A
lthough sharks may attack man without warn-
ing, stingrays are docile, usually nonaggressive,
and do not attack man unless disturbed, by coastal
waders or divers or caught or netted by fisherman.
Because stingrays are ubiquitous in all temperate
and tropical oceans worldwide, and even occur in
many tropical freshwater river systems, human
stingray injuries are common but rarely fatal. In the
United States alone, 750 to 2,000 stingray injuries
are reported each year compared with more than
300 scorpionfish envenomings annually, many in
home aquarists, and thousands of catfish-inflicted
spine injuries, most of which are not reported.1–6
On very rare occasions, stingrays have launched off
surface waters and into anchored or speeding
motorboats, inflicting fatal human injuries. Several
fatalities from penetrating thoracic stingray injuries
and septic stingray wounds have now been re-
ported.1–4,7 Although not as common as injuries
caused by other venomous fish, stingray injuries are
an important group of, mostly preventable, marine
envenomings.1–4
Since the 1950s, stingray injuries treated in
emergency departments and/or reported to poison
control centers have only been described retrospec-
tively and, often, incompletely. To date, no pro-
spective multicenter collaborative investigations by
coastal medical centers have been conducted to ver-
ify the frequencies and fatal and nonfatal outcomes
of stingray injuries. Nevertheless, as more vacation-
ing travelers spend more leisure time exploring
seacoasts and tropical reefs, often in isolated island
areas without immediate access to advanced health
care services, there will be greater potential for
stingray injuries with poor outcomes. A retrospec-
tive meta-analysis of the descriptive epidemiology
of stingray injuries, the mechanisms of stingray en-
venoming, the multiple clinical presentations of
stingray injuries, and the management strategies for
stingray injuries is now indicated and may improve
the clinician’s ability to better manage and to pre-
vent stingray injuries in travelers.

Materials and Methods
To describe the epidemiology, pathophysiology,
presenting manifestations, and any new strategies
in the management and prevention of stingray inju-
ries, the National Institutes of Health/National Li-
brary of Medicine search engines, MEDLINE,
1966 to 2007, and OLD MEDLINE, 1950 to 1966,
were queried with the key medical subject headings,
“stingrays,” “stingray injuries,” “stingrays and bites
and stings,” and “stingrays and venoms and toxins.”
Case reports, case series, epidemiological investiga-
tions, and toxicological studies were reviewed;
high-risk behaviors and occupations for stingray inju-
ries were identified, and human stingray-inflicted
injuries were stratified as bites, lacerations, enven-
omings, or multiple, combined injuries. Traditional
and new, but untested, management strategies for
necrotizing stingray wounds were described.
Results

The Biology, Behavior, and Current Taxonomy of Stingrays

Stingrays are dorsoventrally flattened fish, well adapted for searching seafloors for crustaceans, mollusks, and marine worms, which they efficiently crush with their ventrally placed, powerful mouths. With muscular wings, stingrays are also aerodynamically adapted for effortless cruising over long distances along beachfronts or reefs, often in schools or shoals. Stingrays have even been observed to remain motionless, to drift along underwater currents, to swim backward, and to catapult themselves airborne 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 even 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 backward 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 (Figure 1).

There are approximately 150 species of stingrays divided into two superfamilies, the Dasytoidea, or true stingrays, and the Myliobatoidea, or true rays, with each superfamily further subdivided into three families; some of which have subfamilies (Figure 1). Of the dasyatid stingrays, only the Urogymus species lack tail spines and are not venomous. In addition, many of the myliobatid rays, including the giant manta rays, also lack tail spines and are nonvenomous.

Stingrays are 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 including the Amazon, Araguaia,

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Figure 1 The current taxonomy of stingrays.

*Stingray families most likely to inflict human injuries because of their long tails and more distally located dorsal tail spines.
The dasyatid and urolophid stingrays (or sting-rees) 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 most 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. In the butterfly rays (Gymnuridae), the dorsal tail spines are small, less than 2.5 cm long, and attached to the root or proximal part of the tail. In the eagle rays (Myliobatidae), the dorsal tail spines are long, up to 12 cm, but also proximally perched atop the root of the tail. In the dasyatid and urolophid stingrays, however, the dorsal tail spines are positioned more distally than in other species. Finally, the dasyatid stingrays have significantly longer spines, 30 cm or longer in the largest dasyatid stingrays, than all other species of stingrays. The combination of distally placed long spines on long tails makes the dasyatid and urolophid stingrays the most dangerous group of stingrays during human encounters (Figure 1).

Stingray Venoms and the Mechanisms of Stingray Envenoming

Unlike reptile venoms, 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 snakes, stingrays do not possess distinct venom glands from which venom can be easily milked for analytical investigation and antivenom manufacture. The historic, pioneering work of Russell and colleagues has demonstrated that stingray venoms are composed of many enzymatically active proteins, which are cardiotoxic and heat labile. Russell and colleagues studied the venom of the urolophid round stingray, *Urolophus* (formerly *Urobatis*), 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. In addition, most of the venom’s toxicity was inactivated by freeze-drying. The investigators also found the venom to have cardiotoxic effects in man and experimental animals but no anticoagulant, hemolytic, or neuromuscular-blocking properties. Following electrocardiographic studies, Russell and colleagues ascribed the arrhythmogenic and cardiodepressant effects of stingray venom to direct myocardial toxicity. Nevertheless, the exact molecular mechanisms of the cardiotoxic effects of stingray venoms remain unknown.

More recent studies of the mechanisms of stingray envenoming injuries by US Navy researchers have reported a unique combination of inflammatory cell infiltrates in necrotic tissues debrided 4 days after penetrating stingray injuries. German and colleagues histologically characterized the inflammatory infiltrates in recent stingray wounds as being composed of lymphoid cells, mostly CD3+ and CD4+ lymphocytes and eosinophils. The authors concluded that this unique population of inflammatory cells and their chemical mediators in stingray wounds might contribute to the acute inflammatory reactions and the later necrosis and delayed healing in some stingray injuries.

In 2004, Haddad and colleagues studied freshwater stingray (*Potomotrygon falkneri*) venom by gas chromatography/mass spectrometry in Brazil and detected several unique enzymatic components distributed between 15 and 130 kDa. The investigators further stratified the enzymatic activities in venom extracts as caseinolytic and gelatinolytic between 80 and 100 kDa with all hyaluronidase activity centered around 80 kDa. The authors concluded that such a combination of enzymatic activities in freshwater stingray venom could contribute to the unique pattern of surrounding skin necrosis observed in many patients with freshwater stingray injuries in Brazil.

The stingray spine has both a unique histologic architecture and a venom delivery system. The flat spines are stiletto sharp, with backward-pointed barbs or serrations, and are composed of a strong bone-like cartilaginous material, known as vasodentin. On the underside of the spine are two longitudinal grooves, 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, unroofing 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 gangrenosum (often from marine clostridia or vibrios); osteomyelitis; and delayed, granulomatous foreign body reactions. Broken spines will regenerate rapidly.

The Descriptive Epidemiology of Stingray-Infl icted Injuries
As noted, stingray injuries are common in coastal and island communities worldwide and range from 750 to 2,000 per year in the United States 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. Fatalities from stingray injuries are rare and range from one to two or less per year in Indo-Pacific countries and the United States to as many as eight per year in South American countries with freshwater or Amazonian stingrays (Family Potamotrygonidae). 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, spearfishing, floundering (spearfishing for flounders or other shallow water flat fish), and maintaining home saltwater and tropical freshwater aquariums. Kizer and colleagues described 51 cases of scorpionfish (Family Scorpaenidae) envenomation in the United States, 45 of which were inflicted by lionfish (Pterois volitans) in home saltwater aquarium owners and tropical fish sellers. In 2000, Van Offel and Stevens reported a stingray injury in “a devotee of aquarium fishes” in Belgium, where stingray injuries were rarely reported. The authors encouraged physicians in other nontropical nations to become informed about the clinical presentation and management of stingray injuries in home aquarists and aquarium devotees. The most common occupations that predispose individuals to stingray injuries include commercial divers, sponge fishermen, shrimpers, trawl net fishermen, tropical fish handlers and retailers, home aquarists, and municipal aquarium workers. Bryce reported a very unusual case of an aviator with a stingray-inflicted injury. The most common stingray injuries occur on the extremities, especially on the dorsal aspects of the feet, the ankles, lower legs, and hands. Waders and undersea divers are predisposed to lower extremity injuries and fishermen are predisposed to upper extremity injuries sustained when disentangling stingrays from fishing hooks and trawl nets. Most stingray injuries occur in young males.

In 2001, Isbister conducted a prospective observational study of 22 patients with tropical fish stings in tropical northern Australia. The study population included 19 males and 3 females with a mean age of 35 years. Most (n = 17) of the injuries were inflicted by either stingrays (n = 9) or catfish (n = 8). In 2005, Forrester reported that stingray injuries in coastal Texas occurred most commonly in public beach areas in males aged 19 years and older during warmer, summer months, most often in August, and most injuries were managed (61%) outside of health care facilities.

In 1958, Russell and colleagues reported two fatalities from stingray injuries in the United States. In 1989, Fenner and colleagues 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 6 days earlier. A postmortem examination identified a left pleural effusion of 70 to 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.

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. In 2003, Campbell and colleagues 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.

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 uncommon. In 1989, Ikeda reported managing a patient with supraventricular bigeminy following a stingray injury sustained while swimming in the Hawaiian Islands.

The Multiple Clinical Manifestations of Stingray Injuries
Stingrays may inflict several types of nonfatal human injuries, including 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.1,24,27–32 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.1,24,27–32

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 crushing lesion from a stingray bite.31 Because the powerful mouths of stingrays are specifically adapted for crushing shellfish, a large stingray bite could potentially cause more serious injuries than bites, including crushing injuries to the digits.

Nonvenoming 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. Nonvenoming lacerations can still cause excruciating pain and profuse bleeding. In contrast, envenoming stingray wounds are characterized by combinations of sharp spine lacerations, severe lancing pain, systemic envenoming reactions from retained glandular tissues, and delayed foreign body reactions to retained fragments of vasodentin barbs and spine integument.27–30 The typical stingray wound bleeds profusely at first, and then gradually becomes exceedingly painful over 15 to 90 minutes.9 Although stingray venom was initially thought to have anticoagulant properties, clinical and toxicological studies by Russell and colleagues have not demonstrated specific anticoagulant or hemotoxic effects.13 Nevertheless, Germain and colleagues at the National Naval Medical Center in Bethesda, Maryland, United States, have described delayed petechiae formation around stingray wounds, suggesting local antiplatelet effects.6

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.6,9 Brawny edema and petechiae surrounding the wound site may develop over 30 to 90 minutes and can evolve to affect the entire limb. 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.1,24

The systemic manifestations of stingray envenoming include anxiety, diaphoresis, syncope, nausea, vomiting, diarrhea, 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.11,12 Ikeda later reported supraventricular bigeminy following a stingray injury in a Hawaiian diver.27 Although cardiac arrhythmias may occur following stingray injuries, they are very rarely reported.

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 health care facilities. Stingray injured victims with thoracoabdominal wounds and systemic manifestations should be immediately referred to tertiary care facilities equipped and staffed for all imaging technologies, 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 at the scene, including local anesthetics or vasoconstrictors. If available, the wound should be cleaned with freshwater or sterile irrigating solutions. Because stingray venom is heat labile, many authorities recommend immediate immersion of the affected limb in warmed freshwater after immersing the uninjured contralateral limb first to assure safe water temperature and to prevent scalding.9,22,33,35 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 additional thermal injuries.

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. In 1984, Barss reported his personal experience in surgically managing two cases of stingray injuries inflicted by Australian dasyatid stingrays and associated with extensive tissue necrosis. In one patient, the wound was inflicted by *Dasyatis kuhlii*, the blue-spotted stingray and in the other case, by *D. sephen*, the cowtail ray. Following immediate and extensive debridement, the author reported that the wounds in both patients healed rapidly without complications. Barss recommended immediate wound exploration and thorough debridement of devitalized tissues in all dasyatid stingray injuries, particularly in cases in which effective first aid measures, such as warm water immersion and early wound irrigation, have not been carried out at the scene of injury.

Once admitted to a medical facility, tetanus prophylaxis should be administered, and appropriate analgesia established using parenteral analgesics and peripheral and regional nerve blocks without epinephrine, or other vasoconstrictor-containing (e.g., cocaine, phenylephrine) local anesthetic solutions (e.g., tetracaine–adrenalin–cocaine). After establishing appropriate analgesia, the wound should be carefully and thoroughly explored removing all fragments of spine, barbs, and foreign tissues. Radiographic examinations of the wound sites may reveal retained hyperdense, radioopaque fragments of cartilaginous vasodentin spines or barbs but may not demonstrate hypodense fragments of integumentary and glandular tissues. Because sharks and stingrays have cartilaginous endoskeletons, spine fragments may not be visible on conventional radiographic examinations. Magnetic resonance imaging examinations of wound sites may also help to locate hypodense, space-occupying foreign bodies retained in soft tissues, 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. 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.

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 nonhealing stingray wounds. Neither topical growth factor or hyperbaric oxygenation have, however, been verified as safe and effective therapies for nonhealing stingray injuries in prospective randomized controlled trials.

In a 1987 investigation of bacterial diversity in marine environments, Auerbach and colleagues isolated 67 pure bacterial colonies from seawater; 57% (n = 38) of which belonged to six species of the genus *Vibrio*. 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 chloramphenicol, imipenem, and trimethoprim/sulfamethoxazole. Although the routine use of antibiotics is not recommended for most venomous fish stings, early antibiotic prophylaxis for commonly infecting marine vibrios with trimethoprim/sulfamethoxazole should be considered for deeply penetrating stingray wounds and verified by culture and sensitivity testing from wound aspirates and exudates.

**The Prevention of Stingray Injuries**

Because stingrays are naturally docile and skittish creatures, most stingray injuries may be prevented by simple education and avoidance measures. 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 and their tributaries 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 seabed 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, tropical fish sales personnel, 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.
municipal aquarium operators should reconsider placing venomous marine animals, including stingrays, in petting tanks for children.

Conclusions

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 vasodentin and integument may be associated with later wound necrosis, osteomyelitis, wound botulism, gangrene, or *echyma gangrenosa.* Most stingray injuries are nonfatal, confined to the extremities, and heal without complications. Very rarely, 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.

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 worldwide.

Acknowledgments

Financial support for J. H. D. was provided by departmental and institutional sources and by a State Grant from the Health Education Fund of the Board of Regents, State of Louisiana, entitled “The Assessment and Remediation of Public Health Impacts due to Hurricanes and Major Flooding Events.”

Declaration of Interests

The author states he has no conflicts of interest.

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