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The anatomy of a shark attack: a case report and review of the literature

David G.E. Caldicott *, Ravi Mahajani, Marie Kuhn

Emergency Department, Royal Adelaide Hospital, North Terrace, Adelaide SA 5000, Australia

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Abstract

Shark attacks are rare but are associated with a high morbidity and significant mortality. We report the case of a patient's survival from a shark attack and their subsequent emergency medical and surgical management. Using data from the International Shark Attack File, we review the worldwide distribution and incidence of shark attack. A review of the world literature examines the features which make shark attacks unique pathological processes. We offer suggestions for strategies of management of shark attack, and techniques for avoiding adverse outcomes in human encounters with these endangered creatures.

We are not afraid of predators, we're transfixed by them, prone to weave stories and fables and chatter endlessly about them, because fascination creates preparedness, and preparedness, survival. In a deeply tribal way, we love our monsters…

E.O. Wilson, sociobiologist.

1. Introduction

Few creatures solicit the apprehension that sharks engender. In an aquatic environment where most humans can at best 'keep their heads above water', the predatory capabilities of the shark render land-based, bipedal primates easy prey. The incidence of shark attack in the world could not be said to merit the degree of apprehension or antipathy often expressed towards sharks, but when a shark attack does occur, it is often with an impressive efficiency. In this paper, we report the details of a non-fatal shark attack, and review the incidence and management of a fortunately rare but potentially life-threatening event.

2. Case report

A 26 year old man was surfing with his friend outside the Castles' break of Cactus Beach, a popular yet remote venue on the Great Australian Bight. The attack occurred at approximately 11:00 h on a clear day, with air temperatures in the high twenties and in 20–25 m of clear water. The victim and his friend, who was 15 m away, were alone in the bay. The victim was lying astride his surfboard and paddling with his right arm, gently circling to counter the action of the tide, while waiting for a wave. He was talking to his friend over his left shoulder when, without warning, his paddling arm was seized by a shark, approximately 3–3.5 m in length. He struck the shark with his left arm, which it also seized in its mouth. On seeing him in danger, the patient's friend paddled over, and punched the shark in its gills several times, attempting to make it release the patient. When this did not work, the friend gouged its eyes, and the shark loosened its grip and re-submerged. The patient reported a great deal of blood in the water at this stage, and was unable to see the shark, but knew that it had not gone away because he felt it tugging on the leg-rope of his surf-board, which was dangling in the water. The two surfers brought their boards together and removed their arms and legs from the water, while they decided how to get to the shore. The shark returned a second time, bumping up between the two

* Corresponding author. Tel.: +61-8-82225063; fax: +61-8-82224171.

E-mail address: dcaldico@mail.rah.sa.gov.au (D.G.E. Caldicott).

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surfboards and tipping both surfers into the water. The shark then attempted to attack the patient's friend, who placed his surfboard between himself and the shark, which took two bites in rapid succession out of the surf board. The patient, in the mean time, attempted to reach the nearby reef which, being shallower water (6 ft.), he thought would afford him some protection. The shark pursued him over the 50 m distance, and seized his left arm, just above the elbow. At that moment, the patient noticed a 2.5 m wall of white water approaching over the reef. As it hit both shark and patient, the shark relinquished its grip and ceased its attack. The patient was helped to his surfboard by his friend, and both parties made their way to the beach. The patient was placed supine in the back of his friend's station wagon and they raced to the nearest hospital at Ceduna.

On arrival at Ceduna, the patient was quickly assessed and stabilized. He was administered cross-matched blood, intravenous antibiotics, opiate analgesia, and retrieved by air to the Royal Adelaide Hospital for further management. On arrival, he was cardiovascularly stable, alert and oriented, and his arms were the only sites of visible injury. Both limbs were vascularly intact, both radial pulses were present and there was no evidence of compartment syndrome. The salient pre-operative findings in the ED are presented.

2.1. The left upper limb (see Fig. 1a)

A wrist drop was present, although the sensory component of the radial nerve was intact. Intrinsic function provided by the ulnar nerve, and the muscles innervated by the median nerve were preserved. Radiographs revealed no bony injuries.

2.2. The right upper limb (see Fig. 1b)

Movement of the wrist, especially in extension was limited by pain, due to a wound later shown to have entered the radio carpal joint (see below). A similar wound on the volar aspect of the forearm, just proximal to the carpal canal, had clinically divided the median nerve although the extrinsic flexors of the second to fifth digits were intact. Both the sensory and motor components of the ulnar nerve were intact on examination.

The patient was operated on within 2 h of admission to the Royal Adelaide Hospital. The operating team consisted of two plastic and reconstructive surgical registrars, one operating on each arm.

2.2.1. Left arm

The radial nerve had been 30% partially divided and stripped off at the level of the elbow joint. This same laceration penetrated the elbow joint and partially divided the brachioradialis muscle. The joint was washed out and the structures repaired. The extensor muscle mass had been partially divided proximally and the extensor digitorum communis and the extensor carpi ulnaris divided distally with some loss of tendon substance. Extensor communis function was preserved by suturing the distal divided tendon edges to the intact part of extensor digitorum communis.

Two subsequent operative debridements were required. There were no adverse post-operative complications.

2.2.2. Right arm

On the volar aspect of the right wrist, the median nerve had been divided with a 2 cm gap. The nerve was bruised a further 4 cm proximally and, therefore, was

Fig. 1. (a) Injuries sustained to left arm, as seen in ER; (b) injuries sustained to right arm, as seen in ER.

not repaired primarily. A total division of the flexor policis longus and flexor carpi radialis was repaired with an Adelaide core suture and Silfverskiold epitendinous repair. Other palmar punctures were explored but there was no damage to the palmar neurovascular bundles or tendons.

A penetrating wrist laceration on the dorsum of the wrist had entered the radio carpal joint but the joint itself was intact. A segment of shark tooth had lodged in the wound. The extensor injuries included division of the extensor digitorum communis to the middle, ring and little finger, the extensor policis longus and extensor carpi ulnaris. Other tendons were preserved.

The divided extensors and the median nerve were not repaired initially. The patient was returned to theatre the second day for a further washout and at that time these structures were repaired with the wrist in flexion to provide apposition of the median nerve. Other puncture wounds in the upper arm were small and pierced muscles only. No major injuries were found on exploring these wounds and they were, therefore, duly washed and sutured primarily.

A rigorous hand therapy program was instituted with static splinting for 2 weeks to protect the nerve repairs. This was subsequently converted to dynamic extension splints. The patient's hand therapy is continuing and while movement in the hand has recovered well, there is still decreased sensation in the median nerve territory of the right hand.

3. Discussion

Shark attacks, because of their scarcity, have only been a subject of public interest in the latter half of the 20th century. Scientifically, sharks were thought not to be a danger to the uninjured human prior to the 1930s [1]. Following the problems with shark attacks on navy personnel during WW2 (including the infamous account of the USS Indianapolis in 1945 [2]), the US Navy decided to set up a research program to develop an effective shark repellent. The Shark Research Panel was established in 1958 in order to examine in greater detail the epidemiology of shark attacks. The panel started the Shark Attack File, initially located in the Smithsonian Institute, but then transferred to the Florida Museum of Natural History in 1988. Today the most comprehensive epidemiological data on shark attacks is held by the International Shark Attack File (ISAF), which is administered by the American Elasmobranch Society and the Florida Museum of Natural History. It has details of over 3000 shark attacks in its files, the details of which are available to selected marine biologists and health care professionals [3].

Sharks, along with skates and rays, make up the subclass Elasmobranchii of the class Chondrichthyes, ('cartilagenous fishes'), so called because their skeletons are made completely of cartilage [4]. They represent less than 5% of the sea's fish, the vast majority belonging to the class Osteichthyes or 'bony fish' [4]. Springer and Gold have further subdivided the elasmobranchs into three superorders of living sharks; the Squalomorphii, the Galeomorphii, and the Squatinomorphii [4]. Sharks are an ancient class of fish, first appearing about 400 million years ago. Many living species belonging to the same genera as species that swam in the Cretaceous seas, 100 000 000 years ago [4]. There are approximately 370 species of shark described [5], up to 80 of which are currently endangered.

Sharks are predators, and have many adaptations that have allowed them to maintain this ecological position over the ages. They have been variously described by normally dispassionate scientists as "an integrated weapons system" [1], or even as "meat-seeking missiles" [6]. An understanding of their biology and habits should not only increase respect for their capabilities, but may also provide useful information on how to avoid becoming their next meal.

Sharks' skeletons are made of cartilage, which gives them far greater manoeuvrability than their bony counterparts. They have no swim bladders, which means that, although they will sink if they stop swimming, they can ascend rapidly in pursuit of prey without barotrauma. They can see colour, although they have cone-poor retinae, and like cats, have a light-reflecting layer in their eyes to enhance their night vision. Ironically, they appear to be attracted to the colour international orange, used in many pieces of life-saving equipment [7]. Their chemoreceptor mechanism is exquisitely sensitive, and at least one species (the ocean white-tip) can smell air as well as water. Their 'hearing' is acute particularly to irregularly pulsed, low frequency (< 800 Hz) sounds, and their ability to locate a sound source is extremely accurate. They also have an additional sense of electroreception, via the ampullae of Lorenzi, with which they can identify the small electrical fields given off by every living creature. They are very powerful animals, with the larger species capable of throwing an adult out of the water [8]. They have rows of serrated teeth, which often break off during an attack, and can be used to identify the attacking species. Their bites have been demonstrated to exert as much as 18 tons per square inch at the tips of the teeth [9,10], capable of biting through surfboards, small boats, torsos and limbs. In the extremely rare case of shark attack on a human, the primate is no match for its aquatic adversary.

Sharks are carnivores and scavengers. Of the 370 described species of shark, only 32 have been documented to attack humans [3]. Any shark that can grow larger than 1.8–2.0 m is potentially lethal to a man [11], but even smaller sharks if provoked are capable of

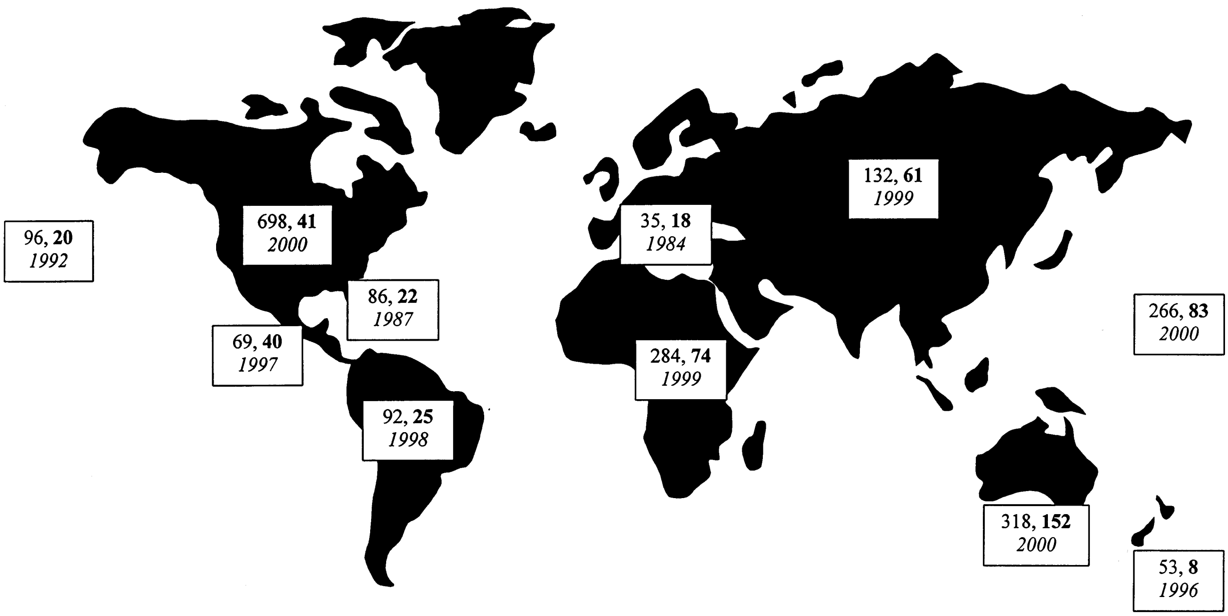

Fig. 2. Number of confirmed, unprovoked shark attacks, 1580–2000 (data from ISAF [3]) (key: total number of attacks, fatalities, year of last fatality).

inflicting a nasty injury. Known attacks have been made by sharks from 45 cm to 6 m in length [3]. Certain species appear to be involved in shark attacks more than others. These include the white shark — *Carcharodon carcharias*, the tiger shark — *Galeocerdo cuvier*, and several members of the *Carcharhinus* spp. [3]. It used to be thought that shark attacks only occur between the latitudes of 42° N to 42° S, but in fact they have been well documented outside these areas. The real reason behind this distribution is probably more due to humans' disposition to swim in warmer water than the sharks' geographical distribution [12].

There are probably between 70 and 100 shark attacks in the world per annum, with between 5–15 deaths [13]. The numbers of confirmed, unprovoked shark attacks in the last 400 years around the world are shown in Fig. 2. The precise figures will never be available. Many attacks occur in third world countries and will not be reported; others remain unreported for fear of bad publicity at otherwise popular resorts. Although the numbers of sharks are thought to be declining, the number of shark attacks is marginally increasing. This is thought to be a reflection in both increased aquatic recreation, as well as simple world population rises. It is possible that the design of modern wetsuits, which permit individuals to spend much longer in the water, has also contributed in increasing the exposure time between sharks and humans. The trends for shark attack incidence over the last century and decade are indicated in Figs. 3 and 4. In interpreting this data, it should be remembered that there is a reporting bias toward the end of the century. The apparent drop in the 1970s and 1980s is in part a reflection of ISAF inactivity during this time period [3].

The mortality of shark attacks has fallen from 40% [8] in the 30 years following WWII to its current rates of approximately 10–20% [3] (see Table 1). Death is usually due to lack of on-scene resuscitation, haemorrhagic shock or drowning.

3.1. Risk of shark attack

Despite its potential danger, the risk of shark attack is extremely small when compared with almost any other injury. When compared to other causes of water related deaths, shark attack is negligible. Table 2 illustrates the number of deaths associated with water related activities in Australia in a 2-year period [14].

Bees, wasps and snakes are responsible for far more fatalities every year. In Australia over the last 200 years, less than one person per year has been killed by sharks — on average, 2–3 people are killed by bee stings [14]. In the areas of sea where shark attacks

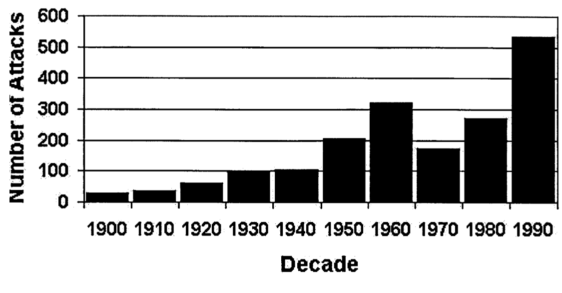

Fig. 3. Trends of shark attack incidence over the last century [3].

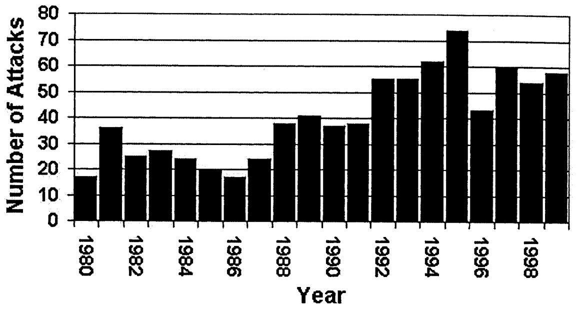

Fig. 4. Trends of shark attack incidence over the last decade [3].

occur most often, drowning, and even cardiac arrests in the water, are far more common than shark attacks [14]. One is more likely to be killed driving to a beach than by a shark swimming there [14].

These figures put shark attack into the unusual category of the zero–infinity problem, in risk management terms; an almost zero probability of occurring, but almost infinite consequences to victims, their families, and tourist economies when they do occur [15].

When shark attacks first came under the eye of scientific scrutiny, it was thought the motivating factor for an unprovoked attack was exclusively hunger. Pioneering work by Baldridge [11] speculated that in fact one could identify a number of different motivations. There are now generally thought to be three general types of unprovoked shark attack [16].

3.1.1. The hit and run attack

This is the commonest type, constituting up to 80% of attacks. The victim is usually just seized and released, or slashed on an extremity, before they have any time to react. Often, it is not until they have left the water that they notice the full extent of their injuries. These attacks often occur in shallow water, and are usually a once-off assault. It has been speculated that these attacks are the action of smaller juvenile sharks and represent an immature predator strategy, 'a state of petulance' on the part of the shark [11], or even mistaken identity of potential prey.

Table 1
Worldwide shark attack incidence and mortality in the last decade [3]

Year	Reported shark attacks	Fatalities	Fatalities (%)
1990	37	2	5.4
1991	38	3	7.9
1992	55	7	12.7
1993	55	14	25
1994	62	9	14.5
1995	74	11	14.8
1996	43	3	6.9
1997	61	12	19.7
1998	58	6	10.3
1999	65	4	6.1
Average	54.8	7.1	12.3

Table 2
Number of deaths associated with water related activities in Australia [14].

	1994	1995
Accidental drowning and submersion	419	441
Drowned while swimming at ocean/beach/river/lake/harbour/estuary/bay/lagoon	79	68
Skin diving SCUBA	27	14
Rock fishing	14	13
Surfing	3	2
Shark attack	0	1

3.1.2. Sneak attacks

The attack comes 'out of the blue', so to speak, and usually involves a diver or swimmers in deeper water. The patient has had no intimation that a shark attack was about to occur.

3.1.3. Bump and bite attacks

The shark circles the victim, bumping them prior to attacking. It is thought that this may be an attempt at assessing the potential danger of a potential meal, or even injuring or incapacitating prey prior to a more concerted attack [1,17].

These last two types of attack tend to occur in deeper water, are multiple and sustained, involve bigger sharks, and cause the majority of deaths by shark attack. They are thought to be associated with intentional feeding behaviour, rather than mistaken identity. We believe that the attack on our patient was of this latter type.

When observed, shark behaviour immediately prior to an attack can be characteristic. The patterns of swimming change from being smooth to erratic and jerky. The pectoral fins, which normally lie almost horizontal, extend as far as 60° downwards. Much of this is aggressive posturing but can escalate into an attack [18].

4. The pathology of shark attack

4.1. Gross pathology

The direct traumatic effects of a shark attack are dependent upon the severity and nature of the attack, as well as the size and species of the shark.

In feeding situations, the spike-like teeth of the lower jaws fix their prey while the upper jaw is protruded, and the serrated upper teeth saw through the flesh. The cutting action is aided by head shaking or rolling movements of the shark [11]. Sharks attack the appendages of their victims (be they seals or humans). These tend to dangle lower than heads and torsos, which stay on the surface. This was the case with our patient. They are unable to chew their prey, and so sequentially strip it [19]. Davies and Campbell [8] proposed the Durban classification of shark-induced injuries, based on their findings in South Africa to predict outcome (see Table 3).

The tentative bites associated with 'hit and run attacks' usually occur in isolation, and usually on an extremity. In 70% of surface swimmers the lower limb only is involved. The upper limb is subsequently injured when patients try to fend off their attacker [20]. Sharks will also bare their teeth and slash, which result in linear lacerations rather than the characteristic bite marks. In these circumstances, tissue loss is uncommon. Wounds are principally incisions, with a minimal crushing component [21]. Bumps alone from shark attacks can cause serious abrasions. Sharks have specialized scales (denticles, or placoid scales), which give the skin of many species the texture of coarse sandpaper. When bumped at speed, these abrasions, can become long deep regular grooves in the skin and underlying tissue.

In more serious, concerted attacks, substantial tissue loss and extremity amputation is more common. Wounds depend on the size of the shark and the degree of dental serration. Species with a finer tooth serration give sharp wound edges, whereas coarse or minimal dental serration leads to deeper puncture wounds [10].

4.2. Microbiological pathology

Considering the diet of the shark, it is not surprising that many shark bites become infected. In addition, contrary to the concept that the sea is a sterile environment for microorganisms, there is an array of atypical bacteria very capable of infecting human tissue. The best described of these are the *Vibrio* and *Aeromonas* spp. These halophillic, hardy bacteria are capable of establishing a rapidly progressive cellulitis or myositis, even within hours of exposure [5]. A number of *Vibrio* spp. have been cultured from shark bites or shark-inflicted wounds [22].

5. The treatment of shark attack

Shark attacks have two distinct characteristics that pose problems to the treating clinician. Firstly, the determined and concerted attack invariably results in massive tissue injury, and frequently causes hypovolaemic shock. The severity of the injuries sustained following shark attack is on a par to those seen in military injuries and high-speed motor vehicle accidents [9,20,23,24]. Secondly, if a patient survives the initial attack, the incidence of atypical wound infections is extremely high. Failure to institute appropriate antibiotic therapy will result in further morbidity and mortality [20,22–25]. The increased survival associated with shark attack has been due to improved training of first-responders and presumptive antibiotic therapy.

5.1. Trauma

Treatment of shark attack begins in the pre-hospital setting, and successful outcome is dependent on adequate pre-hospital care [26–28]. Although injuries sustained are similar in severity to serious motor vehicle crashes, the circumstances are markedly different. Victims are often in a state of extreme exhaustion, having had to make their way through surf with exsanguinating haemorrhage greatly impairing their function [26]. They are often hypothermic and near-drowned [21]. Priorities are to secure the airway, control haemorrhage, institute volume resuscitation and re-warm.

The patient should be removed from the surf, but only as far out of the water as is necessary to commence immediate resuscitation. In the presence of often dramatic wounds, the first priority still remains management of the airway. Direct pressure should be applied to any bleeding points. Haemorrhage may result from a combination of arterial laceration or avulsion, massive tissue avulsion and/or long bone fractures. Wherever possible, the latter of these injuries should be reduced as soon as possible. Specialized training for lifeguards for management of major trauma is thought to have contributed to falling mortality rates from shark attack [21]. The Surf Life Saving Club in South Africa provide the 'Shark Attack Pack' to clubs along its coast-line. It contains the equipment to set up ade-

Table 3
Durban classification of prognosis following shark attack, according to wound type (modified from Ref. [8])

Grade of injury	Wound description	Outcome
I	Both femoral arteries; or one femoral artery and one posterior tibial; or one femoral artery in upper 1/3	Often fatal
II	One femoral artery in lower 2/3; one brachial artery; two posterior tibials; abdominal wounds with bowel involvement (major)	Should survive, with appropriate pre-hospital treatment
III	One posterior tibial; superficial limb wounds; no vessels cut; superficial abdominal wounds; with no peritoneal involvement; both forearm vessels	Always survive with appropriate pre-hospital treatment

quate fluid resuscitation and control haemorrhage as soon as the patient is removed from the water [29].

Patients are often young and can compensate for their assault as long as resuscitation can be started quickly. Many surfing breaks are remote from medical assistance, and transfer of the unresuscitated patient over rough terrain to anywhere but the point of definitive care can have disastrous consequences. Prior notification of the receiving hospital is recommended, and the use of a retrieval team to collect a patient should be seriously considered.

5.2. Hospital

Wound care in hospital requires management in the operating theatre; it should be undertaken in the ED only if the patient is cardiovascularly stable. Assessment of tendon, vessel and peripheral nerve injury should be documented. Plain radiographs should be obtained of all injured areas in order to identify fractures or periosteal stripping, and particles of teeth that can remain embedded in bone and act as a future source of sepsis if not identified and removed. Wounds should be swabbed and sent for culture [21,25], and, if possible, photographs of the injuries should be obtained.

The wounds are often grossly contaminated with sand and debris, and are always microbiologically soiled. Devitalised tissue must be debrided, and copious irrigation should be used in cleaning the wounds. Nerves should be tagged and repaired once 'damage control' surgery has been completed. Fractures should be considered dirty and treated accordingly. Large wounds should either be closed around drains or packed open for delayed primary closure. Abrasions and small punctures can be treated with thorough irrigation and topical antibiotics [16].

Post-operative management of shark attack victims may be prolonged. The combination of massive hypovolaemia, myoglobin release, and the nephrotoxicity of certain antibiotics all contribute to an increased incidence of acute renal failure [9]. Between initial blood loss and blood loss from multiple operative procedures, it is common for patients to require massive transfusions. The coagulopathic implications of this must be anticipated and corrected if necessary, and there is always the risk of infection.

Rehabilitation must be through an aggressive team approach. Plastic surgical procedures are often required for many months after the initial attack to ensure optimal results. The psychological effects of the attack on the patient should also not be underestimated [8,26].

5.3. Infection

With an increasing number of patients surviving the initial shark attack, management of infections has become increasingly important [25]. Empirical antibiotic treatment is currently recommended for all shark bites. Tetanus prophylaxis should be given on arrival in hospital. The choice of antibiotics should include cover for *Vibrio* spp. (e.g. with a third generation cephalosporin or ciprofloxacin), *Aeromonas* spp. (that may require imipenem or an aminoglycoside); Staphylococcal and Streptococcal infections must also be covered. Abdominal injuries should, of course, also be covered by antibiotics effective against enteric organisms.

Wounds caused by shark attack must be closely reviewed, as certain organisms are capable of causing fulminant infections including myositis and necrotizing fasciitis. *V. vulnificans* and *V. parahaemolyticus* are of particular concern, the former being associated with at least 30% incidence of a clinically significant bacteraemia [22]. Infected wounds should be cultured and the microbiologist informed of the nature of the injury so as to select appropriate culture medium. Further surgical debridement may be required.

6. Prevention of shark attack

The risk of shark attack can be diminished by risk minimization strategies, perhaps supplemented by repellent devices.

An understanding of shark behaviour and feeding patterns gives some insight into what may or may not be triggers for shark attack. By avoiding areas where sharks feed, and actions that mimic their normal prey, risk of attack can be minimized. Current recommendations to decrease the risk of attack (Natals Sharks Board, ISAF) are summarized in Table 4.

In the unfortunate case where one is faced with an impending attack, the first step is to leave the water as soon as possible. Do not panic, and avoid any erratic movements. If scuba diving, swim along the bottom. Many larger sharks rely on the element of surprise, and acknowledging their presence can diffuse this. Be aware of the warning signs of attack, and be prepared to retreat or respond immediately.

If attacked, try to remain calm; 70% of attacks are hit and run attacks. If the shark returns, use whatever weapons are to hand to fend off the attack; sharks will find easier prey if you make life too difficult for them. If you need to strike a shark, eyes and gills are considered the most sensitive areas. If bitten, stop the bleeding; you will die of haemorrhage before anything else. Make your way quickly and calmly to the shore and summon help.

Table 4
Combined recommendations on behaviour to minimize the risk of shark attack [3,4,7–9,21]

Action	Reason
Seek local advice before swimming in areas where shark attacks have occurred in the past	Locals know the area better than any guide book
Do not harass sharks, no matter how small	Any sized shark is capable of inflicting injury
Do not enter the water if sharks are known to be present, and leave the water quickly and calmly, if asked by a life-guard	The risk of shark attack is a product of the time humans and sharks spend together; if you are not where the shark is, you are safe
Do not swim or dive alone; stay in groups	Sharks are more likely to attack solitary individuals; diving with a friend reduces the chance of attack by 50%
Do not wander too far from the shore	(1) You become an isolated individual; (2) you are further from assistance
Avoid swimming in darkness or twilight hours	These are the hours when sharks feed
Do not enter water if bleeding or menstruating	Sharks detect blood and body fluids in very small quantities
Do not urinate in the water	(See above)
Do not wear shiny jewellery	The reflected light resembles fish scales
Do not wear high contrast bathing costumes	This attracts sharks
The presence of dolphins or porpoises does NOT imply the absence of sharks	They often feed together
Leave the water when pods of dolphins cluster closer together, or head inshore	This behaviour is associated with the proximity of sharks
Avoid waters with known outflow (harbour mouths, effluent or current flooding)	These areas attract sharks
Avoid waters with commercial fishing, or spear fishing	These areas attract sharks
Avoid waters with active sea-bird feeding	This may indicate the presence of fish which in turn could attract sharks
Refrain from excess splashing	This suggests an animal in distress
Do not allow pets to swim with you	They have a tendency to splash
Be cautious when crossing between sandbars or at steep drop-offs	These are favourite feeding spots
Avoid murky water	Poor visibility for shark
IF IN DOUBT, GET OUT!	

A wide variety of devices have been used to deter sharks from entering large areas, or the individual's 'personal space'. Large area exclusions have been most successfully achieved through the use of shark nets. They do not form a continuous barrier or reach the seabed, but are extended between anchors and buoys. Approximately equal numbers are trapped on the seaward and landward sides of the nets, and it is thought the sharks are drawn to the nets by vibration patterns that they set up underwater [21]. The 50 cm diameter mesh is wide enough to trap sharks by their pectoral fins and tails, and they drown in their struggle to free themselves.

Although undoubtedly effective in reducing shark attack [30], a problem with shark netting has been the 'bycatch' (the unintended entrapment of other species such as dolphins and sea turtles). Experiments using small air-filled floats ('pingers') to alert dolphins to the presence of the nets are under evaluation in South Africa. Exclusion nets are used in Hong Kong, which unlike the mesh nets used in Australia and South Africa, do not kill sharks, dolphins or sea turtles. Baited lines are being used in Eastern Australia and appear to be effective without the unwanted bycatch.

Personal protective devices have included shark billys (a club), powerheads or bang-sticks (a hand held, modified firearm, to the distal end of which is attached an explosive charge of some variety), poisons [31], chemical repellents [32,33], naturally occurring repellents (including a surfactant toxin secreted from the Moses sole (*Pardachirus marmoratus*) [34,35], and electronic devices (acting on the shark's acute sensitivity to electrical fields). It is in these last two areas that safe, effective personal protection is most likely to be found, but a discussion of the relative merits of all of these techniques is beyond the scope of this review.

7. Conclusions

In the short time that humans and sharks have shared the planet, sharks have always been the masters of their environment. Their impact on humans as a species has been minimal.

This case report demonstrates some of the important principles in the management of shark attack. Early resuscitation, early use of antibiotics, rapid retrieval to a point of definitive care, and aggressive surgical intervention are all keys to a successful outcome. The South African experience has shown that beach side resuscitation improves outcome. Beaches where there are regular shark sightings should have the equipment and appropriately trained personnel to manage a shark attack as first responders.

Since the attack on our patient, there have been four more well publicized shark attacks on humans in Australia, three of which have been fatal [36,37]. Shark attacks are devastating to victims and their families. There is "little consolation to a skin-diver or swimmer whether a shark encounter is investigatory, feeding or fighting" [18]. The collection of information about these encounters must be continued, however. It provides vital information that is already being used to try to minimize the threat.

Subsequent identification of the species of shark involved may not directly benefit the patient, but will provide epidemiological data to further research. In the meantime, irrational calls for further culls of shark populations are unfounded in science. To kill all the sharks that we can find to reduce the contact between sharks and humans and, hence, reduce shark attacks is a facile solution to the shark attack problem. It is beholden upon us to design systems that allow peaceful coexistence with one of nature's oldest and more perfectly evolved creatures.

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