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Animal bite wounds and their management in tropical Australia

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A B S T R A C T

Objective: To define the microbiologic characteristics of animal bites in tropical Australia and the appropriateness of current Australian antimicrobial guidelines for their management.
Methods: This retrospective audit examined hospitalizations in tropical Australia after an animal bite or animal-associated penetrating injury between 2013 and 2020. The primary outcome was a composite of death, intensive care unit admission, amputation, quaternary center transfer, or unplanned rehospitalization.
Results: A wide variety of animals were implicated, but snakes (734/1745, 42%), dogs (508/1745, 29%), and cats (153/1745, 9%) were the most common. Hospital presentation after 24 hours (odds ratio (OR) (95% confidence interval (CI)): 68.67 (42.10-112.01)) and a cat-related injury (OR (95% CI): 22.20 (11.18-44.08)) were independently associated with an increased risk of infection. A pathogen not covered by the relevant antimicrobial regimen recommended in Australian guidelines was identified in only 12/1745 (0.7%) cases. The primary outcome occurred in 107/1745 (6%) and was independently associated with tissue trauma (OR (95% CI): 9.29 (6.05-14.25), p<0.001), established deep infection at presentation (OR (95% CI): 2.95 (1.31-6.61), p=0.009) and hospital presentation after 24 hours (OR (95% CI): 1.77 (1.12-2.79), p=0.01).
Conclusions: A wide variety of animals bite humans in tropical Australia, but empiric antimicrobial regimens recommended in current national guidelines cover almost all the microbiologic isolates from the resulting wounds.

Introduction

Animal bites are responsible for approximately 1% of all emergency department presentations in developed counties, and it is estimated that half of the population will suffer a mammalian bite during their lifetime (Baddour and Harper, 2021). Infection commonly complicates these wounds, with the causative organisms either inoculated from the animal's mouth, the patient's skin, or the environment in which the bite occurred (Abrahamian and Goldstein, 2011). Injuries to the extremities, deep puncture wounds, proximity to prosthetic joints, crush injuries, immunocompromise, and delayed presentation increase infection risk (Jha et al., 2014, Tabaka et al., 2015).

Animal bites require wound care, and in many cases, antibiotics, surgery, and consideration of post-exposure prophylaxis (Aziz et al., 2015). However, the data that inform management strategies of animal bite wounds often come from temperate, metropolitan locations and may be less relevant in tropical settings where the animals responsible, and the environment in which they are encountered, is quite different. Animal bites occurring in the sea and freshwater are not uncommon and increase the likelihood of wound infections by water-borne organisms (Abrahamian and Goldstein, 2011). In tropical low- and middle-income countries, where access to sophisticated healthcare is frequently limited, delays in appropriate wound care may also be more common, further increasing the risk of infection.

In tropical Australia, humans are at risk of bites and penetrating injuries from domesticated and wild mammals, venomous and non-venomous snakes, crocodiles, and other marine animals (Smith et al., 2017). These animal encounters frequently occur in remote locations, often several hundreds of kilometers from

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healthcare, posing an additional challenge even for Australia's well-resourced healthcare system.

Australian guidelines currently recommend thorough cleaning, irrigation, debridement, elevation, and immobilization of animal bite wounds (Therapeutic Guidelines, 2021). Amoxicillin-clavulanate is recommended, either as presumptive therapy (before the infection is established in those at high risk of wound infection) or as empiric therapy for active infection. Intravenous piperacillin-tazobactam is an alternative if deeper tissues are involved or if the infection has systemic features. These agents are recommended, as they cover dog, cat, and human oral flora, although they also cover other animals' oral flora and most human skin flora (Abrahamian and Goldstein, 2011, Dendle and Looke, 2009). For bite wounds that have occurred or been immersed in water, antimicrobial regimens are modified to include coverage for aquatic organisms such as *Aeromonas* and *Vibrio* species (Therapeutic Guidelines, 2021).

This study aimed to define the animals responsible for bites and penetrating injuries in tropical Australia and the environments in which these encounters occurred. The study also examined the demographic characteristics of the patients, their clinical presentations, and their subsequent management. Particular attention was paid to the microbiologic isolates, clinicians' adherence to Australian antimicrobial prescribing guidelines, and any association with clinical outcome. It was hoped that these data might inform strategies to optimize the management of animal bites in this and other tropical regions.

Methods

Study design, setting, and participants

This retrospective audit was performed at Cairns Hospital in tropical Australia. The hospital has 531 beds, serves a population of approximately 280,000 people living across an area of 380,000 km^2, and is a tertiary referral center for surrounding rural and regional hospitals. Any hospitalization with a completed discharge summary coded between December 12, 2013, and October 31, 2020, was eligible for inclusion. This time period was chosen, as it coincided with the introduction of electronic medical records in the hospital.

Recruitment and data collection

International Statistical Classification of Diseases and Related Health Problems (ICD)-10 codes relating to animal bites or animal-related penetrating injury were used to identify potential participants. Demographic, clinical, and laboratory data were collected from patient medical records using a dedicated *pro forma*.

Definitions

Only animal bites and penetrating injuries that caused a wound and resulted in hospital admission were examined. Blunt trauma and superficial abrasions, except jellyfish stings, were excluded. Delayed presentation was defined as >8 hours from the animal encounter to the first review by any medical practitioner, and late presentation was defined as hospital presentation >24 hours after the bite or penetrating injury was sustained (Dendle and Looke, 2009).

The medical record was used to determine whether an infection was present on admission. Infection was classified as superficial (cellulitis, lymphangitis, subcutaneous abscess) or deep (septic arthritis, osteomyelitis, tenosynovitis, pyomyositis, bacteremia). Significant tissue trauma was defined as an underlying fracture, traumatic amputation, a significant tissue defect or devitalization of tissues, or major neurovascular injury. Potentially venomous animals included snakes, jellyfish, stonefish, and stingrays. Livestock included cattle, pigs, horses, and goats.

Appropriate antimicrobial therapy was defined as the prescription of a regimen concordant with the current Australian Antibiotic Therapeutic Guidelines within 24 hours of admission. Inappropriate regimens were further categorized as "too broad" (inappropriately covering organisms not relevant to the injury), "too narrow" (not covering anticipated, clinically important organisms), and "other" (incorrect route or other reason). Piperacillin-tazobactam was considered "too broad" after intravenous amoxicillin-clavulanate became available at Cairns Hospital in October 2017.

Microbiologic isolates considered contaminants or that had a clear nosocomial source were excluded. If an organism was cultured in both superficial and operative specimens, both events were recorded; multiple operative specimens isolating the same organism were considered a single event. The primary outcome was a composite of events that reflected a complicated clinical course: death, intensive care unit (ICU) admission, interhospital transfer for quaternary management, amputation or unplanned readmission related to the injury.

Statistical methods

Data were de-identified, entered into an electronic database (Microsoft Excel) and analyzed using statistical software (STATA Statistical Software: Release 14.2. [College Station, Texas. StataCorp LLC.]). Groups were analyzed using logistic regression, the Kruskal-Wallis, chi-square or Fisher's exact test, where appropriate. Multivariate analysis with a backward stepwise approach was employed; only variables with $p < 0.05$ in univariate analysis were included in the multivariate model.

Results

Recruitment and participant demographics

Of the 2740 potential cases identified, 1745 animal encounters occuriing in 1716 individuals were eligible for inclusion (supplementary Figure 1). A total of 1035/1745 (59%) cases were male; male patients were younger than female patients (median (interquartile range (IQR)) age: 34 (20-51) versus 40 (22-55) years, p=0.001, Supplementary Figure 2).

Animals and injuries

Of the 1745 cases, there were 1442 (83%) bites and 303 (17%) penetrating injuries; snakes (734/1745, 42%), dogs (508/1745, 29%), cats (153/1745, 9%), and jellyfish (129/1745, 7%) were most commonly responsible (Table 1). Encounters with aquatic animals were more common in male patients (176/1035 (17%) vs. 84/710 (12%), p=0.003); crocodile-related injuries occurred exclusively in male patients. Livestock-related injuries were also more common in male patients (odds ratio (OR) (95% confidence interval (CI)): 2.96 (1.52-5.75), p=0.001). Cat-related injuries were more frequent in female patients (OR: 3.24; 95% CI 2.28-4.60, $p < 0.001$).

Presentation and clinical features

Presentation was delayed in 313 of 1,745 (18%) cases (Table 2). However, only 20 of 905 (2%) of encounters with potentially venomous animals and 25 of 194 (13%) of wounds after significant trauma had a delayed presentation (Table 3). In contrast, 112 of 153 (73%) cat-related wounds were admitted >24 hours after the encounter.

Table 1
Characteristics of the animal-inflicted injuries in the cohort.

Animal	Total number	Bites	Male	Median age (IQR)	Most common location of injury (%)
Snake	734 (42%)	734 (100%)	453 (62%)	33 (19-52)	Foot/ankle (60%)
Dog	508 (29%)	503 (99%)	290 (57%)	39 (21-54)	Hand/wrist (38%)
Cat	153 (9%)	127 (83%)	51 (33%)	52 (39-67)	Hand/wrist (58%)
Other terrestrial animals[a]	34 (2%)	40 (44%)	20 (58%)	35 (12-60)	Hand/wrist (33%)
Cattle	20 (1%)	0 (0%)	19 (95%)	58 (25-70)	Leg (30%)
Horse	19 (1%)	3 (16%)	9 (47%)	50 (25-65)	Foot/ankle (32%)
Pig	17 (1%)	13 (76%)	17 (100%)	41 (32-58)	Leg (47%)
Jellyfish	129 (7%)	0 (0%)	71 (55%)	23 (13-35)	Arm (22%)
Fish	35 (2%)	8 (23%)	28 (80%)	36 (22-43)	Hand/wrist (63%)
Other aquatic animals[b]	34 (2%)	15 (44%)	30 (88%)	27 (22-36)	Hand/wrist (70%)
Stonefish	22 (1%)	0 (0%)	15 (68%)	33 (16-44)	Foot/ankle (63%)
Stingray	17 (1%)	0 (0%)	15 (88%)	44 (34-52)	Foot/ankle (47%)
Shark	13 (0.7%)	13 (100%)	7 (54%)	29 (22-46)	Leg (30%)
Crocodile	10 (0.6%)	10 (100%)	10 (100%)	44 (23-55)	Multiple sites (30%)
Total	1745	1442 (83%)	1035 (59%)	36 (21-53)	Hand/wrist (33%)

Absolute number (%) presented, unless otherwise stated.
[a] Bird (5), Bat (5), Rat (4), Leech (3), Monkey (3), Dingo (2), Goanna (2), Guinea Pig (2), Wallaby (2), Chicken (1), Goat (1), Kangaroo (1), Monitor lizard (1), Possum (1), Parrot (1).
[b] Crayfish (8), Starfish (8), Sea urchin (5), Crab (4), Prawn (3), Sea snake (3), Turtle (2), Eel (1).
IQR = interquartile range.

Table 2
Presenting clinical features and initial and subsequent infection rates.

Animal	Number	Delayed presentation[a]	Late presentation[b]	Wound soiling[c]	Significant trauma	Infected at presentation	Deep infection at presentation	Developed infection[d]	Developed deep infection D
Snake	734 (42%)	12 (2%)	13 (2%)	1 (0.1%)	2 (0.3%)	0 (0%)	0 (0%)	7 (1%)	1 (0.14%)
Dog	508 (29%)	113 (22%)	193 (38%)	22 (4%)	126 (25%)	140 (28%)	23 (16%)	7 (1%)	2 (0.4%)
Cat	153 (9%)	112 (73%)	112 (73%)	3 (2%)	1 (0.7%)	134 (88%)	21 (16%)	1 (1%)	0 (0%)
Other terrestrial animals[e]	34 (2%)	22 (65%)	22 (65%)	0 (0%)	4 (12%)	14 (41%)	5 (36%)	2 (6%)	0 (0%)
Cattle	20 (1%)	3 (15%)	5 (25%)	6 (30%)	17 (85%)	1 (5%)	0 (0%)	2 (10%)	0 (0%)
Horse	19 (1%)	2 (11%)	5 (26%)	3 (16%)	13 (68%)	1 (5%)	0 (0%)	0 (0%)	0 (0%)
Pig	17 (1%)	4 (24%)	7 (41%)	6 (35%)	6 (35%)	3 (18%)	1 (33%)	0 (0%)	0 (0%)
Jellyfish	129 (7%)	0 (0%)	0 (0%)	1 (0.8%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Fish	35 (2%)	15 (43%)	23 (66%)	16 (46%)	3 (9%)	18 (51%)	6 (33%)	0 (0%)	0 (0%)
Other aquatic animals[f]	34 (2%)	20 (59%)	25 (74%)	12 (35%)	3 (1%)	23 (39%)	5 (15%)	2 (6%)	1 (2.9%)
Stonefish	22 (1%)	1 (5%)	4 (18%)	1 (5%)	1 (5%)	4 (18%)	1 (25%)	1 (5%)	0 (0%)
Stingray	17 (1%)	7 (41%)	8 (47%)	5 (29%)	3 (18%)	8 (47%)	1 (13%)	0 (0%)	0 (0%)
Shark	13 (0.7%)	0 (0%)	1 (8%)	0 (0%)	10 (77%)	0 (0%)	0 (0%)	1 (7%)	0 (0%)
Crocodile	10 (0.6%)	2 (20%)	1 (10%)	2 (20%)	5 (50%)	0 (0%)	0 (0%)	1 (10%)	1 (10%)
Total	1745	313 (18%)	419 (24%)	78 (4%)	194 (11%)	346 (20%)	63 (18%)	24 (1%)	5 (0.29%)

Absolute number (%) presented, unless otherwise stated.
[a] > 8 hours after animal encounter to medical care.
[b] > 24 hours after animal encounter to hospital presentation.
[c] Foreign bodies/macroscopic debris identified in the wound at presentation or first surgery.
[d] After admission; no evidence of infection at presentation.
[e] Bird (5), Bat (5), Rat (4), Leech (3), Monkey (3), Dingo (2), Goanna (2), Guinea Pig (2), Wallaby (2), Chicken (1), Goat (1), Kangaroo (1), Monitor lizard (1), Possum (1), Parrot (1).
[f] Crayfish (8), Starfish (8), Sea urchin (5), Crab (4), Prawn (3), Sea snake (3), Turtle (2), Eel (1).

Table 3
Characteristics of presentations after an encounter with a potentially venomous animal or traumatic injury.

	All cases n=1745	Potentially venomous [a] n=905	Traumatic wound [b] n=194	Neither potentially venomous nor traumatic n=652
Age at admission	36 (21-53)	31 (19-50)	40 (25-54)	42 (23-57)
Male gender	1035 (59%)	557 (62%)	124 (64%)	359 (55%)
Regional referral [c]	601 (34%)	377 (42%)	90 (46%)	136 (21%)
Delayed presentation [d]	313 (18%)	20 (2%)	25 (13%)	269 (41%)
Infection at presentation	346 (20%)	12 (1%)	20 (10%)	316 (48%)
Developed infection [e]	24 (1%)	8 (1%)	6 (3%)	10 (2%)
Any infection [f]	370 (21%)	20 (2%)	26 (13%)	326 (50%)
Empiric antibiotics prescribed	863 (49%)	49 (5%)	192 (99%)	628 (96%)
Required surgery	613 (35%)	14 (2%)	182 (94%)	422 (65%)

Absolute number (%) presented, unless otherwise stated.
[a] Snakes, jellyfish, stonefish, and stingrays.
[b] An underlying fracture, traumatic amputation, significant tissue defect, devitalization of tissues or major neurovascular injury.
[c] Referred from regional hospital or transferred by way of a retrieval service.
[d] First medical review > 8 hours from time of injury.
[e] Not clinically infected at initial hospital presentation.
[f] Infection at any stage during the episode of care.

Table 4
Associations with the development of infection at any stage during the episode of care.

Variable	In the entire cohort	Any infection[a] (n=370)	No infection[a] (n=1375)	p value[b]
Age at admission	36 (21-53)	46 (30-61)	33 (19-51)	0.001
Male gender	1035 (59%)	196 (53%)	839 (61%)	0.005
Bite injury	1442 (83%)	284 (77%)	1158 (84%)	0.001
Presentation >24 hours from injury	419 (24%)	314 (85%)	105 (8%)	<0.001
Referred from regional hospital	601 (34%)	82 (22%)	519 (38%)	<0.001
Foreign body/soiling[c]	78 (4%)	18 (5%)	60 (4%)	0.67
Significant trauma[d]	194 (11%)	26 (7%)	168 (12%)	0.005
Appropriate antibiotics prescribed[d]	1445 (83%)	235 (64%)	1210 (88%)	<0.001
Surgery required	613 (35%)	199 (54%)	414 (30%)	<0.001
Primary closure[f]	243 (14%)	38 (10%)	205 (15%)	0.02
Aquatic animal	260 (15%)	58 (16%)	202 (15%)	0.64
Terrestrial animal	1485 (85%)	312 (84%)	1173 (85%)	0.64
Snake encounter	734 (42%)	7 (2%)	727 (53%)	<0.001
Dog encounter	508 (29%)	147 (40%)	361 (26%)	<0.001
Cat encounter	153 (9%)	135 (36%)	18 (1%)	<0.001

Absolute number (%) presented, unless otherwise stated.
[a] At any stage during the episode of care.
[b] In the comparison of those who did, and those who did not, have infection at any stage during their episode of care
[c] Foreign bodies/macroscopic debris identified in the wound at presentation or first surgery.
[d] An underlying fracture, traumatic amputation, significant tissue defect, devitalization of tissues or major neurovascular injury.[e]Concordant with the Australian Therapeutic Guidelines.
[f] Wound closed for healing by primary intention at first surgery or emergency procedure.

Wounds were infected at presentation in 346 of 1,745 (20%); 307 of 419 (73%) patients presenting >24 hours after their animal encounter had a clinically infected wound, compared with 39 of 1326 (3%) who presented within 24 hours (p <0.001). Only 24 of 1,399 (2%) with an uninfected wound at presentation developed infection subsequently, and in only 4 of 1,399 (0.3%) was this a deep infection.

Factors present on admission that were associated with wound infection are listed in Table 4. In multivariate analysis, presentation after 24 hours (OR (95% CI): 68.67 (42.10-112.01)) and a cat-related injury (OR (95% CI): 22.20 (11.18-44.08)) were associated with increased risk of infection. Conversely, a history of trauma (OR (95% CI): 0.25 (0.14-0.44)), a referral from a regional site (OR (95% CI): 0.36 (0.22-0.57)), or snakebite (OR (95% CI): 0.12 (0.05-0.28)) were associated with a reduced risk of infection.

Antimicrobials and microbiology

Empiric antimicrobial therapy was prescribed in 863/1745 (49%) cases and prescribed more frequently in injuries associated with - rather than without - significant trauma (192/194 (99%) versus 671/1551 (43%), p<0.001). Empiric antimicrobial prescription was inappropriate—according to Australian guidelines—in 300/1745 (17%) cases; it was "too broad" in 183/1745 (10%), "too narrow" in 105/1745 (6%) and was inappropriate for "other" reasons in 12/1745 (0.7%). However, only 1/105 (1%) patients whose antibiotic regimen was "too narrow" subsequently developed an infection, compared with 3/180 (2%) receiving therapy that was "too broad" (p=1.0).

Microbiology specimens were collected in 326/1745 (19%) cases; 167 (10%) had superficial swabs, 201 (12%) had operative specimens, and 45 (3%) had blood cultures. In cases where infection was clinically apparent on arrival, 132/346 (38%) had superficial, and 140/346 (40%) had deep specimens sent for culture.

Despite the variety of animals and the tropical environment in which they were encountered, the isolated pathogens were very similar to those seen in temperate regions (Tables 5 and 6). After excluding "mixed skin flora," the most common organisms isolated from terrestrial animal wounds were *Pasteurella multocida*, methicillin-susceptible *Staphylococcus aureus* (MSSA), *Streptococcus* spp., mixed enteric bacteria, *Pasteurella canis*, mixed anaerobic bacteria, *Neisseria* spp., *Pasteurella dagmatis,* and *Pasteurella stomatis*. For aquatic animal injuries, again excluding 'mixed skin flora', MSSA, methicillin-resistant *Staphylococcus aureus* (MRSA), and *Streptococcus* spp. were the most frequently cultured organisms. There were 12 cases where a clinically relevant pathogen was isolated, which was not covered by the empiric regimen recommended in Australian prescribing guidelines. Only one of these cases had a complicated clinical course unrelated to infection (a traumatic amputation after a dog bite).

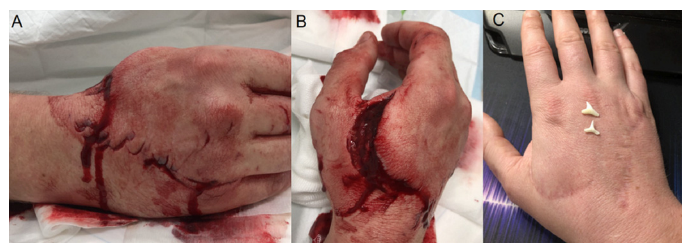

Figure 1. Shark bite injury sustained by a 32-year-old male (who provided informed consent for the publication of the images).
A: Right hand, dorsum puncture wounds. B: Right hand, web-space laceration. C: Healed wounds, shark teeth retrieved from the wound for scale.

Surgical management

Surgery was necessary in 613/1745 (35%) cases; 226/613 (37%) had primary closure (Table 7). Surgery was most common after encounters with crocodiles (9/10, 90%), sharks (11/13, 85%, Figs 1 and 2), livestock (45/56, 80%), dogs (400/508, 79%), and fish (26/35, 74%). Primary closure was most commonly performed for wounds from livestock (27/45, 60%), sharks (6/11, 55%), and fish (14/26, 54%). Infection of a previously uninfected wound was diagnosed intra-operatively in 5/613 (0.8%). Infection developed post-operatively in 7/613 (1.1%) and in only 2/226 (0.9%) of those wounds with primary closure.

Outcomes and predictors

The primary outcome occurred in 107/1745 (6%, Table 8), with 6 patients satisfying ≥2 criteria (3 snakebite deaths in ICU, 1 snakebite requiring ICU care and amputation, 1 shark bite requiring ICU care and amputation, and 1 horse encounter requiring ICU care and interhospital transfer). The three snakebite deaths oc-

Table 5
Antimicrobial therapy prescribed and microbiologic isolates, terrestrial animals.

Animal	Prescribed antibiotics	Appropriate antibiotics [a]	Most frequent isolates	Notable isolates	Isolates either not found or uncommon
Snake (n=734)	22 (3%)	723 (99%)	Mixed skin flora (2) [b] Mixed enteric flora [b] Group C *Streptococcus*	*Arthrobacter cumminisii* [c]	No *Staphylococcus aureus* No *Escherichia coli* No *Morganella morganii*
Dog (n=508)	501 (99%)	354 (70%)	Mixed skin flora (46) [b] *Pasteurella* spp. (37) [g] MSSA (18) [d] *Streptococcus* spp. (17) Mixed enteric bacteria (12) [b] Mixed anaerobic bacteria (11) [b] *Neisseria* spp. (8)	*Bacteroides fragilis* [c] *Capnocytophaga canimorsus* [c] *Actinobacillus lignieresii* (2) *Aeromonas hydrophilia Cupriavidus pauculus Staphylococcus intermedius* (2)	Few MRSA (3) [e]
Cat (n=153)	152 (99%)	97 (63%)	*Pasteurella multocida* (42) Mixed skin flora (16) [b] MSSA (6) [d] *Neisseria* sp. (3)	*Pasteurella multocida* (2) [c] *Streptococcus mitis* [c] *Proteus vulgaris* [c] *Erysipelothrix rhusiopathiae*	Few anaerobes (4) Few *Neisseria* spp. (3) Few *Streptococcus* spp. No *Bartonella henselae*
Other terrestrial animals [f] (n=34)	25 (74%)	19 (56%)	MSSA (3) [d] *Streptococcus* spp. (2) Mixed enteric bacteria (2) [b]	*Kocuria kristinae* (possum) *Eikenella corrodens* (monkey)	No *Streptobacillus moniliformis*/ *Spirillum minus* (rat) No *Haemophilus* spp./*Neisseria* spp./anaerobes (monkeys) No *Pseudomonas aeruginosa* (monitor lizard) No *Aeromonas* spp. (leeches) No *Salmonella* spp. (reptiles)
Cattle (n=20)	19 (95%)	9 (45%)	Various enteric organisms (5) [h]	-	-
Horse (n=19)	16 (84%)	17 (89%)	Mixed skin flora (3) [b] MSSA [d]	-	No *Actinobacillus lignieresii/suis*, no *Bacteroides fragilis*, no *Campylobacter ureolyticus*, no *Neisseria* spp., no *Pasteurella caballi/ pneumotropica*, no *Prevotella* spp.
Pig (n=17)	17 (100%)	8 (47%)	MSSA (5) [d] Mixed skin flora (2) [b]	*Eikenella corrodens*	No *Actinobacillus suis*, no *Bacteroides* spp. no MRSA [e], no *Pasteurella aerogenes/multocida*, no *Streptococcus* spp.

If no number is presented, the organisms was identified in only one encounter
[a] Concordant with the Australian Therapeutic guidelines; this figure also includes the patients who appropriately received no antibiotics.
[b] Isolate identified on microscopy/plate review.
[c] Isolated from blood culture.
[d] Methicillin-susceptible *Staphylococcus aureus.*
[e] Methicillin-resistant *Staphylococcus aureus.*
[f] Bird (5), Bat (5), Rat (4), Leech (3), Monkey (3), Dingo (2), Goanna (2), Guinea Pig (2), Wallaby (2), Chicken (1), Goat (1), Kangaroo (1), Monitor lizard (1), Possum (1), Parrot (1).
[g] *Pasteurella canis* (16), *Pasteurella multocida* (8), *Pasteurella dagmatis* (7), *Pasteurella stomatis* (5), *Pasteurella* sp. (1)
[h] *Citrobacter sedlakii* (1), *Clostridium histolyticum* (1), *Enterobacter cloacae* (1), *Enterococcus faecalis* (1), *Pseudomonas putida* (1), mixed enteric bacteria (1).MRSA = methicillin-resistant staphylococcus aureus; MSSA = methicillin- susceptible staphylococcus aureus.

Figure 2. Shark bite injury sustained by 38-year-old male (who provided informed consent for the publication of the images).
A: Left posterolateral forearm puncture wounds, large tissue flap is visible on the right side. B: Long, continuous anterolateral laceration.

curred after taipan, brown snake, and Papuan black snake envenomation, respectively. Factors associated with a complicated course are listed in Table 9. Multivariate analysis identified three variables independently associated with a complicated course: significant tissue trauma (OR (95% CI): 9.29 (6.05-14.25), p<0.001), deep infection at presentation (OR (95% CI): 2.95 (1.31-6.61), p=0.009) and presentation to hospital after 24 hours (OR (95% CI): 1.77 (1.12-2.79), p=0.01).

Discussion

Bites and penetrating injuries from a wide variety of animals lead to hospitalization in tropical Australia. In the published literature, dogs are responsible for 80-90% and cats for 5-15% of animal bites (Aziz et al., 2015, Griego et al., 1995), but in this cohort, dogs and cats were together responsible for less than 40% of hospitalizations. Instead, snakes (42%) and jellyfish (7%) were commonly responsible, and a large variety of other land-dwelling and aquatic animals were also implicated. However, despite the array of animals—and the significant range of tropical environments in which they were encountered—exotic pathogens were very rarely identified, with regimens recommended in Australian antimicrobial guidelines covering the isolated pathogens in almost all cases. Furthermore, relatively few of the patients who presented with an uninfected wound subsequently developed infection, emphasizing the significant role that prompt review and judicious wound management play in preventing this complication (Aziz et al., 2015).

Indeed, the patients could be divided, approximately, into two broad groups. The first group comprised of patients who had an encounter with a potentially venomous animal or whose encounter

Table 6
Antimicrobial therapy prescribed and microbiologic isolates, aquatic animals.

Animal	Prescribed antibiotics	Appropriate antibiotics [a]	Most frequent isolates	Notable isolates	Isolates either not found or uncommonly found
Jellyfish (n=129)	1 (1%)	129 (100%)	No organisms cultured	-	-
Fish (n=35)	34 (97%)	21 (60%)	*Streptococcus* spp. (6) MSSA (6) [b] MRSA (5) [c]	*Aeromonas schubertii Edwardsiella tarda*	No *Vibrio* spp.
Other aquatic animals [d] (n=34)	30 (88%)	24 (71%)	MSSA (13) [b] MRSA (6) [c]	*Aeromonas jandei*	No *Vibrio* spp. No *Mycobacterium marinum* No *Erysipelothrix rhusiopathiae*
Stonefish (n=22)	10 (45%)	21 (95%)	Mixed skin flora (5) [e] Group A *Streptococcus* (2) *Enterococcus faecalis* (2)	-	No *Vibrio* spp. or *Aeromonas* spp.
Stingray (n=17)	16 (94%)	13 (76%)	Mixed skin flora (3) [e] MSSA (2) [b]	*Shewanella algae*	No *Vibrio* spp. or *Aeromonas* spp.
Shark (n=13)	10 (77%)	7 (54%)	-	*Serratia marcescens Pseudomonas aeruginosa*	No *Vibrio* spp. or *Aeromonas* spp. No *Klebsiella, Proteus, Citrobacter* or *Clostridium* spp.
Crocodile (n=10)	10 (100%)	3 (30%)	Mixed skin flora (3) [e]	MRSA [c] *Staphylococcus lugdunensis*	No *Vibrio* spp. or *Aeromonas* spp. No *Citrobacter, Serratia*, or *Pseudomonas* spp.

If no number is presented, the organisms was identified in only one encounter
[a] Concordant with the Australian Therapeutic guidelines; this figure also includes the patients who appropriately received no antibiotics.
[b] Methicillin-susceptible *Staphylococcus aureus.*
[c] Methicillin-resistant *Staphylococcus aureus.*
[d] Crayfish (8), Starfish (8), Sea urchin (5), Crab (4), Prawn (3), Sea snake (3), Turtle (2), Eel (1).
[e] Isolate identified on microscopy/plate review.MRSA = methicillin-resistant staphylococcus aureus; MSSA = methicillin- susceptible staphylococcus aureus.

Table 7
Surgical management stratified by responsible animal.

Animal	Number	Required surgery [a]	Primary closure performed[b]
Snake	734 (42%)	4 (0.5%)	2 (50%)
Dog	508 (29%)	400 (79%)	144 (36%)
Cat	153 (9%)	79 (49%)	14 (19%)
Other terrestrial animals[c]	34 (2%)	10 (29%)	5 (50%)
Cattle	20 (1%)	17 (85%)	12 (71%)
Horse	19 (1%)	13 (68%)	9 (69%)
Pig	17 (1%)	15 (88%)	6 (40%)
Jellyfish	129 (7%)	0 (0%)	0 (0%)
Fish	35 (2%)	26 (74%)	14 (54%)
Other aquatic animals[d]	34 (2%)	49 (71%)	22 (45%)
Stonefish	22 (1%)	2 (9%)	0 (0%)
Stingray	17 (1%)	8 (47%)	4 (50%)
Shark	13 (0.7%)	11 (85%)	6 (55%)
Crocodile	10 (0.6%)	9 (90%)	2 (22%)
Total	1745	613 (35%)	226 (37%)

Absolute number (%) presented, unless otherwise stated.
[a] At any stage during the episode of care.
[b] Wound closed for healing by primary intention at first surgery or emergency procedure.
[c] Bird (5), Bat (5), Rat (4), Leech (3), Monkey (3), Dingo (2), Goanna (2), Guinea Pig (2), Wallaby (2), Chicken (1), Goat (1), Kangaroo (1), Monitor lizard (1), Possum (1), Parrot (1).
[d] Crayfish (8), Starfish (8), Sea urchin (5), Crab (4), Prawn (3), Sea snake (3), Turtle (2), Eel (1)

resulted in significant tissue trauma. Over 96% of these patients presented within 8 hours, presumably because of concerns about potential envenomation or tissue injury. Over 80% of these patients received no antibiotics or antibiotics with a spectrum of activity that was considered too narrow. However, less than 2% developed a wound infection, with only 0.2% developing a deep wound infection.

The second group comprised of patients who had neither an interaction with a potentially venomous animal nor significant trauma; most of these patients presented to the hospital after 24 hours, and almost 85% presented with - or subsequently developed - a wound infection. Notably, almost three-quarters of the cat-related wounds presented >24 hours after the encounter, over 96% of these wounds were infected or subsequently developed infection. Cat encounters and late presentation were the only variables independently associated with an increased risk of wound infection.

The precise impact of delayed presentation on the development of infection in animal-inflicted wounds has been addressed by a surprisingly small number of studies (Baddour and Harper, 2021, Ellis and Ellis, 2014). A randomized control trial of 168 dog bites found infection rates of 5% and 22%, respectively, for wounds that received treatment before and after 8 hours from the time of injury (Paschos et al., 2014). Increased risk of secondary bacterial infection was associated with >24 hours delay to first medical care for a group of 476 freshwater stingray injuries in a Brazilian cohort (Sachett et al., 2018). In our cohort, late presentation to the hospital (>24 hours after the encounter) was associated with not only an increased risk of infection but also an increased risk of a complicated clinical course.

Surgery has a clear role in managing animal-inflicted injuries. Surgical inteventions include irrigation, removal of foreign bodies, debridement of infected material and excision of nonviable tissues. However, there remains some uncertainty about the ideal timing of wound closure and concern around increasing the risk of infection by placing sutures into the surgical bed (Aziz et al., 2015). In this study, approximately a third of cases had surgery, and approximately a third of these cases had primary closure. Infection developing post-operatively was rare and occurred after primary closure in just two of 226 cases. Two studies, consisting of 168 and 120 dog-inflicted injuries that presented within 48 or 12 hours, respectively, employed amoxicillin-clavulanate prophylaxis and randomized patients to either immediate or delayed closure. There were no differences in infection rates in either study (10% vs. 7% and 7% vs. 5%), although there were better cosmetic scores in one primary closure group (Paschos et al., 2014, Xiaowei et al., 2013). Another study of 96 dog encounters was randomized within 24 hours of injury to have either primary closure or no closure; antibiotics were withheld for all patients but post-operative infection developed in 8% of both groups (Maimaris and Quinton, 1988). A

Table 8
Proportion of patients experiencing a complicated course stratified by responsible animal.

	Number	Complicated course composite [a]	Died	ICU admission	Inter-hospital transfer	Amputation	Unplanned readmission
Snake	734 (42%)	17 (2%)	3 (0.4%)	14 (1.9%)	-	1 (0.1%)	3 (0.4%)
Dog	508 (29%)	48 (10%)	-	-	2 (0.4%)	19 (4%)	27 (5%)
Cat	153 (9%)	11 (7%)	-	1 (0.7%)	-	-	10 (7%)
Other terrestrial animals [b]	34 (2%)	3 (9%)	-	-	-	-	3 (9%)
Cattle	20 (1%)	2 (10%)	-	1 (5%)	-	1 (5%)	-
Horse	19 (1%)	4 (21%)	-	1 (5%)	1 (5%)	3 (16%)	-
Pig	17 (1%)	2 (12%)	-	-	-	1 (6%)	1 (6%)
Jellyfish	129 (7%)	7 (5%)	-	5 (3.9%)	-	-	2 (2%)
Fish	35 (2%)	-	-	-	-	-	-
Other aquatic animals [c]	34 (2%)	3 (9%)	-	-	-	1 (3%)	2 (6%)
Stonefish	22 (1%)	2 (9%)	-	-	-	-	2 (9%)
Stingray	17 (1%)	1 (6%)	-	-	-	-	1 (6%)
Shark	13 (0.7%)	3 (23%)	-	1 (7.7%)	-	3 (23%)	-
Crocodile	10 (0.6%)	3 (30%)	-	-	-	2 (20%)	1 (10%)
Overall	1745	107 (6%)	3 (0.2%)	23 (1%)	3 (0.2%)	31 (2%)	52 (3%)

Absolute number (%) presented, unless otherwise stated.
[a] Death, intensive care unit (ICU) admission, interhospital transfer for quaternary management, amputation, unplanned readmission.
[b] Bird (5), Bat (5), Rat (4), Leech (3), Monkey (3), Dingo (2), Goanna (2), Guinea Pig (2), Wallaby (2), Chicken (1), Goat (1), Kangaroo (1), Monitor lizard (1), Possum (1), Parrot (1).
[c] Crayfish (8), Starfish (8), Sea urchin (5), Crab (4), Prawn (3), Sea snake (3), Turtle (2), Eel (1).ICU = intensive care unit.

Table 9
Association between selected characteristics and a complicated clinical course.

	Uncomplicated course [a]n=1638	Complicated course [a]n=107	Odds ratio (95% CI)	p value [b]
Age at admission	36 (21-53)	45 (20-53)	1.01 (1.003-1.02)	0.01
Male gender	972 (59%)	63 (59%)	0.98 (0.66-1.46)	0.93
Bite injury	1360 (83%)	82 (77%)	0.67 (0.42-1.07)	0.09
Hospital presentation after 24 hours	375 (23%)	44 (41%)	2.35 (1.57-3.51)	<0.001
Referred from regional hospital/retrieval service	556 (34%)	45 (42%)	1.41 (0.95-2.10)	0.09
Infected at presentation	317 (19%)	29 (27%)	1.54 (0.99-2.41)	0.05
Deep infection at presentation	53 (3%)	10 (9%)	3.09 (1.52-6.25)	<0.001
Foreign body/soiling [c]	75 (5%)	3 (3%)	0.60 (0.19-1.94)	0.39
Significant trauma [d]	144 (9%)	50 (47%)	9.10 (6.00-13.80)	<0.001
Empiric antibiotics prescribed	778 (48%)	85 (79%)	4.27 (2.65-6.89)	<0.001
Appropriate antibiotics prescribed [e]	1368 (84%)	77 (72%)	0.50 (0.32-0.79)	0.003
Pathogen not covered in empiric regimen	11 (0.7%)	1 (0.9%)	1.40 (0.18-10.91)	0.75
Surgery required	546 (33%)	67 (63%)	3.35 (2.23-5.02)	<0.001
Primary closure [f]	198/546 (36%)	28/67 (42%)	1.26 (0.75-2.11)	0.38
Aquatic animal	241 (15%)	19 (18%)	1.25 (0.75-2.10)	0.39
Terrestrial animal	1397 (85%)	88 (82%)	0.80 (0.48-1.34)	0.39
Snake encounter	717 (44%)	17 (16%)	0.24 (0.14-0.41)	<0.001
Dog encounter	459 (28%)	49 (46%)	2.17 (1.46-3.22)	<0.001
Cat encounter	142 (9%)	11 (10%)	1.20 (0.63-2.31)	0.57
Jellyfish encounter	122 (7%)	7 (7%)	0.87 (0.40-1.91)	0.73
Shark encounter	10 (0.6%)	3 (3%)	4.70 (1.27-17.3)	0.02
Crocodile encounter	7 (0.4%)	3 (3%)	6.72 (1.71-26.4)	0.006
Potentially venomous animal [g]	878 (54%)	27 (25%)	0.29 (0.19-0.46)	<0.001
Positive blood culture with pathogen	5 (0.3%)	2 (2%)	6.22 (1.19-32.45)	0.03

Absolute number (%) presented, unless otherwise stated.
[a] Death, intensive care unit (ICU) admission, interhospital transfer for quaternary management, amputation, unplanned readmission.
[b] P value of odds ratio presented.
[c] Foreign bodies/macroscopic debris identified in the wound at presentation or first surgery.
[d] An underlying fracture, traumatic amputation, a significant tissue defect or devitalization of tissues or major neurovascular injury.
[e] Concordant with the Australian Therapeutic guidelines.
[f] Wound closed for healing by primary intention at first surgery or emergency procedure. Only includes the 613 patients who had such a procedure.
[g] Snakes, jellyfish, stonefish, and stingrays.CI = confidence interval.

Chinese study of 600 facial injuries from dog encounters presenting within 8 hours of the injury, randomized patients to primary closure or no closure; there was no significant difference in infection rates (6% vs. 8%, respectively) (Rui-feng et al., 2013). These trials, and our findings, suggest that primary closure is reasonable for appropriately selected, uncomplicated wounds and may have cosmetic benefits. Furthermore, our findings can provide some reassurance for clinicians considering the primary closure of more complex wounds; of the 226 wounds in this cohort that underwent primary closure, 137 (61%) were either already infected, had significant tissue trauma, or were in patients that had presented >24 hours after the injury.

In our study, there was a low rate of microbiologic sampling and an even lower rate of clinically significant isolates. This seemingly low rate of sampling likely reflects appropriate rationalization of microbiologic investigations and might be explained in two ways. First, almost half of the cohort had snake bites or suspected Irukandji jellyfish stings, very few of which became infected and very few of which had wounds amenable to microbiologic sampling. Second, a significant number of dog and cat bites presented with cellulitis or lymphangitis rather than a purulent wound. Superficial microbiologic sampling of these cases would be expected to identify skin flora unrelated to the subcutaneous infection. Even with this selective approach, “mixed skin flora” remained the most common microscopy/culture result of the superficial specimens in the cohort. The low rate of microbiologic sampling in this study contrasts with many published studies which highlight organisms of interest but often do not clearly indicate the frequency of culture-negative specimens.

The isolated organisms were similar to those reported in studies from temperate climates (Abrahamian and Goldstein, 2011). The pathogens identified in dog wounds were similar to isolates collected from 18 United States emergency departments during 1994-1995, although cat-inflicted wounds yielded lower rates of streptococci and anaerobes than previously described (Talan et al., 1999). *Pasteurella* species, MSSA, *Streptococcus* species, and anaerobes, all highlighted in Australian guidelines as important in animal bites wounds, were the most common isolates in the current study. *Capnocytophaga canimorsus,* another highlighted organism, was only encountered in 1/508 dog encounters. *Staphylococcus intermedius,* an organism associated with dog bite wounds and which can be confused with *S. aureus*, was only identified in 2/508 encounters. Furthermore, in only 12 patients, a pathogen was isolated that was not covered by the regimen recommended in Australian guidelines, and just one of these 12 patients had a complicated course, a complication (traumatic amputation) which was unrelated to infection.

Although Australian guidelines emphasize the different potential pathogens in water-immersed wounds, a typically "aquatic" organism was isolated in less than 2% of aquatic animal encounters; no *Vibrio* species or *Mycobacterium marinum* were identified in the entire cohort. Instead, MSSA, MRSA, and *Streptococcus* species predominated in the water-immersed wounds, emphasizing the importance of empiric regimens covering common pathogens rather than focusing therapy against putatively "classical" organisms. Trimethoprim/sulfamethoxazole (TMP/SMX) provides more reliable cover against *Staphylococcus aureus* than ciprofloxacin or doxycycline, especially in regions with high rates of community-associated MRSA (Guthridge et al., 2019), and in addition treats many aquatic pathogens. The prescription of TMP/SMX for both saltwater- and freshwater-immersed wounds in place of ciprofloxacin or doxycycline may represent a simpler regimen.

Antimicrobial therapy was appropriately withheld in about half of the patients and appropriately prescribed within 24 hours of admission in about a third. Two-thirds of the inappropriate prescriptions were "too broad"; most involved prescribing piperacillin-tazobactam rather than amoxicillin-clavulanate for dog and cat-related injuries. This agent is unnecessary given the very low rates of resistant Gram-negative organisms seen in the cohort. Indeed, after October 2017, when intravenous amoxicillin-clavulanate became available locally, *Pseudomonas aeruginosa* was cultured from only 1/377 dog and cat wounds. Therapy that was too narrow included "inadequate" cover for water-immersed wounds, the use of only anti-staphylococcal penicillins for cat and dog bites, and the use of ceftriaxone monotherapy (which has limited anti-staphylococcal activity) (Zelenitsky et al., 2018). However, only one of the cases whose therapy was "too narrow" developed infection after admission: this patient developed a superficial *Pasteurella canis* infection after receiving cefazolin monotherapy after a dog bite. Three patients that received therapy that was "too broad" also developed infection after admission, although, again, this was superficial in all cases. This suggests that the time to presentation, the animal involved, and the adequacy of wound debridement have a greater impact on an infection developing than the antimicrobial spectrum of antibiotic therapy, which probably only has an adjunctive role.

This study has several limitations. Its retrospective design prevented the comprehensive collection of clinical data in some cases, and animal species were usually based on patient history, which may be unreliable. It was sometimes difficult to confirm the antimicrobial therapy prescribed by clinicians before referral, which may have increased the number of culture-negative cases and may have also failed to capture the patients' subsequent outpatient course, including representations with relapsed or persistent infection. Patients discharged home from the emergency department were not captured, and it is important to note that it is estimated that only one in five people present for medical attention after a dog bite (Looke and Dendle, 2015). This study was hospital-based and therefore biased to report more severe injuries. Although surgical intervention and primary closure were documented, the extent of first aid administration and precise surgical techniques were not documented in detail. The study's findings may not necessarily be generalizable to other tropical settings, given the different animals and rates of antimicrobial resistance seen in these locations (Semret and Haraoui, 2019). Finally, although the overall cohort was larger than most studies in the published literature, there were insufficient data to inform optimal antimicrobial regimes for individual animals.

Conclusions

This study presents one of the largest - and more heterogeneous - studies of animal-inflicted injuries in a tropical setting. Patients hospitalized with animal bites and penetrating injuries in tropical Australia usually have good outcomes, although those with a late presentation, significant tissue trauma, or established deep infection have a worse prognosis. Despite the diversity of local fauna and the study's unique geographic setting, once snake bites were excluded, domesticated animals were responsible for most presentations. Microbiologic sampling generally had a low yield and rarely changed management. Although antimicrobial therapy is likely to have an important adjunctive role in patient care, there was little association with clinical outcomes, even when the regimen conflicted with Australian guidelines or a resistant organism was isolated. This emphasizes the importance of prompt medical review and meticulous wound care in preventing serious infections and permanent disability that might complicate animal-inflicted injuries.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethical considerations

Ethical approval was provided by the Far North Queensland Human Research Ethics Committee (HREC/2020/QCH/65939-1468QA). As the data were retrospective and de-identified, the Committee waived the requirement for informed consent.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijid.2022.02.026.

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