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Developing a Treatment Protocol for Shark Attack Victims

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Abstract

Shark attacks increased 23% globally within the past 20 years on a multifactorial scale through climate change and human impacts, yet healthcare lacks treatment guidelines for these victims. This systematic review proposed a shark attack treatment protocol that will potentially reduce the morbidity and mortality rates by assessing prehospital management with transfusions, hospital management with prophylactic antibiotics, and mental health evaluations to prevent and/or treat psychological impacts. This study screened 463 sources and eliminated 432 sources due to repetition or irrelevance to this study. The protocol initiates with prehospital management by implementing emergency medical service (EMS) to follow the SHARC protocol (systolic blood pressure (SBP) < 90, hemorrhage, appearance, radius of the bite over 15 cm, and coagulopathy) to administer whole blood transfusions in route to a hospital to prevent hypovolemic shock. The next step is the antibiotic protocol to administer ciprofloxacin or moxifloxacin, and a third-generation cephalosporin with doxycycline to prevent wound infections commonly caused by *vibrio* species. Assessing mental health before and three months after discharge can help prevent and/or treat anxiety, depression, and post-traumatic stress disorder (PTSD).

Keywords

Shark Attack, Hypovolemic Shock, Artificial Blood Products, Trauma, Vibrio Species, Anxiety, Depression, PTSD

1. Introduction

The purpose of developing a treatment protocol for shark attack victims is to lower the risk of morbidity and mortality, and improve the quality of care for nonstandard trauma patients. Developing this protocol will provide quantitative

values of infection rates, transfusion outcomes, and determine its efficacy. Implementing a protocol for EMS to administer blood transfusions will potentially prevent hypovolemic shock and exsanguination. [1] Hypovolemic shock can be managed with various types of transfusion solutions, but each has its own benefits and risks. Shark attack victims have been known to develop post-operative infections due to marine-borne organisms that are not covered by standard trauma antibiotics. [2] [3] Assessing mental health post-trauma is crucial for emotional support and preventative for PTSD, anxiety, and depression. This article explores the clinical approach to creating a unified treatment protocol for a high-risk population.

2. Background

2.1. Shark Attack History

Shark attacks are a multifactorial rare traumatic event that makes headlines internationally. The most common causes are climate change and alterations in shark behavior due to human impacts such as recreational activities. [4]-[10] There is a direct correlation with an increase in climate change leading to an increase in shark attacks. [4]-[6] As global temperatures rise annually, sharks alter their migration patterns to swim closer to coastlines to inhabit warmer waters. [4]-[6] Meanwhile as temperatures rise, higher populations enter the water, which increases the probability of encountering a shark. By using NOAA's 2007 and 2017 weather maps, and the International Shark Attack File, there was a global increase in shark attacks from 2007 to 2017. [4]-[6] Recreational activities also contribute to shark attacks such as shark tours chumming waters, spearfishing, or surfing. [6]-[10]

Although shark attacks are rare, treatment consists of standard trauma guidelines, such as transfusions, standard labs, diagnostic imaging, and prophylactic antibiotics. [11] [12] A primary survey is first performed by the treating provider, which prioritizes to diagnose and treat life-threatening injuries. This consists of airway, breathing, circulation, disability, and exposure, also known as the ABCDEs. [13] Afterwards, a secondary survey is completed, which is a head-to-toe physical exam to assess and treat non-life-threatening injuries further. [13]

2.2. Antibiotic Coverage in Trauma

Trauma patients are treated prophylactically with empiric antibiotics upon arrival to the ED to prevent infections from open wounds. Common causative agents in trauma inflicted wounds are *Bacteroides fragilis*, *Clostridium perfringens*, *Staph aureus*, *Strep pyogenes*, and *Strep anginosus*. [14] Antibiotics used in trauma include first or second-generation cephalosporins (cefazolin or cefotetan), or ampicillin for gram positive coverage added with an aminoglycoside, clindamycin, or carbapenem for gram negative coverage. [11] [12] This is clinically proven to lower the risk of open wounds and open fracture infections. [12] [15]

2.3. Transfusion Solutions

Transfusion guidelines for hemodynamic instability vary depending on the facility

and patient's condition. Transfusion solutions range from 0.9% normal saline to whole blood products. Each solution has their own risks and benefits.

Whole blood is widely used in early acute blood loss due to it containing all the components of blood: red blood cells (RBCs), hemoglobin, coagulation factors, plasma, and platelets. Transfusing is simpler because it does not have to be mixed with another solution. [16] Type O negative blood is the universal donor and is administered while pending type and screen results. Whole blood can be stored between 21 - 35 days depending on the anticoagulant at 2˚C - 6˚C. [16] Stored whole blood is collected from a prescreened donor and screened for microbes versus fresh whole blood is collected from a prescreened donor and immediately transfused. [16] Fresh whole blood is not available for civilian use, and is currently only used by the U.S. military for severe blood loss. [16] The most common risk of whole blood transfusions is ABO incompatibility, causing hemolysis.

Packed red blood cells (PRBCs) are prepared by centrifuging whole blood and removing 80% of plasma with an anticoagulant. [16] One unit of PRBCs can raise an adult's hemoglobin by 1 gram/dL and hematocrit by 3%. [16] The disadvantage of PRBCs for acute blood loss requires a crystalloid solution to be adjunctively transfused, typically 0.9% normal saline, to increase intravascular volume for adequate tissue perfusion. PRBCs also require crossmatching and screening a patient, which can take up to 1 hour before transfusing. This can delay transfusions, increasing morbidity and mortality in hemorrhagic patients. [16] Another disadvantage is that PRBCs do not replenish lost platelets or coagulation factors, which often requires a transfusion of fresh frozen plasma (FFP). [16]

FFP is created from whole blood that was separated into plasma containing coagulation factors and fibrinogen to help stop blood loss. [16] Although this solution is beneficial to help form clots to prevent further blood loss, it is not beneficial for volume resuscitation unless it is mixed with PRBCs and a crystalloid solution. FFP is usually stored frozen and takes ~45 minutes to thaw and prepare for transfusion. Trauma centers usually store unfrozen FFP, which can be kept up to 5 days to avoid delays in transfusion. [16] FFP also has to be ABO compatible, but the Rh group is insignificant. FFP compatibility differs from whole blood or PRBCs because type AB blood is the universal donor instead of type O. Type AB FFP can be transfused while awaiting type and crossmatch results. Since type AB blood is rare, type A FFP can be transfused in emergent situations with close patient monitoring. [16]

2.4. Artificial Blood Products

Artificial blood products, also known as blood substitutes, have been in development since the 1960s, but have yet to become FDA approved. The primary function of artificial blood is oxygen transport whereas whole blood aids in oxygen transport as well as coagulation, immunologic response, and hormone and nutritional transport. [17] Artificial blood products were created to eliminate ABO incompatibility, prevent blood-borne pathogen transmission, solve blood shortages,

and extend the shelflife. [17] The first artificial blood products were oxygen therapeutic agents (OTA) in the 1980s in Japan. OTAs are composed of perfluorocarbons, which contains fluorine and carbon. [17] The benefit was that the rate of oxygen transport was not affected by temperature, whereas temperature can alter hemoglobin in whole blood. Because of this, OTAs were only able to transport 34% of oxygen that was equal to whole blood, which required patients to be on supplemental oxygen. [17] OTAs were revised and underwent different clinical trials, however, the FDA suspended further trials in the 1990s due to increased risk of strokes. [17]

The other type of artificial blood are hemoglobin-based oxygen carriers (HBOC), which eliminated the need for patients to be on supplemental oxygen. The benefit of using hemoglobin-based substitutes was that it had potentially minimal adverse reactions and well mimicked PRBC transfusions. [17] [18] During clinical phases, HBOCs were found to be highly influenced by pH and temperature. The hemoglobin had a much higher affinity to oxygen, which led to oxygen toxicity in surrounding tissues, resulting in necrosis. HBOCs were redeveloped by different pharmaceutical companies into generations to lower adverse reactions. Hemopure is the only HBOC that is FDA approved for emergency use in South Africa and Russia for severe anemia as a last resort. [17]-[19] Other second-generation HBOC products were discontinued during phase II or III clinical trials due to severe adverse reactions, such as myocardial infarction (MI), stroke, acute renal injury, liver damage, and death. [17] [18] As of 2016, Erythromer underwent clinical trials in rats and proved to function similarly to RBC, but require further trials in larger animals to prove its efficacy and adverse effects. [19]

After discovering that severe reactions from HBOCs were caused by hemoglobin not being identical to human hemoglobin, researchers developed PEGylated hemoglobin. [17] PEGylated hemoglobin differed by having a higher molecular weight and lower viscosity than human hemoglobin. Studies revealed that molecules with a higher molecular weight affect vasoconstriction less. This allowed PEGylated hemoglobin to provide adequate tissue oxygenation by not causing vasoconstriction and allowing proper gas exchange within the capillaries. PEGylated products are only FDA approved in certain countries outside the United States. [17] PEGylated hemoglobin products are in different clinical phases internationally. [20] However, there is a lot of controversy about the efficacy of artificial blood products in the U.S. [21]

The latest study on artificial blood products were phase I clinical trials in 2020 on hemoglobin vesicles (HbV). HbV is a cellular structure of HBOCs containing a liposome configuration to help prevent hemoglobin toxicity from the artificial lipid bilayer membrane. [19] The mechanism of action is to mimic RBC membranes to ideally eliminate the adverse effects of MI and stroke. [19] The study used 12 healthy adult males aged 20 - 50 years old. Adverse reactions were limited to elevated body temperature, highest of 38.1˚C, low back pain, and rash. Once the infusions were stopped, the majority of reactions resolved without medical

intervention. [19] Because the subjects were healthy adult males, it is unclear if it aided in tissue oxygenation. Artificial blood products are currently cutting edge in research. Pharmaceutical companies and researchers are expecting new clinical trials in the nearby future to ensure products' safety and efficacy.

2.5. Emergency Medical Service Transfusion Guidelines

EMS does not have a clear transfusion protocol for trauma patients. Guidelines differ between healthcare facilities or EMS companies. It is primarily based on a clinical scenario. Paramedics are authorized to transfuse blood products when transporting hemorrhagic patients, but sometimes the clinical signs are not clear and a patient can deteriorate quickly in route. [22] [23] The majority of ambulances do not carry blood products, which results in solely using crystalloid solutions to be administered during hemorrhagic shock in trauma. [22] [23]

2.6. Mental Health Awareness

Post-trauma patients commonly develop anxiety, depression, or PTSD after being discharged from the hospital. [24] There are currently no studies that researched mental health on shark attack victims, but there are only speculated risks. [24] Common risk factors for PTSD are predisposing mental health disorders, genetics, traumatic childhoods, life-altering events, and hospitalizations. Symptoms for PTSD include nightmares or terrors, reliving traumatic events, intrusive thoughts, paranoia, and flat affect. [25] Depression or anxiety can arise from chronic or acute medical issues, recent trauma, hospitalization, increased stress, female gender, and family history of depression and/or anxiety. [26] Common symptoms of depression are sadness, hopelessness, lack of interest in activities, alterations in sleep and/or appetite, and suicidal ideation. [26] Anxiety presents with difficulty concentrating, feeling worried or overwhelmed, restlessness, and sleep disturbances. [27] Treatment for PTSD, anxiety, and depression can be either psychotherapy, pharmacological, or a combination of the two. [25] [28]

3. Methods

Two databases were used, Access Medicine and Google Scholar. Sources were chosen based on relevance, nonrepetitive, credibility, and published after 2020. Certain articles were exempt from the publication date criteria due to lack of studies on shark attack victims. The article "Direct and indirect psychological impacts of shark-bite events" published in 2019 was used because it was the only article that discussed psychological impacts on shark attack victims. [24] Additionally, the article "Shark Attack: Review of 86 Consecutive Cases" published in 2001 was the only article that determined the dimensions of shark bites affecting morbidity and mortality. [27] "Administration of intravenous antibiotics in patients with open fractures is dependent on emergency room triaging" published in 2018, was used to reiterate antibiotics used in standard trauma and if regimens were updated. [12] NOAA's weather maps from 2007 and 2017 were used to prove the effect of climate

change mitigating shark migration patterns utilizing the "2023 International Shark Attack File." [4]-[6]

Only the first 3 pages on both databases were screened due to high volume. There were no duplicates of the sources screened. Search terms "marine-borne bacteria," "shark attacks," "hypovolemic shock," "PTSD," "anxiety/depression," and "antibiotic marine coverage" were searched in Access Medicine. During the search of "marine-borne bacteria," sources that did not discuss sharks were excluded. The term "shark attack" was used to provide background information on shark attack trends. "Hypovolemic shock" was used to provide the benefits and risks of various transfusion solutions. "PTSD" and "anxiety/depression" were searched to supply symptoms and risk factors of each disorder. "Antibiotic marine coverage" was used to determine antibiotic resistance to marine-borne organisms.

Google Scholar was used for the remaining sources. Innumerable versions of the shark attack file were found, but the Florida Museum of Natural History was used due to citations in countless articles. "NOAA weather map" was used in a previous paper, which helped prove shark migration patterns are correlated with climate change. "Shark attack trends" was also searched to provide trends and historical information on shark attacks. "Shark attack mental health" was searched to evaluate any studies on the psychological impacts of shark attacks. "EMS transfusion guidelines" were found through paramedic educational sources. An extensive number of sources for "artificial blood products" were seen in Google Scholar, but many were excluded due to high volume and repetition. Many sources of "infected shark bites" and "trauma antibiotics" were omitted due to case studies that excluded treatment details. "Sharks and *vibrio* species" was assessed to configure the correlation *vibrio* species contains with sharks and the clinical significance.

Articles that did not directly discuss antibiotics that are routinely used in trauma or used for *vibrio* species and/or shark bites were excluded. Sources referencing artificial blood products and transfusion solutions regarding only anemias were eliminated. Papers that contained information that was already obtained from prior sources were also disqualified.

4. Results

Out of 5,365,326 sources, 31 sources were used. Google Scholar contained 5,343,920 and Access Medicine composed 21,408 sources (see **Figure 1**). No duplicates were detected of the 463 sources screened. 12 studies included a quantitative synthesis and 19 studies had a qualitative synthesis (see **Figure 1**). Of the sources screened, 432 were eliminated because they were irrelevant to this study based on title and/or abstract. In Access Medicine, the term "marine-borne bacteria" yielded 3 sources whereas "shark attack" yielded 6 sources. "Hypovolemic shock" generated 400 sources, while "PTSD "generated 841 articles, and "anxiety" and "depression" generated 6477 and 13,677 articles in Access Medicine.

In Google Scholar, the search term "EMS transfusion guidelines" composed 16,000 sources, whereas "artificial blood products" composed 4,150,000 sources.

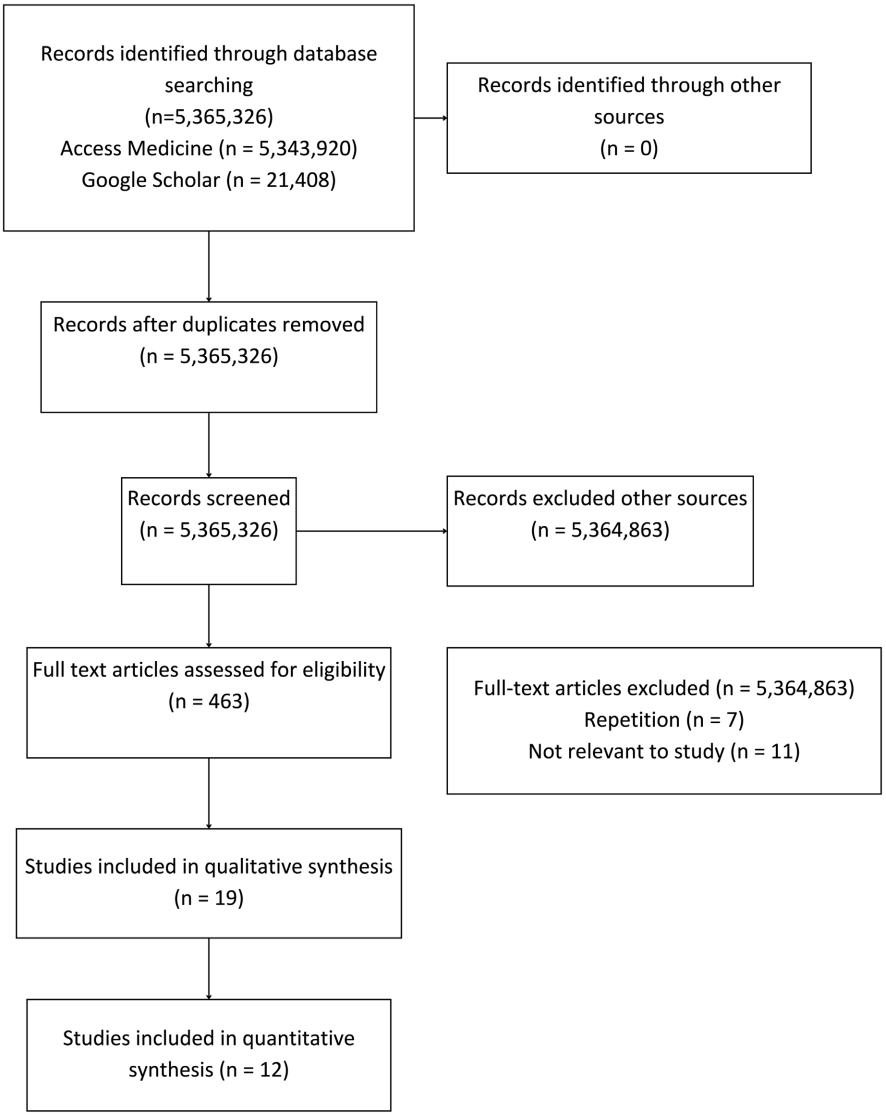

Figure 1. Diagram represents methodology of evaluating full number of sources. 5,365,326 sources were generated. 463 sources were screened due to high volume. No duplicates were detected out of the 463 sources screened.

"Infected shark bites" obtained 17,000 articles and "trauma antibiotics" obtained 1,090,000 sources. "Sharks and *vibrio* species" yielded 6920 sources. The terms "shark attack trends" and "shark attack mental health" generated 32,000 sources each.

5. Discussion

5.1. SHARC Protocol for Emergency Medical Services (EMS)

The leading cause of fatal shark attacks is exsanguination. Shark attack victims have a greater risk of hypovolemic shock and hypothermia because victims have to swim or be rescued to shore. This eliminates the possibility of estimating blood loss and exerts reserved energy. Treatment should be immediately initiated. While

lifeguards have minimal training and equipment to handle severe injuries, EMS is not always on scene at the time of the incident.

Due to the lack of EMS guidelines for blood transfusions, I propose that implementing the SHARC protocol will decrease the morbidity and mortality of shark attack victims. SHARC stands for systolic blood pressure (SBP) < 90, hemorrhage, appearance, radius of the bite over 15 cm, and coagulopathy history. The protocol entails that if the victim has 2 or more of the following, EMS is to provide whole blood transfusions until the patient reaches a hospital. If patients do not meet the criteria, EMS is to administer 0.9% normal saline due to acute blood loss (see **Figure 2**). The value of SBP < 90 was determined from studies that proved poor tissue transfusion and oxygenation when SBP was less than 90. It also showed an increased risk of hypovolemic shock. [1] Hemorrhage was selected due to the elevated risk of morbidity and mortality, along with poor tissue oxygenation. Appearance refers to quality of the patient's circulation, such as cyanotic lips, fingers, or extremities. The radius of bite over 15 cm was chosen due to studies proving increased risks of extremity ischemia, limb loss, and exsanguination from prior shark bites. The study stated that when the bite size is over 15 cm, there is a higher probability of damaging major blood vessels. [26] Patient history of coagulopathy was determined due to trauma studies discussing an increased risk with exsanguination and post-operative complications. [1] Coagulopathy conditions include but are not limited to Von Willebrand disease, hemophilia, or thrombocytopenia.

The transfusion solution to be used by EMS would be type O negative whole blood due to it containing all the clotting factors and plasma. It also results in the lowest risk of electrolyte imbalances, transfusion induced coagulopathy, requires lower amounts of blood products, and is easy to store. [16] [29] [30] The first step when receiving a blood product at a hospital is to perform a type and screen of the patient to determine the patient's blood type and screen for specific antibodies to avoid transfusion reactions. Hospitals routinely administer O-negative blood products during emergency transfusions because it is the universal donor. Whole blood is effective at aiding in hemostasis during acute blood loss because it contains all the components. [18] [29] [30] This allows whole blood to be transfused easily since other solutions do not have to be administered adjunctively, which lowers adverse effects. [29]-[31] Whole blood can be stored at 2˚C - 6˚C up to 35 days.

This would require ambulances to carry a minifridge or a cooler that could be kept at 2˚C - 6˚C, which some ambulances already contain. [23] [29] [30] To ensure blood units to not exceed the expiration date, EMS would check expiration dates at the beginning of every shift along with their routine checklists. Ambulances will carry 1 - 2 units to limit waste of expired units. Once EMS administers a transfusion, it will receive a new unit to be stored for its next use. If ambulances begin to routinely carry whole blood, this will require further guideline development for EMS to use for any trauma patient since shark attacks are rare, and could decrease morbidity and mortality rates for any trauma patient.

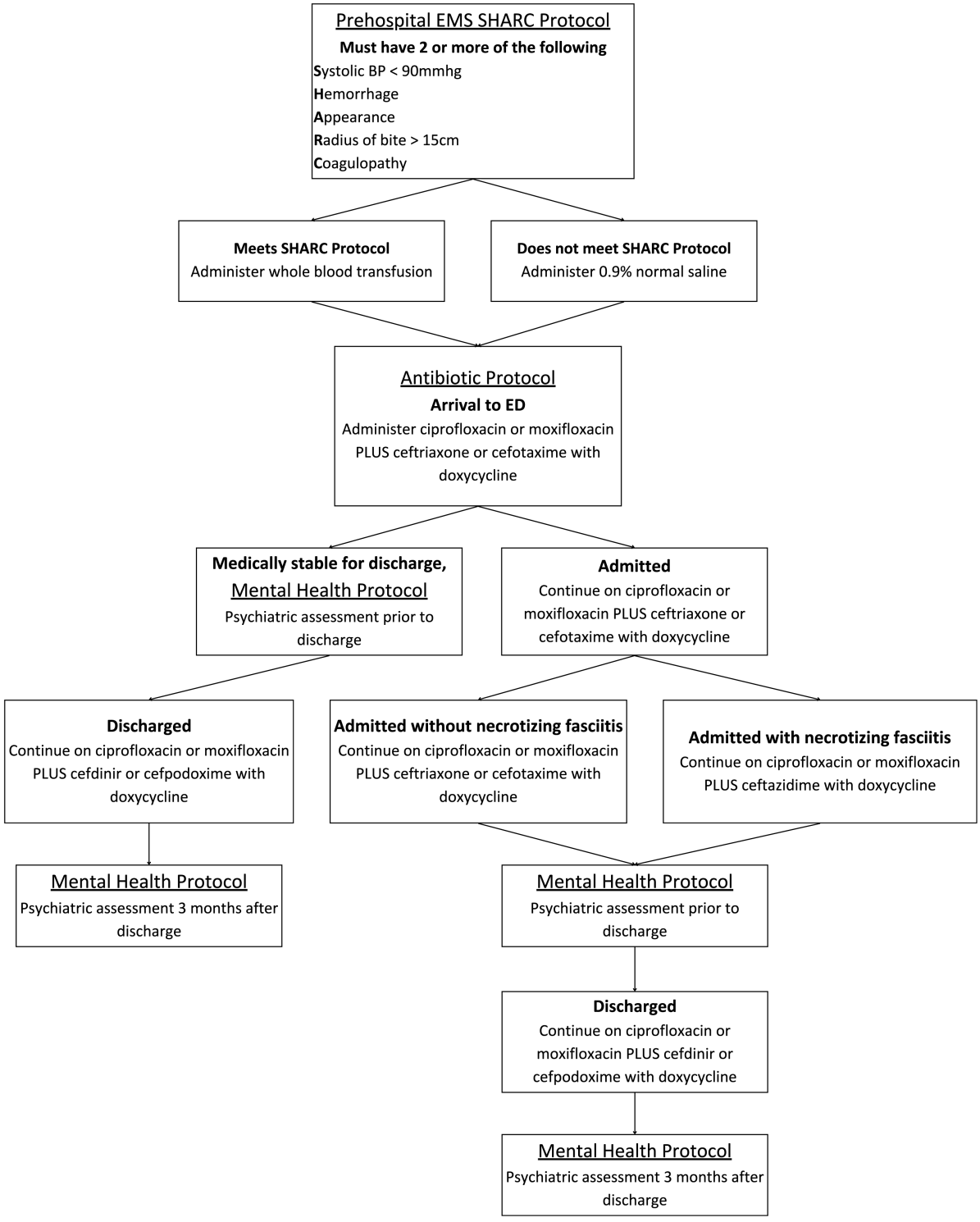

Figure 2. Shark attack treatment protocol algorithm. Treatments for mental health will vary for each individual.

The benefit of artificial blood products for EMS is the long shelf life at room temperatures, easy to transfuse, and help solve nationwide blood shortages. Because artificial blood products still have a high-risk profile, further research and development is needed before it can be considered as a transfusion solution for

EMS. PRBCs and FFP were excluded due to needing a crystalloid solution to be transfused simultaneously, and shorter shelf lives at colder temperatures. Crystalloids can be continued to be used with whole blood transfusions as secondary solutions to help increase intravascular volume.

5.2. Antibiotic Protocol

Appropriate antibiotic coverage is an essential element of this proposed protocol. Marine animal bite infections are not widely studied. Shark bites are more vulnerable to infections due to multiple factors. Shark bites are immediately exposed to marine-borne organisms in the water, in the shark's mouth, and debris when being rescued to shore. Depending on the extent of the wound and amount of debris, it is sometimes impossible to clean the wound on scene. It is important to consider what organisms are naturally found in a shark's mouth. Healthcare professionals are trained on common bacteria in household pets' mouths, but lack the training in wildlife bacteria. There are no statistics on the infection rate of shark bites. Creating a prophylactic antibiotic regimen for shark bites will also help determine the infection rate and to adjust the regimen as needed.

Common bacteria native to shark mouths are *Aeromonas* species *Chromobacterium violaceum*, *Edwardsiella*, marine *Mycobacterium* species, *Shewanella* species, and *Vibrio vulnificus*. [2] [30] [31] Infected shark bites pose a greater morbidity and mortality risk than average trauma patients. *Vibrio* species is one of the most common pathogens in infected shark bites with tissue necrosis, necrotizing fasciitis, and bacteremia. [2] [3] Necrotizing fasciitis caused by *Vibrio* species presents 7 - 12 days after exposure beginning with ecchymosis, painful bullae, and edema. [3] If treatment is not promptly initiated, symptoms progress quickly and can be fatal. [3] The treatment that provides the best prognosis with antibiotics is debridement of the affected area or amputation if necessary. [2] [3] This occurs in 33% of infected shark bites with a 33% fatality. [2] [3] It is important to consider that patients with predisposing conditions such as diabetes mellitus, liver disease, or immunocompromised are more susceptible to infections with a higher complication rate. [30]

Marine-borne organisms are often resistant to ampicillin, and first and second generation cephalosporins. Proper treatment should include a fluoroquinolone and a third-generation cephalosporin. [30] [31] There are different regimens for *vibrio* species skin infections ranging from cellulitis to necrotizing fasciitis. Studies proved that treatment for *vibrio* species necrotizing fasciitis should include ceftazidime and doxycycline, and administer doxycycline and moxifloxacin for non-necrotic wound infections. [3]

I propose the next step of this protocol is to prophylactically administer ciprofloxacin or moxifloxacin, and a third-generation cephalosporin with doxycycline to shark attack victims (see **Figure 2**). Levofloxacin was excluded due to the lack of research on treatment of *vibrio* species infections. It is advised to reserve ceftazidime for necrotizing fasciitis and sepsis to prevent resistance. Patients can be treated with oral antibiotics if being discharged (see **Figure 2**). Patients should

be administered these antibiotics on arrival to an ED, and should not be treated with ampicillin, first or second-generation cephalosporins, aminoglycosides, clindamycin, or carbapenems as they do not cover marine-borne organisms. Preventing wound infections is vital in decreasing the amount of psychological stress during recovery.

5.3. Mental Health Protocol

Addressing mental health after a traumatic event is crucial to prevent PTSD, anxiety and depression. The two most common patient demographics for shark attack victims are patients that grew up participating in recreational water sports such as spearfishing or surfing that now developed a fear to perform their lifelong hobbies, or someone who was on vacation and now associates the ocean with fear. [24] This poses an increased risk of developing depression or anxiety from changing daily hobbies. Victims reported symptoms of anxiety, depression, and flashbacks of the incident when returning to the ocean. [24]

There are no current studies on mental health effects of shark attacks. [24] Studies showed that victims with disfiguring injuries or with complicated recoveries have a higher risk for developing anxiety, depression, or PTSD. [24] [27] Patients with debilitating injuries such as extremity amputation or severe muscle loss reported higher stress and aggravation due to having to relearn activities of daily living. For example, people with an upper extremity amputation had to relearn how to dress themself, cook, clean, and write if it was their dominant hand. Patients who had massive muscle loss from their lower extremities may have to relearn how to walk. These individuals also have to accept their new body. [24] [27]

The media can negatively affect the psychological recovery from a shark attack by sharing the story on multiple platforms, interviews, and being contacted by shark experts to share their story. [24] Unfortunately, it is nearly impossible to avoid shark media since society has a huge fascination with sharks, such as shark week and shark movies. As shark week has become more popular, there has been a higher number of shows that interview shark attack survivors and have actors reenact incidents. [24] It is more important to help patients overcome media exposure and to prevent developing mental health disorders.

PTSD, depression, and anxiety have two different times of onset, just after the incident and approximately three months later. This is due to the initial shock of the event and then progressive frustration with managing life-altering changes. [24] The final step of the shark attack treatment protocol is mental health assessments before and three months after discharge (see **Figure 2**). This enables patients to process the event at the two common time periods these disorders onset for post-trauma patients. Treatment should be tailored to the patient, which can vary from psychotherapy, pharmacological, or inpatient hospitalization if needed.

6. Conclusions

Even though shark attacks are a rare event, they are increasing globally and lack

treatment guidelines. This systematic review concluded that developing a shark attack treatment protocol could help lower morbidity and mortality rates, but lack the clinical data. Implementing first-rate pre-hospital management with EMS following the SHARC protocol to initiate whole blood transfusions is imperative to prevent hypovolemic shock in route to a hospital. Tailoring intrahospital guidelines to follow the antibiotic protocol to cover marine-borne organisms could reduce the risk of post-operative infections. This entails administering ciprofloxacin or moxifloxacin, and a third-generation cephalosporin with doxycycline to prevent wound infections, commonly caused by *vibrio* species and other marine-borne organisms. To conclude this protocol, the final step is to provide patients with mental health assessments before and three months after discharge to monitor and/or treat anxiety, depression, or PTSD.

The limitation of this protocol is the lack of clinical evidence to support the effectiveness of these guidelines. Future directions should include clinical trials to quantify the effectiveness of the protocol proposed here in comparison to existing care strategies. Education about the specific medical and psychiatric care considerations should be offered to those responders most likely to encounter an apparent shark bite victim as well as hospital care providers treating acute and lasting injuries following an attack. This will provide quantitative values that will help tailor this protocol to maximize quality patient-centered care.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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