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*REVIEW*

# Marine biological injuries and their medical management: A narrative review

Xiao-Yu Geng, Ming-Ke Wang, Jin-Hong Chen, Liang Xiao, Ji-Shun Yang

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## Abstract

The marine environment can be extremely dangerous, and the harm caused by marine organisms when they contact the human body can be especially harmful, even deadly. Contact includes stings, bites, wounds, and consumption as food. In this article, the characteristics of the common marine biological injuries are summarized, the major marine organisms causing damage in China's marine waters are described, and injury prevention and treatment methods are discussed.

**Key Words:** Marine organism; Injuries and wounds; Prevention; Treatment



**Core Tip:** With the changes occurring in the marine environment caused by the climate change and the continuous development of marine resources, marine biological injuries are increasing. This article classifies marine biological injuries such as stabs and bites, describes the characteristics of infections by marine microorganisms, and summarizes the prevention and treatment of major marine biological injuries in China's sea areas.

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## INTRODUCTION

In recent years, due to changes in the marine environment caused by the climate change, there have been outbreaks of some harmful marine organisms, such as jellyfish and microorganisms, and the rate of marine biological injury has increased yearly. Tens of thousands of people worldwide are injured every year. For example, off the coast of Australia, about 10000 people are injured by jellyfish stings every year. Marine biological injuries can be roughly divided into marine microbial infections, marine plant or animal stabs and bites, which can range from local skin damage to systemic poisoning reactions [1]. This article was written in response to the greater need for a reference on the prevention and treatment of these injuries for coastal residents, naval officers, and soldiers who may be involved in the accelerated implementation of China's marine development strategy in their daily life and training. For this article, we reviewed various academic papers written in the past 30 years since 1993, classified them according to the types of marine biological injuries mentioned, described the characteristics of the injuries and the key points of prevention and treatment, and put forward future research directions and suggestions for existing problems.

## THE BASIC SITUATION OF MARINE BIOLOGICAL INJURIES RESEARCH

Using the search terms "marine biological injury" in Wanfang, China National Knowledge Infrastructure (CNKI), PubMed, and other public databases, a total of 842 research reports related to marine biological injury were found from 1993 to 2022. We found that 612 articles written in Chinese accounted for 43.3% of the total. The 801 articles in English accounted for 56.7% of the total. There were an additional 175 articles in Chinese that were also reviewed, accounting for only 12.4% of the total. After a more accurate search for marine biological injury, taking the Chinese literature found in Wanfang and CNKI as an example, there were only 52 related articles. In general, the number of cases of marine biological injury has increased since 2005, and attention has been paid to the research on marine biological injury, showing an increasing trend year by year (Table 1). The domestic research on marine biological injury and its prevention and treatment are still in development compared with foreign countries.

## CLASSIFICATION AND INJURY CHARACTERISTICS OF MARINE ORGANISMS

According to the investigation by Liu *et al* in 2020[2], during the coastal training of the Chinese army, the officers and soldiers commonly encountered a variety of toxic marine organisms such as jellyfish, sea snakes, sea urchins, conches, and stinging fish. The main types of marine biological injuries were jellyfish stings and sea snake bites, of which jellyfish stings accounted for about 60.81% of the total number of those reported. This finding is roughly the same as the 2009 survey results reported by Zhong *et al*[3]. Zeng's survey showed that marine biological injuries in the 10 sea ports and sea areas of the South China Sea during 2002–2006 were mainly jellyfish stings, stingray stings, and sea snake bites. Among them, jellyfish stings accounted for 58.83% of the total number of reported injuries, stingray stings accounted for 16.41%, and sea snake bites accounted for 6.2%. Most of these injuries were associated with bacterial infections. For example, *Clostridium* spores are a common source of infection and have greatly increased the difficulty of treatment and the rate of disability and death. That said, prevention and control measures for all types of marine biological injuries can be effective, but according to the report by Liu *et al*[2], taking jellyfish stings as an example, less than 30% of subjected Chinese soldiers have correctly mastered these prevention and control measures against marine biological injuries, and this issue is likely to have a negative impact on the combat strength of Chinese officers and soldiers at sea. In the next section, we describe three main categories of marine biological injuries: microbial infection, animal stings, and animal bites.

### *Marine microbial infection*

There are about 10 to 200 million kinds of bacteria in seawater, of which 95% are gram-negative bacteria and facultative anaerobic bacteria. The distribution of seawater samples from the East China Sea and the Yellow Sea showed that the *Vibrio* genus ranked first, accounting for 52.9% of the samples, including *V. alginolyticus*, *V. parahaemolyticus*, *V. fluvialis*, *V. vulnificus*, and *V. carchariae*. The next common source of microbial infections is Enterobacteriaceae, including *Escherichia coli* and *Enterobacter cloacae*, which mainly come from human sources and pollution[4,5]. Disease related to Enterobacteriaceae is mainly caused by food, and there are a few cases of marine Enterobacteriaceae. The *Bacillus* genus also has strong pathogenicity. These microbes are mainly introduced into the body through a wound caused by a marine organism. After a wound caused by a marine organism is soaked in seawater, the infection rate of *Bacillus* is high, about 15%. The next section will mainly summarize the research on Vibrionaceae and *Bacillus* (Table 2).

**Table 1 Research and development status of marine biological injury from 1993 to 2022**

| The number of studies in the literature | | | |
|---|---|---|---|
| **Published time** | **Case analysis** | **Prevention and control measures** | **Review** |
| 1993-1998 | 7 | 7 | 16 |
| 1999-2004 | 12 | 22 | 21 |
| 2005-2010 | 25 | 38 | 32 |
| 2011-2016 | 32 | 37 | 43 |
| 2017-2022 | 30 | 50 | 61 |
| Total | 106 | 154 | 173 |

**Table 2 Characteristics of marine bacteria and therapeutic drugs**

| Bacillaceae (genus) | Bacterial species | Characteristics | Therapeutic drugs |
|---|---|---|---|
| Vibrio family | *Vibrio alginolyticus* | Strongest salt tolerance; prone be involved in infection after trauma | Imipenem, meropenem, cefepime, ceftazidime, chloramphenicol, tetracycline, levofloxacin |
| | | Combined with seawater immersion | |
| | *Vibrio parahaemolyticus* | Mainly exists in seafood, common bacteria of food poisoning | |
| | *Vibrio fluvialis* | Mainly transmitted through the seafood, gangrene is likely to occur if the wound is infected | |
| | *Vibrio vulnificus* | Rapid onset and high mortality | |
| | *Vibrio carchariae* | Rare report | |
| Bacillus family | *Clostridium tetanus* | Strong vitality and can be implanted through sponge abrasion, fin stabbing, *etc.* | Prophylactic vaccination with tetanus antiserum |
| | Anaerobic *Clostridium perfringens* | The disease develops rapidly and can be implanted through fin stabbing, *etc.* | Prophylactic inoculation with gas gangrene antitoxin |

### *Vibrio genus*

*Vibrio* is widely distributed in the ocean. More than 60 kinds of *Vibrio* have been isolated from the ocean, 12 of which are related to human diseases[5-7]. The prevalence of *Vibrio* infection in humans is likely to follow regional climate trends and erupt during unusually warm weather[8]. Pathogenic *Vibrio* can cause intestinal infections, wound infections, food poisoning, and other diseases. Marine *Vibrio* has special properties including being halophilic, psychrophilic, barophilic, and oligotrophic. The secondary infection caused by marine *Vibrio* is different from an ordinary bacterial infection. *V. alginolyticus*, *V. parahaemolyticus*, *V. fluvialis*, and *V. vulnificus* are the main pathogenic Vibrio representatives in China's marine waters. They have been documented to be involved in marine environment injuries related to war, trauma, and bacterial infections[9]. *V. alginolyticus* is one of the most salt-tolerant *Vibrio* species. It is also one of the most isolated *Vibrio* species in the coastal waters of China. *V. alginolyticus* is also an important pathogen of infection after wound trauma combined with seawater immersion. It can cause acute enteritis, food poisoning, otitis media (ear infection), wound infection, bacteremia, and other diseases by producing enterotoxin, hemolysin, and other harmful substances produced by pathogens [10]. Regarding otitis media, it has been reported that the production of bacterial toxins, coupled with excessive immune response[11,12], can lead to inflammatory damage to cochlear structures and sensory cells and ultimately lead to devastating sensorineural hearing loss[13]. Unfortunately, *V. alginolyticus* infection is not easily diagnosed, but early treatment with an external antibiotic can increase the chances for rehabilitation and full recovery from hearing damage[14]. *V. parahaemolyticus* exists in seawater, fish and shrimp, shells, and processed seafood. It is a common pathogen of food poisoning in China's coastal areas for troops stationed on islands and on long-distance ships. According to statistics, this bacterium was also the main cause of bacterial infectious diarrhea in southern China from 2007 to 2012[15]. Climate warming may further cause these sickness emergencies[16]. For example, large-scale and collective food poisoning caused by this bacterium often occurs in the summer, when the weather is much warmer. The pathogenic factors of *V. parahaemolyticus* include enterotoxin, heat-resistant direct hemolysin, and similar hemolysin. In addition to food poisoning and acute diarrhea, *V. parahaemolyticus* can also cause wound infection and bacteremia[10]. Summer is the season of eating more raw and cold

food and seafood, and it is also the peak of the prevalence of intestinal infectious diseases. The clinical characteristic symptoms of diarrhea and food poisoning caused by pathogenic *Vibrio* are less severe, which makes this type of infection more easily ignored and addressed.

*V. fluvialis* is a pathogen transmitted by mouth. The human body is infected by ingesting polluted water and food. Common foods that are connected to this form of infection include fish, shrimp, crabs, oysters, clams, and snails. Poisoning results from, for example, ingesting raw seafood, repeated pollution after cooking has taken place, and cross-pollution between raw and cooked seafood. The sickness from *V. fluvialis* mainly causes acute gastroenteritis, and there are also reports of extraintestinal infections such as hemorrhagic cellulitis, encephalitis, bacteremia, acute otitis, and peritonitis[17]. The symptoms of gastroenteritis are very similar to cholera[18]. The typical symptoms are watery stool, abdominal pain, mild to severe dehydration, and often a fever. If a wound directly contacts the water or seafood polluted by *V. fluvialis*, the bacteria or the virulence factors produced by them will quickly fester and form gangrene, which may also cause cellulitis. An important symptom to notice for clinical diagnosis of this type of infection is hemorrhagic herpes[19,20]. *V. vulnificus* causes the most serious disease among pathogenic *Vibrio*. The course of sepsis caused by *V. vulnificus* is rapid and often fatal. Once infected with sepsis, the initial mortality rate exceeds 60%[20], the highest mortality rate among all foodborne pathogens[21,22]. Its pathogenic factors include enterotoxin, hemolysin, cytotoxin, protease [23], iron chelator[24], adhesion factor, and phospholipase A2[25], which can cause intestinal and extraintestinal infections, such as primary sepsis, traumatic infection, and acute gastroenteritis. And most of these conditions may also develop into sepsis, severe cellulitis, and necrotizing fasciitis. *V. vulnificus* infection tends to occur in men over 45-years-old or in patients with potential liver damage [21]. Infection occurs through raw seafood and open wound contact with seawater[26]. Gastrointestinal symptoms of infected patients are usually not obvious, but systemic poisoning symptoms are common, and the mortality rate is high. Therefore, it is very important to prevent *V. vulnificus* infection. Patients with chronic liver disease and kidney disease should not eat raw seafood, and people with skin wounds should avoid contact with seawater.

### *Bacillus genus*

*Bacillus* can form spores (endospores), which have a strong resistance to harmful external factors and are widely distributed. The endospores have high-temperature resistance, rapid reactivation, strong secretory enzymes, and the ability to survive in both aerobic and anaerobic environments. Marine *Bacillus* is also very hardy and can form spores under unsuitable living conditions. As dormant bodies, endospores can quickly revive under suitable conditions. The common marine bacilli causing injury mainly include *C. tetanus*, anaerobic *C. perfringens*, and a genus found in marine fish, *Mycobacterium. C. tetanus* is a gram-negative bacterium, and its propagules are gram-positive. Its resistance is similar to that of other bacteria, but its spores have especially strong resistance. They can endure boiling for 40–50 min and can survive in the soil for decades. The bacterium is often implanted into the human body through a sponge abrasion or by fin stabbing by a stone fish, scorpion fish, or lionfish[27]. The incubation period is 2–21 d[28,29]. Its typical tetanus are clenched teeth, angular tension, and dysphagia. Patients often die of physical failure, asphyxia, or pulmonary complications[30].

Anaerobic *C. perfringens* is one of the most common pathogens of gas gangrene in the clinic. The name of the condition is related to the fact that the bacterium can decompose the sugar in muscle and connective tissue, produce a large amount of gas, and cause severe emphysema. The bacterium often enters the human body through an injury caused by sharp fish fins or marine animals' bones or the bite of marine animals. An infection results, and a systemic infection of *C. perfringens* may lead to the production of gases and toxins, leading to tissue necrosis[31] and gas gangrene. The incubation period is 1–2 d, and the onset is acute. The main manifestations are severe pain in the injured body part, deep mass muscle necrosis, and a purple-black coloration of the skin. There are also serious and bloody secretions flowing out of the wound. If the skin around the wound is gently pressed twists, the number of white blood cells increases, and the cardiopulmonary resuscitation value increases[32]. The patient shows obvious anemia, the body temperature and pulse speed rise, and the condition gets worse rapidly. If not treated properly, the injured often die within a few days.

### *Stabbing injuries caused by marine animals*

Stabbing injuries caused by marine animals are probably the most common. Marine animals use their stings and thorns to commit attacks and defend themselves. The injected venom from a stinger into the human body can cause localized poisoning, skin damage, and even systemic poisoning, leading to shock and even death. This section will focus on the types of stabbing injury and related research.

### *Stabbing type*

Regarding stabbing injuries from coelenterates such as jellyfish, anemones, and corals, the stinger bag or stinging device has an osmotic pressure of 140 atmospheres in the bag. When encountering stimulation, it can shoot the stinger violently, with a speed 40000 times the acceleration of gravity. This force can penetrate not only human skin but also crustaceans[33]. When the barb of the stinger inserts into its target, it is difficult to remove. With a light injury, there will be skin redness, swelling, heat and pain.

With a more severe injury, there may be organ failure or even death. Jellyfish stings are the most common gill stings. Jellyfish stings often occur in warmer months of the year. It is estimated that there are about 150 million jellyfish stings worldwide every year[34,35]. Jellyfish are widely distributed in the subtropical or tropical waters found on the Atlantic, Pacific, Asia, Pacific, and Australian coasts. There are a wide variety of jellyfish, and they can cause more than 100 kinds of human poisoning. Jellyfish are considered the most harmful toxic marine animal to human beings[36]. In 2022, a survey of officers and soldiers in a marine training unit showed that 136 of the 222 officers and soldiers surveyed had been injured by marine organisms during the coastal training, accounting for 61.26% of the total number surveyed. Among them, the type of injury with the highest incidence was the jellyfish sting, accounting for 60.81%. After a human is stung by a jellyfish, the victim will feel an immediate tingle followed by a feeling of burning as if hot oil has hit the skin. In the stung area of skin, rashes, blisters and bleeding spots will soon appear. Scratching aggravates the pain. In severe cases, there may be gastrointestinal dysfunction, hypotension and vomiting, massive sweating, restlessness, excessive trembling, fever, tachyarrhythmia, and hypertension[37]. Life-threatening conditions such as hypertensive cardiogenic shock, pulmonary edema, or cerebrovascular accidents may occur under severe toxicity. The lethal rate of a highly toxic jellyfish sting such as from the box jellyfish stinger is about 15%–20%, and there is a lack of specific therapeutic drugs for this type of injury.

Sea anemones are mainly distributed in the intertidal zone or hidden in reef walls or grooves and live a sedentary life. Because of their simple structure and no central information processing mechanism, they do not have the ability to attack actively. They poison mainly through skin or digestive tract contact[38]. Among the sea anemones, there is the rock sand sea anemone toxin with strong toxicity, and the lethal dose 50 by intravenous injection is 63–83 ng/kg[39]. When this toxin takes effect, the coronary artery contraction is 100 times stronger than that of angiotensin[40]. It is a typical cardiotoxin, and the strongest known coronary artery constrictor. The toxin can cause the patient to have a sudden heart attack and die within a few minutes. The local symptoms are generally edematous erythema and papules, which subside after several days. It is necessary to distinguish these symptoms from jellyfish stings. The tentacles of anemones are short, and the skin symptoms are multiple red and round spots [41]. In severe cases, local burning pain and tingling sensation occur within a few minutes, followed by blisters, bleeding, or ulcers. The systemic symptoms mainly include cardiovascular, neuromuscular, gastrointestinal and renal dysfunction, and occasionally there are cases of death[42].Corals are mainly distributed in the South China Sea. Most of them grow on reefs in clusters, forming unique corals, such as the Shizhi coral, Pufu coral, Cang coral, and so on, with a total of more than 100 species. Coral polyps are small, hydra-type individuals. They are hollow, cylindrical, and have mouths at the top. There are up to eight or more tentacles distributed around the mouth. Barbed cells are distributed on the tentacles to release barbed sacs that can paralyze prey[43]. However, these stinging cells rarely attack humans. At present, coral injuries are often caused by accidental encounters with coral (by hitting or rubbing against it) while working in the sea or swimming or snorkeling. The skin wounds usually heal slowly and tend to cause inflammation.

### *Ratchet type*

A ratchet-type of stabbing injury is mainly caused by echinoderms, such as sea urchins, starfish, and marine vertebrates, such as stingrays and stone fishes. Echinoderms have a layer of skin with spines on their body surface. There are pedicles on the hard shells between the spines, and most of them have poison glands that can be used for defense and attack[44]. The tail spines or fin spines of the marine vertebrates mentioned above are also toxic. They not only cause wounds but alsoinject poison causing muscle spasms, nausea, vomiting,and other systematic symptoms.Sea urchins have a hard shell, and there are many thorns (spines) attached to the shell. Most of these thorns have barbs, which can increase mechanical damage to skin in the event of an injury. The neurotoxins in the thorns can poison people. There are 28 species of poisonous sea urchins in China, most of which live in tropical shallow sea reefs, especially in the Nansha Islands[44]. If you are accidentally stabbed by a sea urchin, the injury will immediately produce pain or a burning sensation, which is often accompanied by burning erythema, swelling, bleeding, and purple or black discoloration of the skin[45]. If the stabbing location is in the spine or joints, it may also cause synovitis, which lasts from 2 mo to 1 year[46]. It is reported that if multiple punctures (> 15-20 punctures) occur, systemic effects result including paralysis, bronchospasms, and hypotension, but this has not been confirmed[47].

Starfish, also known as sea pans in China, have many varieties and a wide distribution. Most of them store the toxin. They are non-toxic as long as they are not eaten. However, some starfish, such as the spiny crown starfish, have many thorns containing venom, which can also cause contact poisoning[47, 48]. These venom stings can increase the permeability of blood vessels resulting in edema, bleeding, and muscle necrosis. After stabbing by one of these spines, the injured person experiences extreme pain, redness, swelling, and numbness near the wound, accompanied by continuous vomiting and limb paralysis[33]. Stingrays, also known as devil fish and commonly known as pot fish in China because they looks like a kind of pot, have tails with poisonous spines. The main components of the venom are nucleotidase and phosphodiesterase[49]. The venom has great neurotoxicity. Fortunately, a stingray stabbing injury is relatively rare. Usually, they only attack each other with tail stabbing. However, when people press, grasp, or step on their tail, and the attack usually affects the limbs[50]. The venom enters

the body at the wound, mainly neurotoxic symptoms result. These include nausea, vomiting, muscle spasms, shortness of breath, other spasms, arrhythmia[51], and local and even systemic infection. In severe cases, the injured person may die or have multiple organ failures[52]. The effects of the injury progress rapidly, extensively involve the body, and easily lead to infection as well as secondary degeneration and necrosis of tissue cells[53]. The stonefish is one of the most toxic fish in the ocean. It mainly exists in the tropical waters of the Pacific and Indian oceans. China has reported many cases of stonefish poisoning. Toxic spines are distributed in the dorsal fin, gluteal fin, and ventral fin of the stonefish, and there are toxic sacs on both sides of the dorsal fin spines. The toxins in the toxic sacs show hyaluronidase activity, muscle toxicity, neurotoxicity, and hemolysis. These toxins can make blood vessels contract strongly, they increase blood vessel permeability[54], and they may lead to the reduction of myocardial contractility[55]. After being stabbed by the poisonous spines of a stonefish, an injured person may not feel affected instantly, but they may experience severe pain 1 hlater[56]. This pain may be accompanied by unstable blood pressure, edema, nausea, dizziness, chest tightness, delirium, other symptoms, and even death in severe cases[57].

### *Marine animal bites*

Marine animal bites may be the most dangerous kind of marine biological injury because in addition to soft tissue laceration and hemorrhagic shock, there is also the invasion of venom, which can lead to heart failure or even death. The death rate of sea snake bites is as high as 10%, which is the most serious injury among marine organisms. All sea snakes are poisonous. However, this does not mean that all sea snake bites will release venom. About one-third to one-half of all sea snake bites will not release venom [58]. There are nine genera and 15 species of sea snakes in the southeast waters of China, mainly including the black-headed sea snake in the East China Sea and the black-tailed sea snake in the South China Sea, and the followed is the green ring sea snake, known as the “snake king,” and the green grey sea snake and the ring sea snake are common in Hainan[59]. Sea snakes are usually docile, but their aggression will increase during the mating season or when they are mistreated. For example, sea snake bites often occur when catching and killing sea snakes. At first, most people bitten by sea snakes only feel that their skin is stabbed, and there are a pair of tooth marks on their skin. There is usually no pain, itching, bleeding, or swelling in some parts. However, the venom secreted by sea snakes through venom glands eventually affects the nervous system of the human body 0.5–l h after the injury. The injured person can experience paralysis in all four limbs, drooping eyelids, difficulty speaking clearly, dysphagia, progressive dyspnea, and severe cases can lead to respiratory failure or acute renal failure [60], heart failure, asphyxia, and death. The inconspicuous nature of sea snake bite marks, the absence of local reactions, and nonspecific pathological reactions, make the diagnosis of sea snake bites difficult. Therefore, the potentially lethal nature of sea snake venom neurotoxicity makes this difficulty troublesome[61]. However, if no symptoms appear within 6–8 h, the possibility of infection can be ruled out[47].Shark bites do not often occur[62]. Generally, if people do not provoke or play with them, they rarely take the initiative to hurt people. The teeth are sharp and irregularly arranged. Therefore, after a person is bitten by a shark, the main feature is massive hemorrhage due to large-area tissue laceration, contusion or abrasion, all of which can result in hemorrhagic shock. After the injury, patients often have dizziness, tinnitus, a pale complexion, cold hands and feet, sweating, thirst, restlessness, fear or indifference, a rapid and weak pulse, and decreased blood pressure[1]. It should be noted that the shark's mouth is a breeding ground for a variety of bacteria, and these bacteria are easily transferred to the human body in the event of a shark bite. In addition, shark bites easily cause post-traumatic stress disorder in patients.Therefore, psychological intervention and antibacterial treatment should both be considered carefully when treating shark bites[63,64].

## PREVENTION AND TREATMENT OF MAJOR MARINE BIOLOGICAL INJURIES ACQUIRED IN CHINA'S SEAS

Previous reports have shown that the main biologically-caused injuries in China’s sea areas include jellyfish stings, sea snake bites, spine stings from fish like stingrays, and infections of wounds bymarine bacteria.

### *Jellyfish sting treatment*

First, quickly remove the tentacles of the coelenterate from the wound[65]. Do not scrub the skin with fresh water or cold water so as to avoid further aggravation due to the release of toxins by the stinging cells (nematocysts). It is also not advisable to use isopropanol or acetic acid for first aid as previously reported[66]. The use of isopropanol and acetic acid in first aid can promote further release of nematocysts, which may aggravate the condition[67]. The combination of seawater, 5% sodium bicarbonate, and 1%–2% lidocaine[68] can be used for treatment. This treatment promotes an analgesic effect by blocking the sodium or calcium channels of the cell membrane of the jellyfish silk sac so as to stop further stinging[69]. For skin symptoms caused by jellyfish stings, such as blisters, ecchymosis,

bleeding spots, *etc*., local alkaline drugs and topical hydrocortisone ointment or betamethasone neomycin ointment can be applied. Additionally, a small number of painkillers and steroid hormones can be taken orally to prevent inflammation. Immunomodulators such as pimecrolimus, tacrolimus, and corticosteroids can reduce the incidence of recurrent dermatitis[70]. In the case of acute pulmonary edema, renal failure, and anaphylactic shock, treatments should be according to the corresponding medical guidelines already in place for addressing these conditions.At present, the research on antidote and treatment drugs for jellyfish stings is still in the early stage. The field medical units lack targeted and standardized antidote and treatment drugs and as well as training in first-aid measures for these types of injuries. For example, naval field medical units and some residential coastal areas of China use unproven treatment methods for jellyfish stings. The prevention of jellyfish stings involves two strategies: (1) Education about marine biological injuries needs to be improved for those who live, work, and train in and near marine waters; and (2) avoidance of jellyfish as much as possible and mastering the knowledge needed to treat stings.

### *Sea snake bite treatment*

Immediately following a sea snake bite, wash the wound with seawater. On land, wash the wound repeatedly with clean water, soapy water, and cold saline[33]. As for the treatment of terrestrial poisonous snakes, the patient should keep the affected limb fixed and in an independent posture. Under the condition that the arterial blood flow is not blocked, pressure fixation should be taken into consideration[47]. Use cloth, gauze, bandage, or rope to perform circular ligation at the proximal end of the wound to maintain the compression state. The tightness of the ligation cloth should not affect the deep arteriovenous blood flow of the limbs. The ligation should be relaxed for 1–2 min every 15–20 min. Sea snake antivenom is the most effective drug for the treatment of sea snake bites at present. Use of this antivenom is essential to prevent severe muscle toxicity[71]. The earlier the antivenom is used, the better the effect will be. In the absence of antivenom for sea snake bites, antivenom for cobras or Bungarus antivenom can be used. Sea snake venom has cross-immunity with these two venoms. In addition, to increase survival rate, a ventilator should be used to assist with breathing, and it is important to monitor electrolytes and renal function. Fluid replacement should be carried out in time. In case of myoglobinuria, sodium bicarbonate shall be used to alkalize urine, and diuretics shall be taken to maintain the water-electrolyte balance and prevent renal failure[72].The sea snakes' activity area is not large. Most of them live in offshore waters within 60 km offshore. Most of them feed on fish. Turtles often gather at the estuary of rivers with a large amount of organic matter, and this is also an area where sea snakes often hunt. Most sea snakes, which are active at night, are sensitive to lights. In addition, the behavior of sea snakes changes with the tides. As the tide rises, snakes tend to enter newly flooded areas, and with the water level rising, snakes becoming more active[73]. When human activities are carried out at a similar time, they should try to avoid the areas where sea snakes are often active.Before going to a strange marine area for activities, people should know whether there are reports of sea snakes hurting people in that area. If there is a threat of sea snakes, it is important to be aware of the types of sea snakes present and to be prepared in the event of a sea snake bite. A sea snake bite looks like a tiny puncture wound. If such a wound is found on the skin, it is necessary to know whether the patient has been in or out of the sea snake activity area in a short time. If the patient has weak muscle pain and other symptoms, an infection should be considered, and treatment should be given immediately[47]. The prevention of sea snake bites is more important than the treatment. However, as a marine biological injury with the highest mortality rate, medical workers, especially military doctors, should be aware of this type of injury.

### *Stingray and other stinging fish stabbing injury treatment*

For stingray and other stinging fish stabbing wounds, early emergency treatment is the key to success. The wound must be cleaned with flowing water immediately after the injury, and the blood must be extruded from the centrifugation direction near the heart to prevent the absorption of poisons[74]. Stingray venom contains a kind of hyaluronidase, which can decompose tissues and stimulate nerves causing severe pain. It is recommended to immediately immerse the wound in tolerable hot water (upper limit 45°C, 30–90 min) after washing with flowing water. In fact, a meta-analysis of hot water therapy for all stinging marine organisms, including four randomized controls and six case studies, showed that soaking at 42 °C–45 °C for 30–90 min or until the pain disappears is safe and effective for all marine stinging fish injuries[75]. If necessary, taking analgesics is recommended to relieve pain and poisoning symptoms. Stingrays and other stinging fish wounds can be treated with systemic antibiotics for 5 d at the initial stage of infection. Ciprofloxacin, trimethoprim, and sulfamethoxazole seem to be the most suitable antibiotics for the prevention or treatment of local infection[76]. Debridement and local antibacterial operations are performed on the wound, and the exudate is absorbed to lockout bacteria and water in order to prevent infection. If possible, infrared and red light treatment is useful for wound treatment (for 10-min periods). The light promotes cell proliferation and anabolism, improves microcirculation, promotes the growth of granulation tissue, and enhances leukocyte phagocytosis, which helps reduce swelling and inflammation of the wound[77].Treating stingray and other stinging fish stabbing wounds quickly is very necessary. Clean the wound with clean water immediately after the injury, tie a bandage 20 cm above the wound, and squeeze blood from the centrifugation direction near the heart is

an effective measures to prevent the absorption of poisons, and then immediately send the patient to a hospital. All stingrays and other stinging fish stabbing wounds need to be inoculated with tetanus antitoxin serum[78]. People working at sea should avoid touching or catching any animal that has spines on their backs and tails.

### *Treatment of wounds complicated by marine bacterial infection*

The problems associated with a marine bacterial infection in a wound that took place in a marine environment followed by seawater immersion has attracted more and more attention in the medical community. Because of the different types of seawater bacteria, the infection time is often advanced, and the degree of the infection is aggravated. We cannot only rely on experience with treating microbial infections on land. Treating marine bacterial infections require different strategies. Targeted antibiotic treatment is an important treatment for wounds complicated by a marine bacterial infection. The results of bacteria isolated from seawater in China showed that the main bacteria in seawater were from the genus *Vibrio* and the Family Enterobacteriaceae. The results of the drug sensitivity test showed that *Vibrio* and Enterobacteriaceae in seawater were highly sensitive to imipenem, meropenem, cefepime, ceftazidime, and levofloxacin, with a sensitivity rate of more than 90%[5]. These antibiotics should be the first choice in the early treatment of marine operation injuries and accidental injuries that have also been affected by sea water immersion. The sensitivity to tobramycin, cefuroxime, cefazolin, and ampicillin was low[79], so these antibiotics should be used with caution or not used at all. Other antibacterial drugs should be used as alternative to these.

Marine *Vibrio* and bacilli rarely cause death after infection. However, if the infected patient has cirrhosis, diabetes, chronic kidney disease, acquired immune deficiency syndrome,low immune function, or long-term alcoholism, this individual is high-risk and the chances of mortality after infection is very high[80]. Therefore, the above-mentioned high-risk groups should avoid working offshore and/or avoid becoming injured in offshore locations. *C. tetanus* and anaerobic *C. perfringens* implanted into the human body due to sponge abrasion or stabbing injury by a marine animal cannot be ignored. If not treated properly, the mortality rate will be very high. Serum therapy should be selected for a *C. tetanus* infection, as well as intravenous infusion of tetanus antiserum $20 \times 10^4$ μL, once a day, for 2consecutive days. Additionally, intramuscular injection of chlorpromazine or intravenous drip of thiopental sodium should be used to alleviate muscle spasms. Medical caregivers should pay attention to maintaining oxygen supply and the acid-base balance in the body, and if necessary, continuous renal replacement therapy can be used[28]. Coastal residents as well as officers and soldiers stationed at sea who are stationed on long-term offshore operations can be vaccinated with Tetanus Toxoid to prevent tetanus. Anaerobic *C. perfringens* infection can easily cause gas gangrene[81]. After infection, the necrotic tissue must be removed immediately, the wound washed with 3% hydrogen peroxide and 1/5000 potassium permanganate solution, and the gas gangrene antitoxin injected into the muscle. The patient should be given high protein, high nutrition, and vitamin support to improve their resistance. Prevention of anaerobic *C. perfringens* infection mainly involves debridement as soon as possible in case of deep wounds that might lead to an anaerobic infection. Foreign bodies should be removed and the patient should be treated with a preventive intramuscular injection of dry refined multivalent gas gangrene antitoxin and antibiotic interventions such as the combination of penicillin and clindamycin [82].

## CONCLUSION

Marine biological injury is a major obstacle to the improvement of China's maritime power. However, China's current research on marine biological injury is still relatively lagging behind. The United States has published a manual and first aid guide for toxic and harmful marine organisms, and asked Navy divers and Marines to master the treatment methods for toxic and harmful marine biological trauma and poisoning. Australia has developed antivenoms for organisms such as sea snakes and jellyfish, and shark repellents. By contrast, China still has a long way to go in the field of marine biological injury prevention and control. To meet the actual needs of naval forces and coastal residents, China's relevant scientific research and health personnel should focus on the living habits of common toxic marine organisms along the coast of China; the physical and chemical properties and physiological activities of related toxins; and the prevention, first aid, and treatment of common marine biological injuries and implement relevant measures; strengthen the understanding and prevention awareness of coastal residents and officers and men working at sea on marine organisms; and promote the mastery of basic first aid and prevention measures. At the same time, as the research on drugs for the prevention and treatment of marine biological injuries in China is still in the early stage, average medical units lack targeted and standardized prevention and treatment drugs and first aid measures to treat marine biological injuries. Additionally, the prevention methods and treatment methods for marine biological injuries are still relatively unscientific, uninformed, and lack effectiveness. At present, the treatment measures used are mainly only treat symptoms. Based on this status, researchers with expertise in this subject in China should speed up research in this area to achieve breakthroughs and overcome technical

difficulties. This work and research is also of great practical significance to improve the combat effectiveness of our Navy.

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