The Epidemiology, Evaluation, and Management of Stingray Injuries

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A descriptive analysis and review of the world's salient scientific literature on stingray injuries was conducted in light of recent high-profile cases of fatal and near-fatal thoracic stingray injuries to guide clinicians in evaluating and managing stingray injuries. Data was extracted from observational and longitudinal studies over the period, 1950-2006, to permit (1) a stratification of stingray injuries as bites, penetrating lacerations with and without envenoming, and combinations of deeply penetrating and envenoming wounds; and (2) an assessment of new management strategies for thoracoabdominal penetrating trauma and non-healing, necrotic stingray wounds. Unlike their Chondrichthyes classmates, the sharks, stingrays are docile and non-aggressive; and will not attack with their spined tails, unless provoked. Although some occupations are predisposed to stingray injuries, most stingray injuries can be avoided by observing seafloors and adopting simple practices when wading, swimming, diving, or fishing in temperate oceans and some tropical freshwater river systems. All stingray injuries should be managed initially with wound irrigation to dislodge retained spine fragments and envenoming tissues and warm water immersion to inactivate heat-labile toxins.

INTRODUCTION

Although sharks may attack man without warning, bottom-dwelling stingrays are non-aggressive and docile, and do not attack man, unless disturbed, by coastal waders or divers, or caught or netted by fishermen. On rare occasions, stingrays have launched off surface waters and into anchored and speeding motorboats inflicting fatal and nonfatal human injuries. Since stingrays are ubiquitous in all temperate and tropical oceans, and even occur in some tropical freshwater river systems, human stingray injuries are very common, but rarely fatal. In the United States (US) alone, 750 to 1,500 stingray injuries are reported each year, compared to an estimated 300 scorpionfish envenomings annually, many in home aquarists, and thousands of catfish-inflicted spine injuries, many of which are not reported.[1–3] Thus, stingrays are an important group of venomous marine fishes.[1–3]

Several fatalities from penetrating thoracic stingray injuries and septic stingray wounds have now been reported.[1] On September 4, 2006, an Australian amateur naturalist was killed by a penetrating stingray injury to the chest while filming venomous marine animals, including stingrays, on the Great Barrier Reef. On October 18, 2006, a 75-year-old retired man was critically injured by a penetrating cardiac stab wound from a stingray that leaped into his boat while he was fishing with his granddaughter in Florida's Intracoastal Waterway. Although these are anecdotal and rare, sensational accounts of stingray attacks, other fatal stingray attacks have been reported and the causes of death determined at autopsies.

As more vacationers spend their leisure time exploring seacoasts and tropical reefs, often in isolated areas without immediate access to advanced health care, there will be greater potential for stingray injuries with poor outcomes.

CME INFORMATION

TARGET AUDIENCE

This CME article is intended for pediatricians, primary care physicians, family medicine practicioners, general internists, emergency medicine practitioners, critical care practitioners, general surgeons, and cardiovascular surgeons.

EDUCATIONAL OBJECTIVES

After reading this article, the healthcare provider should be prepared to diagnose, manage and make recommendations for the prevention of several types of stingray injuries. Estimated time to complete this activity is one (1) hour.

CREDIT

The LSMS Educational and Research Foundation designates this educational activity for a maximum of one (1) *AMA PRA Category 1 Credit*™. Physicians should only claim credit commensurate with the extent of their participation in the activity.

DISCLOSURE

Dr. Diaz has nothing to disclose.

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A retrospective analysis of the descriptive epidemiology of stingray injuries, the mechanisms of stingray envenoming, the multiple clinical presentations of stingray injuries, and the rationale supporting new critical care management strategies for stingray injuries is now indicated and may improve the public health community's ability to better manage and to prevent stingray injuries.

MATERIALS AND METHODS

In order to describe the current global epidemiology, presenting manifestations, and new strategies in the management and prevention of stingray injuries, the National Institutes of Health/National Library of Medicine (NIH/NLM) search engines, MEDLINE, 1966–2006, and OLD MEDLINE, 1950–1966, were queried with the key medical subject headings (MESH), "stingrays", "stingray injuries", and "stingray venoms and toxins". Case reports, case series, epidemiological investigations, and toxicological studies were reviewed; high risk behaviors and occupations for stingray injuries were identified; and human stingray-inflicted injuries were stratified by types of injury as bites, lacerations, envenomings, or multiple, combined injuries. New management strategies for necrotizing stingray wounds, such as hyperbaric oxygenation and topical human growth factors, were presented and discussed.

RESULTS

The biology, behavior, and taxonomy of stingrays (Figure).

Stingrays are dorsoventrally flattened fish, well adapted for searching sea floors for crustaceans, mollusks, and marine worms, which they crush with their ventrally placed, powerful mouths. With muscular wings, stingrays are also hydrodynamically adapted for effortless cruising over long distances along sandy shore lines, often in schools or shoals. Stingrays have even been observed to remain motionless; to drift along underwater currents; to swim backwards; and to catapult themselves off wave tops, like flying fish. When not feeding or schooling, stingrays bury themselves in soft sandy or muddy sea or river bottoms, with their dorsally placed eyes protruding and looking out for potential meals or few predators. Some freshwater eels and stingrays can emit electrical currents to stun prey or predators. When disturbed, stingrays would rather escape quickly than attack with their dorsally spined tails. Most stingrays are very capable of defending themselves when provoked with single or multiple tail spines which jackknife into lacerating positions when their whip-like tails flick sideways or backwards over their bodies. Even divers approaching stingrays from underside or ventral surfaces are at risk of spine injuries as stingrays can quickly arc in circles flipping their tail spines into striking ranges.

There are approximately 150 species of stingrays divided into two super-families, the Dasytoidea, or true stingrays and the Myliobatoidea, or true rays, with each super family further subdivided into three families; some of which have sub-families (Figure).[3, 5] Of the dasyatid stingrays, only the *Urogymus* species lack tail spines and are not venomous.[5] In addition, many of the myliobatid rays, including the giant manta rays, also lack tail spines and are non-venomous.[5] The current taxonomy of stingrays is depicted in Figure.

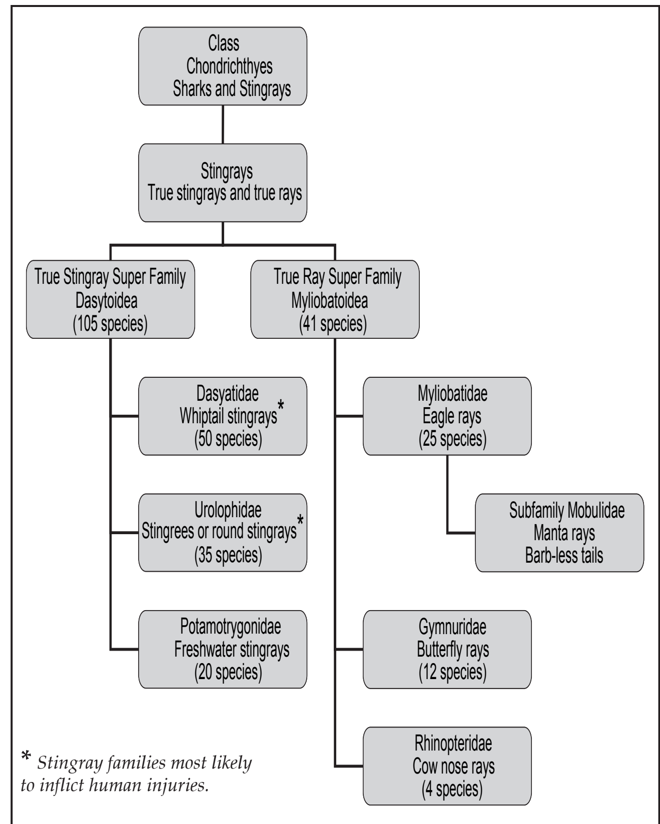

Figure. The taxonomy of stingrays.

Stingrays are widely distributed throughout the temperate and tropical oceans of the world. The freshwater stingrays of the family Potomotrygonidae inhabit the brackish waters, lagoons, and freshwater tributaries of some of the world's major tropical river systems. The smallest stingrays, also known as stingrees, or round stingrays, mostly from the family Urolophidae, have body diameters of 30 cm or less. The giant dasyatid stingrays may have body diameters of more than 2 m and body weights of over 300 kg.[3, 5] The dasyatid stingrays are widely distributed, and bottom-feed in shallow brackish and saltwater and near reefs.[5] The myliobatid rays may also reach very large sizes, especially the giant manta rays (Subfamily Mobulidae), and many species are characterized by spineless tails.[5] The myliobatid rays and the gymnurid or butterfly rays inhabit temperate and tropical oceans worldwide, and frequently school in large shoals.[5] The rhinopterid or cow-nose rays are also distributed in oceans worldwide, including the Mediterranean Sea.[5]

The dasyatid and urolophid stingrays (or stingrees) cause the majority of venomous marine stings in man for several reasons. First, these two families of true stingrays comprise the largest number of stingray species and are the most frequently encountered stingray species in temperate and tropical oceans worldwide. Second, and more importantly, the dorsal location of the barbed tail spine in dasyatid and urolophid stingrays makes these species more efficient stingers than other species. The longer the stingray spine and the more distally located the spine is on the whip-like tail, the greater the danger to humans from stingray spine injuries.[5]

Stingray venoms and the mechanisms of stingray envenoming.

Stingray venoms have not been well studied for a number of reasons including lack of venom glands, difficulty of venom extraction and isolation, physically unstable venom constituents, and unique mechanisms of envenoming. Unlike reptiles, stingrays do not possess distinct venom glands from which venom can be easily milked for analytical investigations. The pioneering work of Dr. Findley E. Russell and his co-investigators has demonstrated that stingray venoms are composed of enzymatically active proteins, which are cardiotoxic and heat-labile.[6–8] Russell and colleagues studied the venom of the urolophid round stingray, *Urolophus* (formerly *Urobatis*) *halleri*, and found it to be composed primarily of 5′-nucleotidase and phosphodiesterase, to have an LD50 of 28 mg/kg in experimental animals, and to be heat labile at warm and hot temperatures.[6] In addition, most of the venom's toxicity was inactivated by freeze drying.[6] The investigators found the venom to have cardiotoxic effects in man and experimental animals, but no anticoagulant, hemolytic, or neuromuscular blocking properties.[7, 8] Following electrocardiographic studies, Russell and co-investigators ascribed the arrhythmogenic and cardiodepressant effects of stingray venom to direct myocardial toxicity.[7, 8] Nevertheless, the exact molecular mechanisms of the myotoxic effects of stingray venoms remain unknown.

The stingray spine has both a unique histologic architecture and venom delivery system. Spines are flat and stiletto-sharp with backward pointed barbs or serrations. They are composed of a strong bone-like cartilaginous material known as vasodentin. On the underside of the spine are two longitudinal groves which run the length of the spine and are filled with venom-secreting glandular cells. Both the vasodentin spine and its ventral glandular tissues are sheathed in an integument, or epidermis, that tears open when the spine is plunged into a victim, un-roofing glandular tissue to diffuse venom. Bits of integument, spine barbs, and venom-secreting glandular cells often remain in deep lacerations increasing risks of prolonged envenoming; septic wound necrosis (often from marine vibrios); septicemia; *ecthyma gangrenosa* (often from marine clostridia or vibrios); osteomyelitis; and delayed, granulomatous foreign body reactions.[9] Broken spines will regenerate rapidly.

The descriptive epidemiology of stingray injuries.

As noted, stingray injuries are common in coastal and island communities worldwide and range from 750 to 1,500 per year in the US to thousands of cases per year in tropical regions with freshwater stingrays inhabiting delta and inland river systems, heavily relied upon for recreation, transportation, and fresh seafood.[3, 5] Fatalities from stingray injuries are rare and range from one to two or less per year in Indo-Pacific countries and the US, to as many as eight per year in South American countries with freshwater or Amazonian stingrays (Potamotrygonidae).[5]

Certain hobbies and occupations appear to predispose individuals to stingray injuries. Hobbies that put potential victims in close proximity to stingrays and stingray injuries include wading, snorkeling, scuba and skin diving, beach or wade-fishing, bottom fishing, spear-fishing, floundering (spear-fishing for flounders or other shallow-water flat fish), and maintaining home saltwater and tropical freshwater aquariums.[10, 11]

The most common occupations that predispose individuals to stingray injuries include commercial divers, sponge fishermen, shrimpers, trawl net fishermen, tropical fish handlers and retailers, and municipal aquarium workers.[11] Bryce reported a very unusual case of an aviator with a stingray inflicted injury.[12]

The most common stingray injuries occur on the extremities, especially on the dorsal aspects of the feet, the ankles, and the hands.[13–15] Waders and undersea divers are predisposed to lower extremity injuries, and fishermen are predisposed to upper extremity injuries sustained when

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disentangling stingrays from fishing hooks and trawl nets. In 2005, Forrester conducted a retrospective, descriptive analysis of 153 stingray injuries reported to poison centers in Texas over the period, 1998–2004.[15] Forrester noted that stingray injuries occurred most commonly in public beach areas in males 19 years of age and older; during warmer, summer months, most often in August; and mostly were managed (61%) outside of health care facilities.[15]

In 1958, Russell and colleagues reported two fatalities from stingray injuries in the US.[1] In 1989, Fenner and coauthors described a delayed death from cardiac tamponade in a 12-year-old boy who had sustained a penetrating stingray spine wound through the left chest at the nipple from a leaping stingray, while riding in a speeding motorboat off the coast of North Queensland six days earlier.[16] A post-mortem examination identified a left pleural effusion of 70–100 mL of fresh blood, a puncture wound of the left mid-pericardium, a 1 cm thick rind of clotted blood in the pericardial cavity, and a fresh left ventricular perforation.[16]

In 2001, Weiss and Wolfenden reported the case of a survivor of a penetrating stingray injury to the heart, who was evacuated to Sydney, Australia, for immediate cardiac surgery and repair of a cardiac laceration.[17] In 2003, Campbell and coauthors reported their experience in repairing a pseudoaneurysm of the superficial femoral artery that resulted from a stingray spine laceration to the groin in a young woman diving off the coast of Nova Scotia, Canada.[18] Although thoracoabdominal stingray spine injuries are rare and unusual, they can be fatal and often require surgical exploration and critical care monitoring for cardiac arrhythmias, cardiac tamponade, and aneurysms and arteriovenous fistulae resulting from vascular injuries.[26–18]

Although Russell and colleagues reported the cardiotoxic effects of stingray venoms and studied the electrocardiographic changes induced by stingray venoms, reports of cardiac arrhythmias following stingray injuries are also uncommon.[6–8] In 1989, Ikeda reported managing a patient with supraventricular bigeminy following a stingray injury sustained while swimming in the Hawaiian islands.[19] Thus, electrocardiographic monitoring is indicated in serious stingray injuries, especially following thoracoabdominal stingray injuries.[6–8, 19]

Since the 1950s, stingray injuries treated in emergency departments and/or reported to poison control centers have only been described retrospectively. To date, no prospective multi-center collaborative investigations by coastal medical centers have been conducted to verify the frequencies and fatal and nonfatal outcomes of stingray injuries.

The multiple clinical manifestations of stingray injuries.

Stingrays may inflict several types of nonfatal human injuries, including innocuous bites, superficial lacerations without envenoming, deeply penetrating lacerations, prolonged envenoming from retained glandular tissues, and combined penetrating and envenoming wounds with retained foreign body fragments. Much less common than nonfatal stingray injuries, fatal stingray injuries may result from penetrating thoracic trauma with immediate or delayed cardiac tamponade; cervical lacerations with airway compromise; penetrating vascular wounds with hemorrhagic shock; and delayed wound infections with gangrene, wound botulism, and septic shock.[1, 16–18]

Although most stingray injuries are inflicted by the barbed dorsal tail spine, all stingrays have ventral scooping mouths with raspy "teeth" of vasodentin designed for crushing crustacean and mollusk shells. In 1996, Evans and Evans reported a case of a relatively minor soft tissue lesion from a stingray bite, which they described as a stingray "hickey".[20] Since the powerful mouths of stingrays are specifically adapted for crushing shellfish, a stingray bite could potentially cause more serious injuries than "hickeys", including crushing injuries to the digits.[20]

Non-envenoming stingray lacerations are caused by superficial or regenerating spine injuries not associated with retained bits of glandular tissues and integumental sheaths, which may have been stripped off in recent defensive actions. Non-envenoming lacerations can still cause considerable pain and bleeding. On the other hand, envenoming stingray wounds are characterized by combinations of stiletto-sharp spine lacerations, severe lancinating pain, systemic envenoming reactions from retained glandular tissues, and delayed foreign body reactions to retained fragments of vasodentin barbs and integument.[9] The typical stingray wound bleeds profusely at first, and then gradually becomes exceedingly painful over 15 to 90 minutes.[5] Although stingray venom was initially thought to have anticoagulant properties, clinical and toxicological studies by Russell and co-investigators have not demonstrated anticoagulant or hemotoxic effects.[8]

As the acute bleeding resolves, the tissues surrounding the wound site take on an erythematous color that fades into a bluish-gray or cyanotic hue. Brawny edema surrounding wound site may develop over 30 to 90 minutes, and can evolve to affect the entire limb.[5] Unless relieved by treatments including warm water immersion, local or regional anesthetic blocks, and parenteral analgesics, the lancinating pain will persist for several hours and may extend to the entire limb. Thoracic injuries are associated with dyspnea and hypoventilation.[5]

The systemic manifestations of stingray envenoming include anxiety, diaphoresis, syncope, nausea, vomiting, diarrhea, cardiac arrhythmias, hypotension, and, potentially, cardiogenic shock. As noted, Russell and colleagues were among the first investigators to identify the direct cardiotoxic effects of stingray venoms and to study the electrophysiologic effects of stingray venom on the electrocardiogram (ECG).[6, 7]

In summary, stingray injuries may range from bites and regenerating spine lacerations without envenoming to deeply penetrating lacerations with prolonged venom release from wound-embedded glandular tissues. Delayed foreign body and septic reactions to retained fragments of

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vasodentin and integument may be associated with later wound necrosis, osteomyelitis, wound botulism, gangrene, or *echythema gangrenosa*.[9] Although most stingray injuries are nonfatal, confined to the extremities, and heal without complications, wound sepsis and osteomyelitis may result in amputations of extremities, and thoracic injuries have resulted in immediate and delayed fatalities from cardiac laceration and tamponade.[1, 16]

The management of stingray injuries.

The initial management of stingray injuries should begin at the scene immediately, and be followed by wound exploration and management at nearby healthcare facilities. Stingray injured victims with thoracoabdominal wounds and systemic manifestations should be referred to tertiary care facilities equipped and staffed for all imaging technologies (radiographs, ultrasound and magnetic resonance imaging), critical care management, and cardiovascular surgery.

Initial management of stingray injuries should begin in the water as the victim is primarily assessed for cardiopulmonary stability; and the wound is gently bathed in seawater to remove fragments of spine, glandular tissue, and integument. The victim should be removed from the water, and the spine removed, only if superficially embedded; and not penetrating the neck, thorax, or abdomen; or penetrating through-and-through the extremities. Any significant bleeding from lacerated vessels should be staunched with local pressure only and not by a tourniquet or by pressure immobilization. The wound should not be incised or have anything introduced directly into it, including local anesthetics or vasoconstrictors, at the scene. If available, the wound should be cleaned with fresh water or sterile irrigating solutions.

Since stingray venom is heat labile, many authorities recommend immediate immersion of the affected limb in warmed fresh water after immersing the uninjured contralateral limb first to assure safe water temperature and to prevent scalding.[5, 7] Some surgical experts feel that immediate salt then freshwater wound irrigation and warm water immersion of stingray-inflicted lesions at the scene of injury will have an impact on the amount of subsequent wound necrosis, need for extensive wound debridement, and rapidity of wound healing. Nevertheless, warm water immersion has never been verified as a safe and effective early therapy for stingray injuries in prospective randomized controlled trials and has the potential to cause further thermal injuries.

Once admitted to a medical facility, the victim should be reassessed for cardiorespiratory stability. Tetanus prophylaxis should be administered, and appropriate analgesia established using parenteral analgesics and peripheral and regional nerve blocks without norepinephrine, or other vasoconstrictor (eg, phenylephrine), containing

local anesthetics.[21] After establishing appropriate analgesia, the wound should be carefully and thoroughly explored removing all fragments of spine, barbs, and foreign tissues.[21, 22] Radiographic examinations of the wound sites may reveal retained hyperdense, radiopaque fragments of cartilaginous vasodentin spines or barbs; but may not demonstrate hypodense fragments of integumentary and glandular tissues.[22] Since sharks and stingrays have cartilaginous endoskeletons, spine fragments may not be visible on conventional radiographic examinations. Magnetic resonance imaging and ultrasound examinations of wound sites may also help to locate hypodense, space-occupying retained foreign bodies, gas pockets, and cyst-abscesses in septic wounds.

Expert surgical consultation should be sought for the repair of vascular injuries and lacerated nerves and tendons, and for all stab wounds of the neck, thorax, or abdomen. Penetrating wounds of the neck, thorax, and abdomen may be associated with significant cardiovascular injuries including cardiac stab wounds and neurovascular bundle injuries. Such wounds should be managed as contaminated knife wounds and will require surgical exploration under general anesthesia with removal of the stingray spine and its fragments and repair of neurovascular and cardiac injuries. Cardiopulmonary bypass may be required for penetrating cardiac injuries. Pseudoaneurysm formation, and even arteriovenous fistulae, may follow deeply penetrating stingray vascular injuries, and require vascular repair of lacerated arteries and veins.[18]

Following wound exploration, debridement of devitalized tissues, and repair of vessel, nerve, or tendon injuries, stingray wounds should not be closed primarily, but left open for drainage.[22] Clean, superficial wounds may be loosely sutured closed later. Deeply penetrating wounds may require additional surgical drainage and be allowed to remain open to heal by secondary intention through granulation.[22] In reported cases where stingray wound management was complicated by continuing tissue necrosis and ulceration, the topical application of recombinant human platelet-derived growth factor-BB (0.01% becaplermin gel) and hyperbaric oxygenation were used with standard wound management to successfully treat non-healing stingray wounds.[23, 24] Neither topical growth factor nor hyperbaric oxygenation, however, have been verified as safe and effective therapies for non-healing stingray injuries in prospective randomized controlled trials.

In a 1987 investigation of bacterial diversity in marine environments, Auerbach and coauthors isolated 67 pure bacterial colonies from seawater; 57% (n = 38) of which belonged to six species of the genus *Vibrio*.[25] Antibiotic sensitivity testing of the *Vibrio* isolates demonstrated resistance to a wide variety of antibiotics. However, antibiotics effective against all six species of *Vibrio* isolates included chloramphemicol, imipenem, and trimethoprim/sulfamethoxazole.[25] Thus, early antibiotic prophylaxis for commonly infecting marine vibrios with trimethoprim/sulfamethoxazole and for marine mycobacteria with rifampin should be considered for all penetrating stingray wounds, and verified by culture and sensitivity testing from wound aspirates and exudates. Mycobacterial infections may require prolonged treatment with rifampin.

The prevention of stingray injuries.

Since stingrays are naturally docile and skittish creatures, most stingray injuries may be prevented by simple education and avoidance measures. Since stingrays are bottom-dwellers, waders, skin and scuba divers, and snorkel divers should always observe the seafloors and not intentionally provoke encounters with stingrays. Crossing murky shallow bays, estuaries, tidal pools, and some tropical freshwater rivers, should always be undertaken with care, shuffling one's feet or even poking the bottom with walking sticks.

Divers should not swim too close to the sea bed to avoid potentially fatal thoracoabdominal stingray injuries. Diving suits and diving boots will provide no protection against stingray spine lacerations. Fishermen should not attempt to disengage or disentangle a stingray from a fishing line or net, or try to grab a stingray flapping on deck to fling it overboard. Saltwater and tropical freshwater aquarium owners and municipal aquarium workers must be observant and careful when cleaning and maintaining their aquariums as even the smallest saltwater and freshwater stingray species can inflict painfully envenoming wounds. Finally, municipal aquarium operators should re-consider placing venomous marine animals, including stingrays, in petting tanks for children.

CONCLUSIONS

Stingray injuries range from inconsequential bites or "hickeys", to envenoming and non-envenoming lacerations of the extremities, to potentially fatal cervical and thoracoabdominal penetrating trauma. Although non-fatal wound necrosis and infections are not uncommon following significant stingray injuries to the extremities, fatalities from stingray injuries are very rare and usually follow thoracic stingray injuries. All stingray injuries should be managed immediately with flushing irrigation of penetrating wounds to flush out retained spine fragments, barbs, envenoming tissues, and bits of integument; and warm water immersion to inactivate any heat-labile toxins. All deeply lacerating and thoracoabdominal injuries will require early referral to healthcare facilities equipped for medical and surgical critical care, including all imaging technologies and cardiopulmonary bypass. Although some occupations are predisposed to stingray injuries, most stingray injuries can be avoided by careful observation and simple behavioral practices when wading, diving, or fishing in temperate oceans and tropical freshwater river systems.

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1. The mechanisms of envenoming by stingrays are characterized by
   a. Breakaway venom cells.
   b. Discrete venom glands.
   c. Hollow barbed spines.
   d. Poison-tipped spines.

2. Stingray venom components have been demonstrated to exert all of the following pharmacologic properties except
   a. Anticoagulant.
   b. Arrhythmogenic.
   c. Cardiodepressant.
   d. Thermal instability.

3. Retained stingray spine fragments are best detected by
   a. Computerized tomography.
   b. Conventional radiographs.
   c. Magnetic resonance imaging.
   d. Microscopic wound exploration.

4. The most common contaminating microorganisms in penetrating stingray injuries are the marine
   a. Clostridia.
   b. Mycobacteria.
   c. Rotaviruses.
   d. Vibrios.