำหนัก 0.29 กิโลกรัม ได้รับบาดเจ็บที่ศีรษะจากการถูกกัดจากสกังก์อย่างรุนแรง ถูกส่งมาที่โรงพยาบาลสัตว์พนาลัย โดยสุนัขแสดง อาการเซื่องซึม เดินเซ และหมุนซ้ายเป็นวง อัตราการเต้นของหัวใจ อัตราการหายใจ การเติมเลือดฝอย และอุณหภูมิทางทวารหนักอยู่ในเกณฑ์ปกติ การตรวจวินิจฉัยด้วยเอกซเรย์คอมพิวเตอร์ (CT-scan) พบว่ากระดูกส่วนหน้าผาก (Frontal bone) และกระดูกขม่อม (Parietal bone) ยุบตัวเข้าไปในสมองบริเวณกลีบขม่อมซ้าย รวมถึงพบกิ่งตั้งของกระดูกขากรรไกรหัก (Vertical ramus of the mandible) หลังจากการวินิจฉัยสุนัขจิ้งจอกเฟนเนกจึง เข้ารับการผ่าตัดโดยยกกระดูกส่วนที่แตกแล้วกด เนื้อสมองออก เพื่อลดแรงที่กระทำต่อเนื้อสมองที่บริเวณกระดูกหน้าผากและขม่อม หลังจากนั้นจึงทำการเย็บกะโหลกศีรษะที่แตกด้วยเข็มเย็บปลายเรียวและไหมเย็บชนิด 4-0 โพลีไดออกซาโนนในลักษณะการเย็บแบบธรรมดาปมเดี่ยว โดยไม่ใช้ตาข่ายกะโหลกศีรษะเทียม การดูแลหลังผ่าตัดประกอบด้วยการติดตามอาการเรื่องระบบประสาท บาดแผล การกินอาหาร และสัญญาณชีพอื่นๆ โดยสุนัขจิ้งจอกเฟนเน็กได้รับยาอะม็อก-ซิซิลลิน-คลาวูลานิกแอซิด (Amoxicillin-clavulanic acid) และเปลี่ยนเป็น เซโฟเวซิน โซเดียม (Cefovecin sodium) เพื่อควบคุมการติดเชื้อ พรีกาบาลิน (Pregabalin) สำหรับบรรเทาอาการปวดจากเส้นประสาท เมล็อกซิแคม (Meloxicam) เพื่อลดการอักเสบ วิตามินบีคอมเพล็กซ์ (Vitamin B complex) และ Aktivait Dog® เพื่อส่งเสริมการทำงานของเส้นประสาท และ ไดเมนไฮดริเนต (Dimenhydrinate) เพื่อลดอาการเวียนศีรษะจากความผิดปกติของระบบทรงตัว รวมไปถึงการบำบัดด้วยเครื่องบำบัดด้วยออกซิเจนแรงดันสูง (Hyperbaric oxygen therapy) และการฝังเข็ม เพื่อฟื้นฟูสมอง รักษาบาดแผล และกระตุ้นการหายของระบบประสาท เมื่อเวลาผ่านไปอาการทางระบบ ประสาทและแผล ดีขึ้นตามลำดับ และสุนัขจิ้งจอกเฟนเนกสามารถฟื้นตัวเต็มที่ภายในสองเดือน กลับมาใช้ชีวิตประจำวันได้ตามปกติ แต่ยังพบอาการทางระบบประสาทโดยมีการเดินเป็นวงกลมก่อนกินอาหาร ในรายงานกรณีศึกษานี้ได้ให้ความ สำคัญของการรักษาอย่างทันท่วงทีและเทคนิคการผ่าตัดที่เรียบง่าย แต่ให้ประสิทธิภาพสูงซึ่งเหมาะกับลักษณะ ของกะโหลก ที่บางในสัตว์ที่กะโหลกศีรษะบาง และสามารถปรับใช้เพื่อจัดการกับอาการบาดเจ็บที่ซับซ้อน ในสัตว์เลี้ยงลูกด้วยนมขนาดเล็กชนิดอื่นที่มีกะโหลกศีรษะที่บอบบางเช่นเดียวกัน

คำสำคัญ : การตรวจวินิจฉัยด้วยเอกซเรย์คอมพิวเตอร์ กะโหลก การเย็บ การรักษา การผ่าตัด

Introduction

The fennec fox (*Vulpes zerda*), the smallest member of the family Canidae, possesses a delicate and lightweight skull adapted for its desert habitat (Merritt 2010). The unique anatomy of the fennec fox presents several challenges in the treatment of skull fractures. The fennec fox's skull is characterised by its delicate and thin cranial bones (Kingdon 2013), which are more susceptible to fractures from even minor trauma and can suffer severe consequences from head injuries. Additionally, the small size of the fennec fox requires precise and delicate handling during both diagnostic imaging and surgical procedures.

Surgical intervention in human head trauma focuses on intracranial hemorrhage, midline shifts in computed tomography (CT) scan), and intracranial pressure (ICP) measurements, while it has traditionally been less common in veterinary cases due to the perceived rarity of significant hemorrhage. However, evidence suggests dogs and cats may benefit from surgery for manageable hemorrhages. With greater access to CT imaging, procedures like addressing skull fractures, removing contaminated fragments, and reducing ICP through craniotomy may gain importance in veterinary practice (Dewey and Da Costa 2015). Skull fractures and traumatic brain injury in dogs can range from mild to fatal. Understanding brain and meninges anatomy is crucial while working with the skull, especially the calvarium, dorsal section, paired frontal, and parietal bones. Cranial fractures can compress and harm the meninges' major venous sinuses and cerebral cortical functioning. Surgical techniques differ by skull fracture type and part.

In dogs, skull fractures are managed using a variety of advanced stabilization techniques. Titanium locking plates are commonly utilized due to their ability to provide strong and durable support for complex fractures, particularly in cases involving severe comminution (Illukka and Boudrieau 2014). Bioabsorbable implants offer an innovative alternative, reducing the need for secondary surgeries to remove implants and minimizing long-term foreign body reactions (Salmina et al., 2023). The titanium plates manufactured using 3D printing technology were used to close the skull in dogs. These titanium plates were custom designed for each patient to ensure a precise fit for the cranial structure after craniectomy to remove tumors; in addition, titanium mesh can also be used effectively in similar cases (Dierckx De Casterlé et al., 2017; James et al., 2020). If multiple linear fractures depress the brain, causing depression fractures, and the brain was depressed, surgery for calvarium elevation was required (Dewey and Da Costa 2015). Calvarium depressions should be lifted from underneath. Normally, elevating the lesion requires multiple large burr holes. Fragment edges can lacerate meninges, venous sinuses, and cerebral cortex. Surgeons should remove highly comminuted fracture pieces. Calvarial abnormalities might result from large comminuted areas. The temporalis muscle protects most animals, but some need rib or iliac crest onlay grafts (Nunamaker 1985).

Despite these advancements in canine skull fracture management, there is a significant gap in research regarding small mammals. Their unique anatomical and physiological characteristics present considerable challenges, as most existing surgical techniques and fixation devices are incompatible with their fragile skulls. In cases where rigid fixation is impractical, the simple interrupted suture method, widely used in soft tissue applications, offers controlled tension distribution, minimal disruption to vascular supply and maintains independent stabilization at each suture point compared to simple continuous suture method (Jarasviriyagul and Chanasriyotin 2023) maybe useful for this challenge. The suture method allows for precise adjustment at each suture point, reducing the risk of excessive compression or ischemia while ensuring adequate fixation. Additionally, its adaptability and minimal foreign body reaction make it a viable alternative when rigid fixation is impractical. Given the fragile skull of the fennec fox, this technique was applied as a stabilization method to assess its effectiveness in cranioplasty for such delicate structures.

Polydioxanone (PDS) suture is a monofilament, synthetic absorbable suture widely used in orthopedic and soft tissue surgeries. Its high tensile strength, prolonged absorption time; the maximum retention of original tensile strength after 28 days is 50%, and minimal tissue reactivity make it particularly useful in procedures requiring extended wound support. Unlike multifilament sutures, which may harbor bacteria and increase infection risk, PDS provides a smooth surface that reduces tissue drag and minimizes inflammation. Its degradation occurs through hydrolysis, ensuring a predictable absorption timeline without significant foreign body reactions (AlSarhan 2019; Anderson et al., 2020). Due to these properties, PDS was selected in this case to provide stable temporary cranial support, aligning with the skull healing timeline while minimizing the risk of excessive compression, inflammation, or foreign body reaction.

Case Description

A 1-month-old 0.29 kg female fennec fox was referred to Panalai Veterinary Hospital to perform the computerized tomography (CT-scan). The fennec fox was bitten by a skunk on his head five days ago before being presented at Panalai Veterinary Hospital. The previous physical examinations at another veterinary hospital were stupor, lateral recumbency, swollen head, and edema. After initial stabilization included intravenous fluid normal saline rate 2 ml/hr for resuscitation, mannitol 1 g/kg, slow intravenous (IV), q6h, transamin 10 mg/kg, IV, q8h, buprenorphine 0.02 mg/kg, intramuscular, q8h, amoxicillin-clavulanic acid 25 mg/kg, subcutaneous (SC), q24h, and meloxicam 0.3 mg/kg, SC, q24h. After treatment at previous veterinary hospital for 6 days, fennec fox's mental status and swollen head were gradually improved. Although she was responsive, she still had left circling and loss of balance. When the fennec fox presented at Panalai Veterinary Hospital, the further investigations were approached immediately. There was a puncture wound on the fennec fox's head, and the left side of the head appeared depressed compared to the right. Her vital signs were stable, with a heart rate of 120 bpm, respiratory rate of 30 bpm, rectal temperature of 100°F, and a capillary refill time of 2 seconds. She underwent a neurological re-evaluation, and the findings were summarized in the Tables 1-5. The pain score of the fennec fox was estimated to be grade 2-3/4. However, accurate pain assessment was challenging due to concurrent neurological impairment, which may have blunted the typical behavioral responses to pain. Hematological analysis showed mild anemia, suspected to result from blood loss due to the bite wound. As automated complete blood count (CBC) analysis lacked species-specific reference values for fennec foxes, a blood smear examination was performed for differential blood count assessment. The smear revealed leukocytosis as a response to trauma and hypochromic normocytic anemia due to blood loss. The blood biochemistry revealed hypoalbuminemia, likely due to trauma-induced inflammation; hyperglycemia, attributed to a stress response; and low BUN and low creatinine, resulting from young age and reduced protein intake (Tables 6-8). The CT scan revealed a skull fracture measuring approximately 1.39 cm x 2.29 cm in the frontal and parietal bones, with some displaced fragments compressing the left parietal-temporal lobe of the brain. The skull thickness was measured at 1.12 mm, highlighting its fragility. Additionally, a fracture of the vertical ramus of the left mandible was observed (Figures 1-5).

Table 1. Neurological examination of this patient: observation from Day 0 to Day 70.

Observation	Day 0	Day 7	Day 18	Day 28	Day 35	Day 63	Day 70
Mentation	Disorientation	Obtunded	BAR	BAR	BAR	BAR	BAR
Posture	Head turn left	Head turn left	Normal	Normal	Normal	Normal	Normal
Gait	Left circling	Left circling	Sometimes left circling	Sometimes left circling	Sometimes left circling	Sometimes left circling	Sometimes left circling

Day 0 is the 1st visit at Panalai Veterinary Hospital and before surgery.

BAR; Bright. alert and responsive.

Table 2. Neurological examination of this patient: postural reaction results from Day 0 to Day 70.

Postural reaction	Day 0	Day 7	Day 18	Day 28	Day 35	Day 63	Day 70
Proprioception							
Lt FL	+1	+2	+2	+2	+2	+2	+2
Rt FL	+1	+2	+2	+2	+2	+2	+2
Lt HL	+1	+2	+2	+2	+2	+2	+2
Rt HL	+1	+2	+2	+2	+2	+2	+2
Hopping							
Lt FL	+1	+2	+2	+2	+2	+2	+2
Rt FL	+1	+2	+2	+2	+2	+2	+2
Lt HL	+1	+2	+2	+2	+2	+2	+2
Rt HL	+1	+2	+2	+2	+2	+2	+2
Wheel barrowing							
Lt FL	+1	+2	+2	+2	+2	+2	+2
Rt FL	+1	+2	+2	+2	+2	+2	+2
Ext.post.thrust							
Lt HL	+1	+2	+2	+2	+2	+2	+2
Rt HL	+1	+2	+2	+2	+2	+2	+2
Visual placing							
Lt FL	+1	+2	+2	+2	+2	+2	+2
Rt FL	+1	+2	+2	+2	+2	+2	+2
Tactile placing							
Lt FL	+1	+2	+2	+2	+2	+2	+2
Rt FL	+1	+2	+2	+2	+2	+2	+2
Lt FL	+1	+2	+2	+2	+2	+2	+2
Rt FL	+1	+2	+2	+2	+2	+2	+2

Day 0 is the 1st visit at Panalai Veterinary Hospital and before surgery.

Lt FL: Left forelimb, Rt FL: Right forelimb, Lt HL: Left hindlimb, Rt HL: Right hindlimb, Ext.post.thrust: Extensor postural thrust. Result: +1 = Decrease reflex, +2 = Normal reflex.

Table 3. Neurological examination of this patient: spinal reflex results from Day 0 to Day 70.

Spinal reflex	Day 0	Day 7	Day 18	Day 28	Day 35	Day 63	Day 70
Flexor reflex							
Lt FL	+2	+2	+2	+2	+2	+2	+2
Rt FL	+2	+2	+2	+2	+2	+2	+2
Lt FL	+2	+2	+2	+2	+2	+2	+2
Rt FL	+2	+2	+2	+2	+2	+2	+2
Ext.carp.radialis							
Lt FL	+2	+2	+2	+2	+2	+2	+2
Rt FL	+2	+2	+2	+2	+2	+2	+2
Patella reflex							
Lt FL	+2	+2	+2	+2	+2	+2	+2
Rt FL	+2	+2	+2	+2	+2	+2	+2
Perineal reflex							
Lt	+ve	+ve	+ve	+ve	+ve	+ve	+ve
Rt	+ve	+ve	+ve	+ve	+ve	+ve	+ve
Cross extensor							
Lt	-ve	-ve	-ve	-ve	-ve	-ve	-ve
Rt	-ve	-ve	-ve	-ve	-ve	-ve	-ve
Panniculus							
Lt	Present at T3-L3						
Rt	Present at T3-L3						

Day 0 is the 1st visit at Panalai Veterinary Hospital and before surgery.

Lt FL: Left forelimb, Rt FL: Right forelimb, Lt HL: Left hindlimb, Rt HL: Right hindlimb, Ext.post.thrust: Extensor postural thrust. Result: +2 = Normal reflex, +ve: Positive result, -ve: Negative result. T3 = 3rd thoracic spine, L3 = 3rd lumbar spine.

Table 4. Neurological examination of this patient: cranial nerve reflex results from Day 0 to Day 70.

Cranial nerve reflex	Day 0		Day 7		Day 18		Day 28		Day 35		Day 63		Day 70	
	Lt	Rt	Lt	Rt	Lt	Rt	Lt	Rt	Lt	Rt	Lt	Rt	Lt	Rt
Smell (l)	+ve		+ve		+ve		+ve		+ve		+ve		+ve	
Menace (ll/Vll)	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2
Pupil size (ll/lll/Sympathetic)	Symmetry		Symmetry		Symmetry		Symmetry		Symmetry		Symmetry		Symmetry	
Direct pupillary light reflex (ll/lll)	Normal		Normal		Normal		Normal		Normal		Normal		Normal	
Indirect pupillary light reflex (ll/lll)	Normal		Normal		Normal		Normal		Normal		Normal		Normal	
Oculocephalic reflex (lll/lV/Vl/Vlll)	Normal		Normal		Normal		Normal		Normal		Normal		Normal	
Nystagmus/Strabismus (lll/lV/Vl/Vlll)	Normal		Normal		Normal		Normal		Normal		Normal		Normal	
Cotton ball (ll/Vll)	-ve	-ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
Dazzle (ll/Vll)	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
Palpebral (V/Vll)	+1	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2
Corneal (V/Vl/Vll)	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2
Nostril sensation (V)	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2
Ear sensation (Vll)	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2
Trigeminofacial reflex (V/Vll)	+1	+2	+1	+2	+1	+2	+2	+2	+2	+2	+2	+2	+2	+2
Gag reflex (lX/X)	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
Tongue (Xll)	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
Trapezius (Xl)	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve

Day 0 is the 1st visit at Panalai Veterinary Hospital and before surgery. Lt: Left, Rt: Right. Result: +1 = Decrease reflex, +2 = Normal reflex, +ve: Positive result, -ve: Negative result.

Table 5. Neurological examination of this patient: sensation result from Day 0 to Day 70.

Test	Result
Superficial pain at forelimb	Positive
Superficial pain at hindlimb	Positive
Deep pain at forelimb	Positive
Deep pain at hindlimb	Positive
Hyperesthesia	Negative
Self mutilation	Negative

Table 6. Complete blood count of the patient on Day 0.

Parameters	Results	Reference range*	Unit
White blood cell	10.20	5.0-14.1	10^9/L
% Lymphocyte	15.31	8-21	%
% Monocyte	3.12	2-10	%
% Neutrophil	79.22	58-85	%
% Eosinophil	1.85	0-9	%
% Basophil	0.44	0-1	%
Red blood cell	5.05	4.95-7.87	10^{12}/L
Hemoglobin	8.0	11.9-18.9	g/dL
Hematocrit	28.3	35-57	%
Mean corpuscular volume	56.2	66-77	fL
Mean corpuscular hemoglobin	15.8	21.0-26.2	pg
Mean corpuscular hemoglobin concentration	28.2	32.0-36.3	g/dL
Platelet	733		10^9/L

*Reference ranges in dog used at the Laboratory of Panalai Veterinary Hospital, Thailand.

*Reference ranges of automated complete blood count analyzed by URIT 5160 5-part diff hematology analyzer.

Day 0 is the 1st visit at Panalai Veterinary Hospital and before surgery

Table 7. CompleteDifferential blood count from blood smear on Day 0.

Parameters	Results	Reference range*	Unit
White blood cell estimates	10.0	5.96±2.33	10^9/L
Platelet counts	584.0+giant plt	471±222	10^9/L
% Band neutrophil	0		%
% Segment neutrophil	7.4	2.86±1.57	%
% Lymphocyte	2.3	2.40±1.43	%
% Monocyte	0.3	0.26±0.18	%
% Eosiophil	0		%
% Basophil	0		%
Red blood cell morphology		Hypochromic normocytic anemia	

*Reference ranges of blood biochemistry of fennec fox from International Species Information System (ISIS, March 2002). Day 0 is the 1st visit at Panalai Veterinary Hospital and before surgery

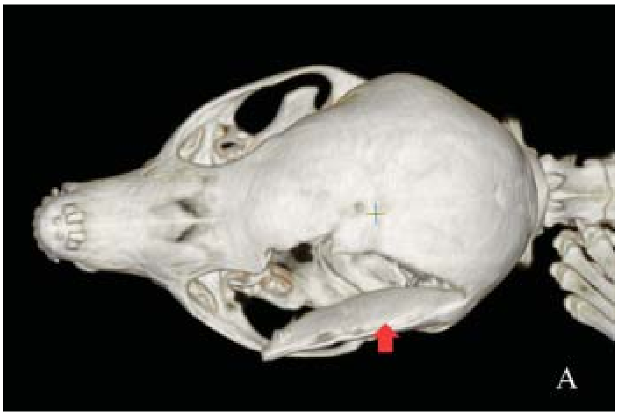
Table 8. Blood biochemistry of the patient on Day 0.

Parameters	Results	Reference range1*	Reference range2*	Unit
Albumin	1.8	2.5-4.4	3.0±0.5	g/dL
Alkaline phosphatase	81	20-150	54±55	U/L
Alanine transaminase	120	10-118	88±63	U/L
Amylase	134	200-1200	54.95±21.83	U/L
Total bilirubin	0.3	0.1-0.6	0.3±0.3	mg/dL
Blood urea nitrogen	16	7-25	78.54±28.56	mg/dL
Calcium	10.7	8.6-11.8		mg/dL
Phosphorus	8.0	2.9-6.6		mg/dL
Creatinine	0.2	0.3-1.4	0.7±0.18	mg/dL
Glucose	135	60-110	66.6±19.98	mg/dL
Sodium ion	155	138-160		mmol/L
Potassium ion	6.0	3.7-5.8		mmol/L
Total protein	4.7	5.4-8.2	5.6±6	g/dL
Globulin	2.9	2.3-5.2	2.5±0.6	g/dL

1*Reference ranges in dog used at the Laboratory of Panalai Veterinary Hospital, Thailand.

1*Reference ranges of blood biochemistry analyzed by VetScan VS2.

2*Reference ranges of blood biochemistry of fennec fox from International Species Information System (ISIS, March 2002). Day 0 is the 1st visit at Panalai Veterinary Hospital and before surgery



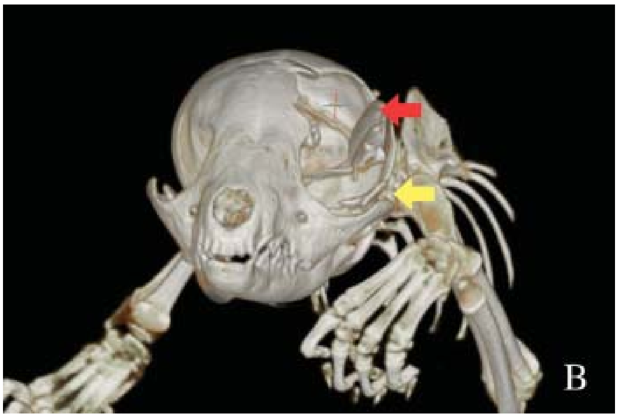


Figure 1. 3D volume rendering, dorsal view of skull, shows a fracture of frontal and parietal bones of the skull (A, B; red arrow) and the vertical ramus of the left mandible (B; yellow arrow).

Figure 2. The fracture, involving the frontal and parietal bones, measured approximately 1.39 cm x 2.29 cm.

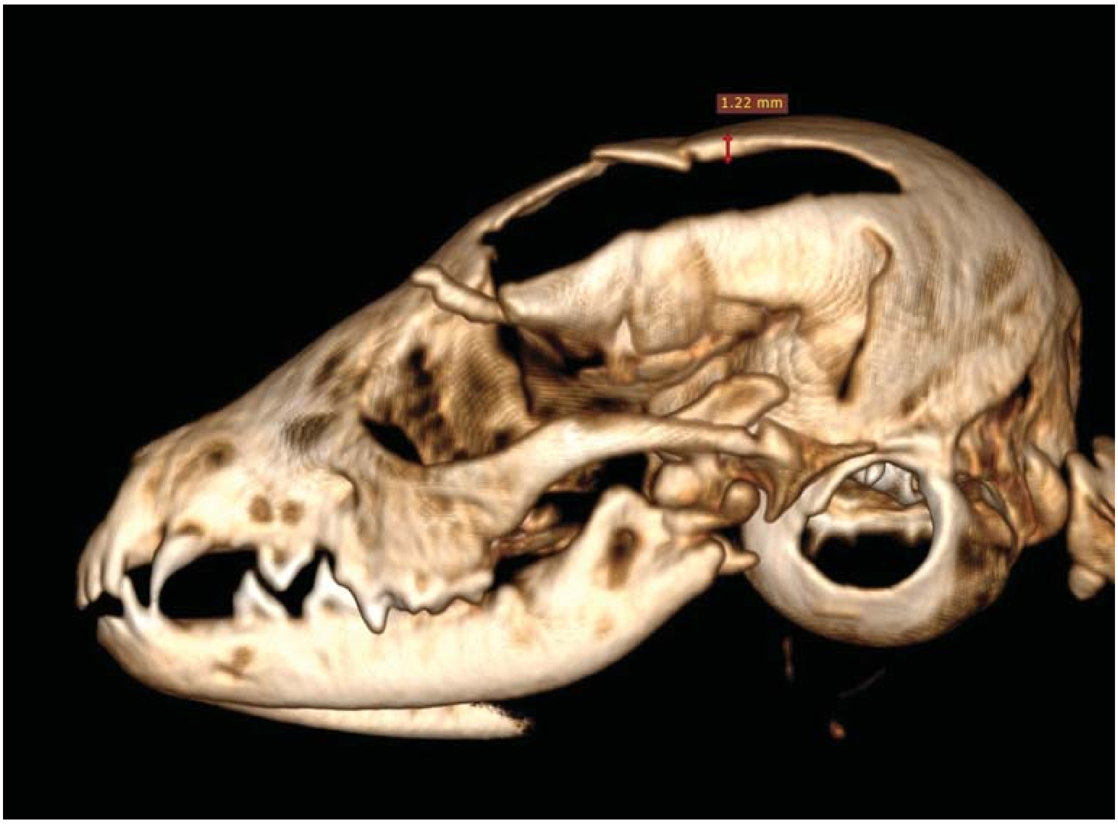


Figure 3. The skull thickness of this fennec fox measured approximately 1.12 mm.

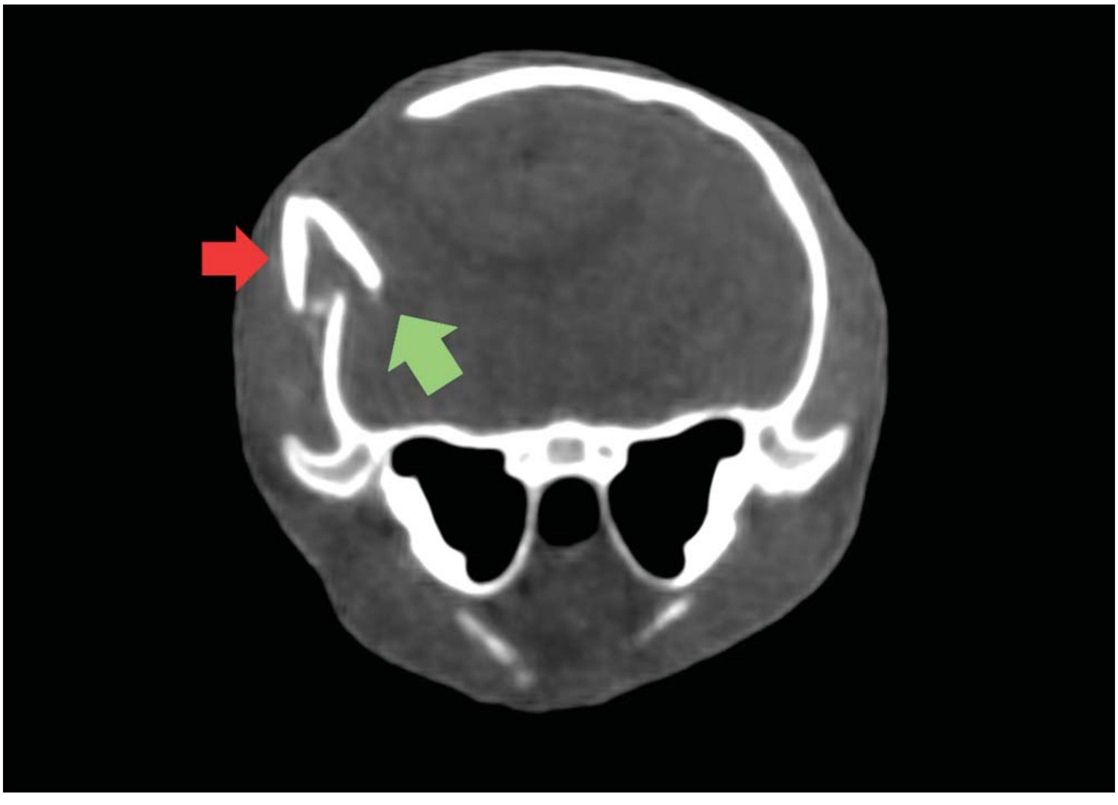


Figure 4. Soft tissue window CT: The transverse image shows no dilation of lateral ventricle, a fragmented piece of skull folded back (red arrow), and penetrated the left lobe of brain (green arrow).

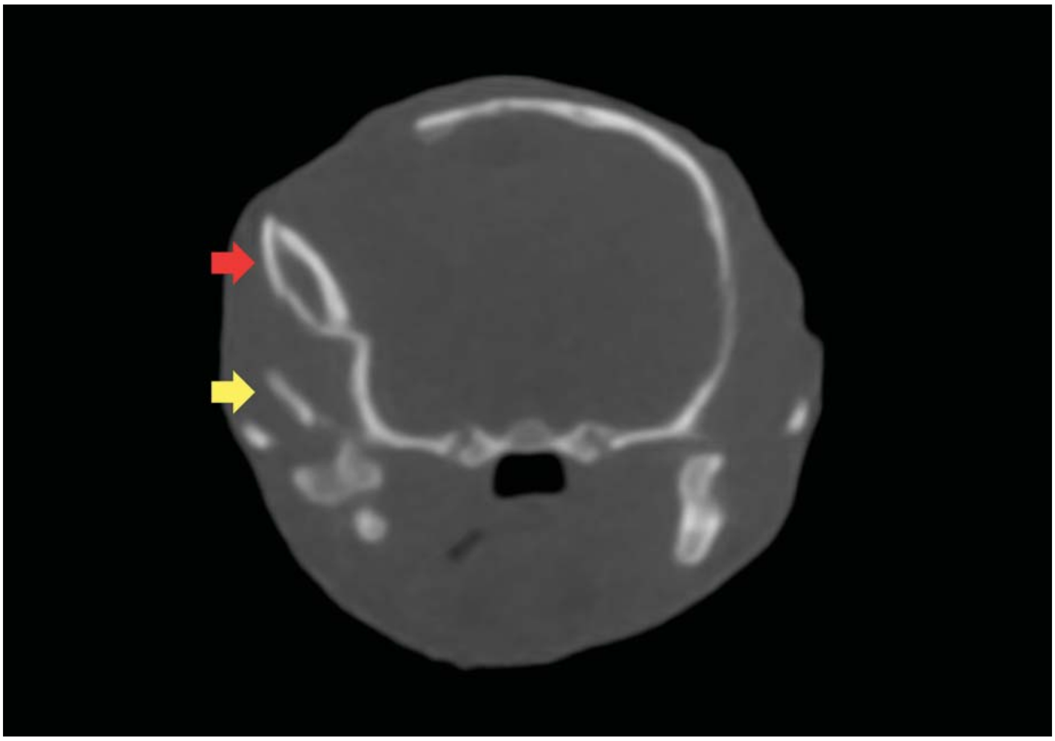


Figure 5. Bone window CT: The transverse image shows a fracture of the frontal and parietal bones of the skull (red arrow) and a fracture of the vertical ramus of the left mandible (yellow arrow).

Based on the compressed frontal-parietal lobe, surgical intervention was performed to elevate the fractured bone. The fennec fox was assessed as ASA (American Society of Anesthesiologists) score III, considering multiple factors including its young age, controlled seizure activity, responsiveness. The fennec fox was anesthetized using a combination of intramuscularly administered drugs for premedication and induction, consisting of medetomidine (Sedator®, Dechra, United Kingdom) at a dosage of 0.02 mg/kg, zolazepam-tiletamine (Zoletil®, VALDEPHARM, France) at 3.5 mg/kg, and butorphanol (Butodol®, NEON LABORATORIES LIMITED, India) at 0.1 mg/kg. Following anesthesia premedication and induction, an intravenous catheter was placed, and the animal was intubated using a 2.0-size endotracheal tube. Anesthesia was maintained with sevoflurane inhalation. The patient was positioned in sternal recumbency, and routine skin preparation was performed (Figure 6). The surgical procedure commenced with the decompression of the affected area, guided by palpation of the dented frontal bone. An elliptical incision on the skin affected area was made along the fracture line of the skull to expose the fractured skull, and careful blunt dissection was performed around the bone fragment and associated blood clots. A Lone Star® retractor system and elastic stay (CooperSurgical, USA) was employed to provide better visualization and access to the surgical site (Figure 7). The compressed bone fragment was gently elevated and repositioned (Figure 8), then sutured to the edge of the parietal bone using a tapered needle and polydioxanone, absorbable suture (MonoPlus® 4-0, B Braun, Spain), for 6 stitches with simple interrupted pattern suture (Figure 9). The subcutaneous tissue was subsequently closed with polydioxanone, absorbable suture (MonoPlus® 5-0, B Braun, Spain) with subcuticular pattern suture. The bacterial culture was performed around the wound. And the skin incision was sealed using tissue adhesive (Figure 10). The bacterial culture showed no bacterial growth at days 3 and 7.

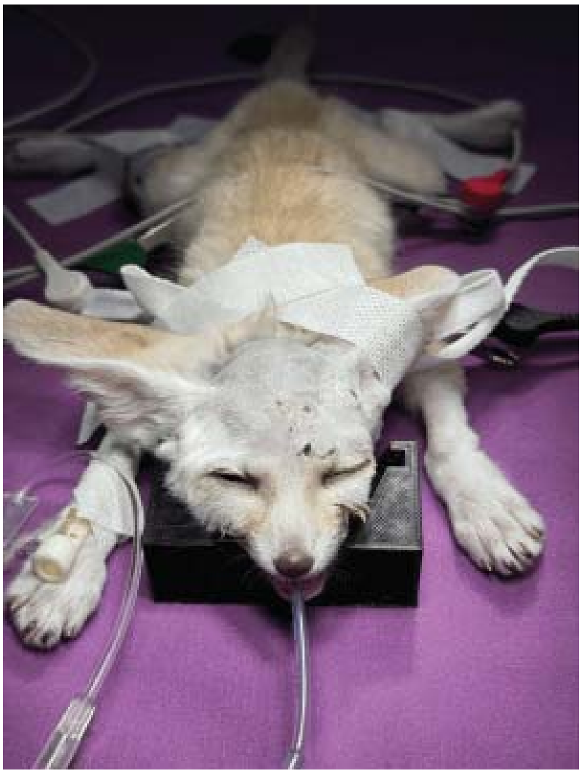


Figure 6. The patient was positioned in sternal recumbency, with preparation and monitoring prior to the operation.

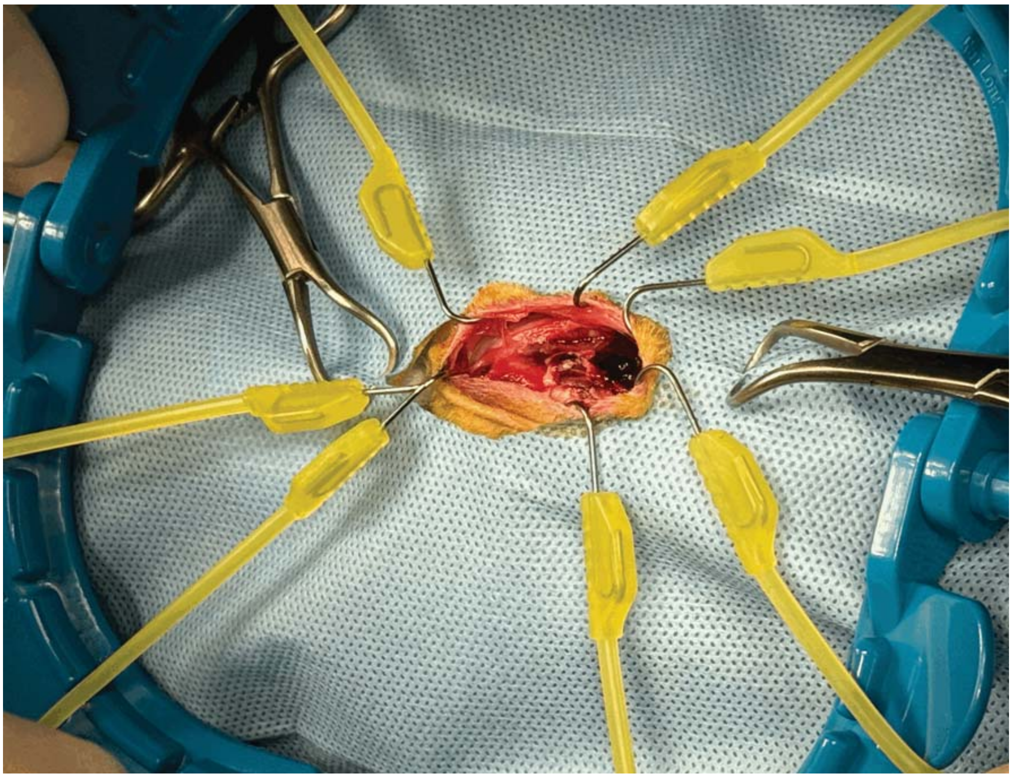
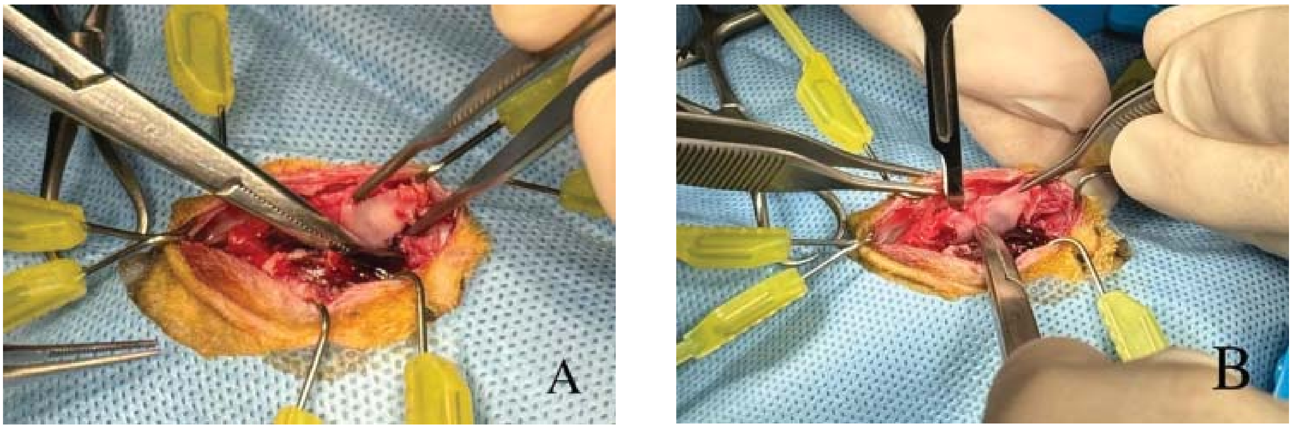


Figure 7. A Lone Star® retractor system and elastic stay were employed to provide better visualization and access to the surgical site.



Figures 8. The compressed bone fragment was gently elevated and repositioned (A, B).

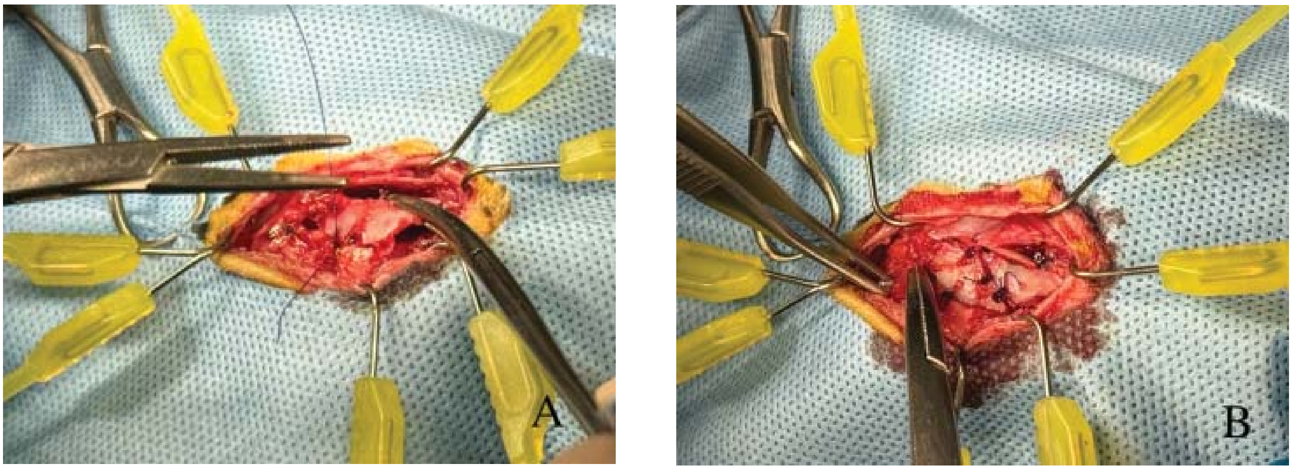


Figure 9. The fractured skull fragment was sutured to the edge of the parietal bone using a tapered needle and 4-0 polydioxanone suture material (A), then sutured along the fractured line (B).

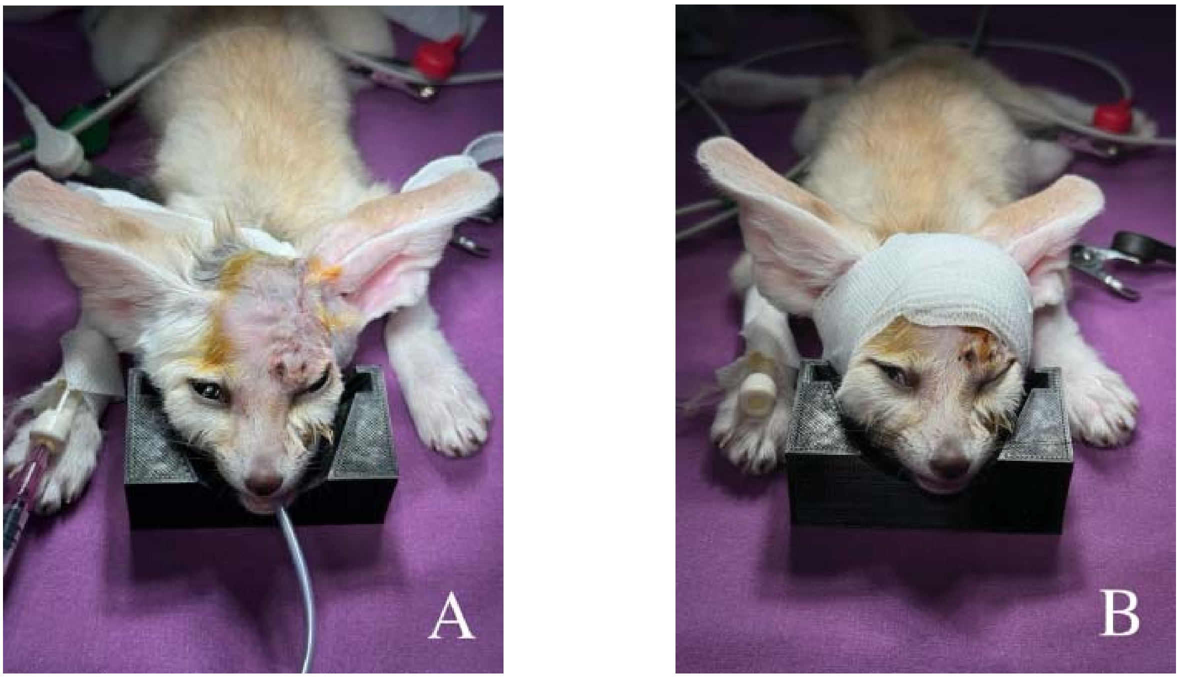


Figure 10. The patient skin incision was sealed using tissue adhesive (A) and then bandaged (B).

After the surgery, the fennec fox smoothly recovered. The medicines in post-postoperative care were Amoxicillin-clavulanic acid 25 mg/kg (Cavumox®, Siam Bheasach Co., Ltd., Thailand), intravenous twice a day for 2 days, then Amoxicillin-clavulanic acid 25 mg/kg (Synulox™, Haupt Pharma S.r.l.-Latina, Italy) subcutaneous, once a day for 8 days. However, as the fennec fox showed good clinical improvement but began resisting manual restraint for oral medication administration, the antibiotic was switched to cefovecin sodium (Convenia®, Zoetis Inc, USA) at 8 mg/kg, SC, once. This change aimed to reduce stress and handling time, minimizing the risk of increased intracranial pressure that these problems could affect the healing brain injury. Additional medications included pregabalin 4 mg/kg (Toprelin®, Buymed Siam Co., Ltd., Thailand) peroral twice a day, vitamin B complex (B1 100mg, B6 5mg, B12 50μg) (Bee Three®, Medicine Products Co., LTD., Thailand) 5 tab combined with co-dergocrine mesylate (1 mg) (Hydrine®, T.O.Chemicals (1979) LTD., Thaliand) 1 tab in multivitamin 10 ml give 0.3 ml twice a day, Aktivait dog® (VetPlus Ltd, United Kingdom) 0.45 ml peroral once a day, dimenhydrinate (H.K.Pharmaceutical Co., LTD., Thailand) 8 mg/kg per oral twice a day for 11 days. Additional post-operative care included providing sufficient nutrition with wet food, attended the hyperbaric oxygen therapy for 2 hours twice a day, and restricted area. Her mental status and neurological signs were gradually improving each day. She came back to bright alert and responsive on day 5 post-operative and expressed normal behavior like digging. At first, she was circling in a small circle, her circle was bigger consecutively (Tables 1-5). Her wound was good and no exudate in day 7 post-operative. Finally, the fox was discharged on day 11 post-operative, her clinical signs were circling in a big area. The 1 week recheck after discharging, she walked normally but circled in the big area. Then, she was performed the dry needle acupuncture once a week at GV-17, GV-20, GB-20, An-shen, Long-hui (Figure 11). After 4 sessions of acupuncture, the fennec fox did not continue an acupuncture due to the family condition. Two months later, the owner mentioned that she can live happily like a normal fennec fox though she rarely a little circling sign before eating.

Figure 11. The fennec fox was restrained to perform the acupuncture.

Discussion

The application of CT-scan in evaluating the skull fracture of this fennec fox underscores its versatility in veterinary medicine, extending beyond common species like dogs and cats. CT-scan imaging is essential for the precise identification of the extent and complexity of traumatic skull fractures in companion animals, which in turn informs treatment decisions (Amengual-Batle et al., 2020). This case illustrates that CT-scan can be effectively applied to exotic species, such as the fennec fox, where anatomical distinctions require precise preoperative imaging to plan surgical interventions. CT-scan provides veterinarians with the ability to customize surgical techniques, such as elevating and suturing cranial bones, to the patient's specific requirements by providing comprehensive visualisation of fracture configurations. Moreover, the timely decision to perform surgery to relieve brain compression significantly increases the chances of survival compared to relying on medical treatment alone.

Craniotomy is a routine procedure in human medicine, but its application in veterinary practice remains limited, particularly in small mammals like the fennec fox, where no prior case reports exist. The severity of this case, involving frontal and parietal bone fractures with significant depression compressing the brain, along with an infected wound from a skunk bite, made surgical intervention both challenging and necessary to improve survival. Given the lack of established guidelines for exotic species, the decision to proceed was based on human neurosurgical criteria for depressed cranial fractures, which recommend surgery in cases of severe skull depression, dural penetration, significant hematoma, frontal sinus involvement, infection, or pneumocephalus (Bullock et al., 2006). In this case, the fennec fox met multiple high-risk criteria, neurological signs, infection risk, and significant skull depression, surgical intervention was the most viable option to prevent worsening brain injury, secondary complications, and poor long-term prognosis.

The potential of minimalist approaches in species with delicate cranial structures is demonstrated by the effective use of decompression and suturing techniques in the repair of a fennec fox's fragile cranium. Unlike dogs and humans, the fennec fox's skull is exceptionally thin and lightweight, an evolutionary adaptation to its desert environment. Given the lack of species-specific fixation techniques for exotic mammals, a suture-based approach was chosen for stabilization. PDS suture was selected due to its high tensile strength, prolonged absorption period, and minimal tissue reactivity, making it well-suited for stabilizing delicate cranial fractures. Unlike rapidly degrading sutures, PDS maintains adequate tensile support for up to 6 weeks before gradual absorption, which aligns with the early phases of skull healing, providing structural support while minimizing foreign body reactions (Wolfs et al., 2022). In contrast, rigid fixation devices, such as titanium plates, bioresorbable implants, or mesh, are designed for larger species like dogs and humans, making them disproportionately large and heavy for a fennec fox's delicate skull. Their weight and stiffness could impose mechanical stress, increasing the risk of pressure-related complications and impaired healing (Dierckx De Casterlé et al., 2017; James et al., 2020; Salmina et al., 2023). Additionally, such implants require extensive soft tissue dissection and may not conform well to the thin, curved cranial anatomy of small exotic species. By using PDS in a simple interrupted suture pattern, the fractured cranial segments were secured with minimal additional weight and preserved vascular integrity, promoting natural osteosynthesis.

The medical management of skull fractures and traumatic brain injury (TBI) in fennec foxes remains largely uncharted due to the lack of species-specific guidelines. Given the absence of prior case reports, treatment in this case was adapted from established protocols in dog and human (Bullock et al., 2006; Dewey and Da Costa 2015). The primary focus of medical stabilization was intracranial pressure (ICP) management, utilizing osmotic therapy to mitigate cerebral edema, along with fluid therapy to maintain adequate cerebral perfusion. Pain control was prioritized using opioid analgesia, which is critical in TBI cases to prevent excessive sympathetic stimulation. Antibiotic therapy was administered prophylactically to prevent post-traumatic infections, particularly given the open wound and skull compression. In addition to standard TBI management, neuroprotective strategies were considered. These interventions were chosen based on their proven efficacy in canine patients with similar injuries.

In the postoperative treatment, there are articles demonstrating the safety and tolerability of hyperbaric oxygen therapy (HBOT) in dogs and cats with various conditions, including head trauma, showing its capability to enhance oxygen delivery, reduce inflammation, and improve healing (Birnie et al., 2018). Similarly, the acupuncture's efficacy in stimulating nerve regeneration and improving neurological outcomes in dogs with severe head injuries that were unresponsive to conventional treatments (Oraveerakul 2003). These therapies were effective in the recovery of neurological functions, including balance and mobility, in the case of a fennec fox, as they were in canine species. The treatment was enhanced by acupuncture, which promoted circulation and alleviated pain, while HBOT reduced inflammation and facilitated healing in the fox's delicate cranial tissues. These findings are consistent with the known advantages of these modalities in small companion animals, underscoring their adaptability and potential as essential components of a multimodal approach to head trauma rehabilitation.

This study presents several limitations due to the unique challenges of treating an unusual pet species. The lack of species-specific medical data for fennec foxes necessitated adapting treatment protocols, drug dosages, anesthetic management, and surgical approaches from studies in dogs. While this method provided a practical reference, physiological and anatomical differences between species may affect the direct applicability of these treatments. Additionally, assessing brain damage in skull fractures would ideally require MRI, which offers greater soft tissue contrast and more detailed visualization of intracranial structures. However, MRI was not feasible in this case due to limited equipment availability and the prolonged anesthesia time required, which could increase surgical risks in such a small exotic species. Although CT imaging provided essential structural details, it lacks the ability to fully assess soft tissue damage, hemorrhage, or subtle brain injuries compared to MRI.

Conclusion

This case emphasises the effective management of a skull fracture in a fennec fox by utilising a multidisciplinary approach that was specifically designed for the animal's unique anatomy. The precise decompression and suture-based stabilisation of the vulnerable cranial structure were made possible by CT imaging, which provided critical insights for surgical planning. Wound healing and neurological recovery were significantly enhanced by postoperative care, which encompassed hyperbaric oxygen therapy and acupuncture. The positive result shows the potential of integrating diagnostics, delicate surgical techniques, and comprehensive treatments to treat complex cranial injuries in fennec foxes. Notably, this is the first reported case of cranioplasty suturing in a fennec fox, paving the way for surgical decision-making in small exotic mammals to improve survival rates through timely and effective interventions.

Acknowledgments

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