Near-Complete Traumatic Amputation of the Forefoot After Motorboat Propeller Injury

Julia S. Retzky, BA[1] and Casey Jo Humbyrd, MD[1] ⓘ

Abstract

We report a case of a near-complete amputation of the forefoot of a 20-year-old man as a result of a motorboat propeller injury sustained in a saltwater river. He was treated with open reduction, percutaneous pinning, extensor tendon repair, and an extended course of antibiotic prophylaxis. We review the literature regarding motorboat propeller injuries to the foot and ankle.

Keywords: amputation; forefoot; high-energy injury; motorboat propeller

Motorboat propeller injuries are rare but can have devastating outcomes, from deep lacerations to complete limb amputations and even death.[22] Between 2009 and 2016, 1397 injuries and 202 deaths resulted from propeller injuries in the United States. Of the 1397 injuries, 257 were amputations, 29 of which involved the foot.[25-32] It is important to note that it is impossible to determine whether these amputations were total or subtotal on the basis of the published data.

Eight cases of motorboat propeller injuries involving the foot and ankle have been reported in the literature, one of which involved complete amputation of the foot and another of which involved a near-complete amputation at the ankle.[11,13,22] In the current article, we present a case of a subtotal amputation of the forefoot as a result of a motorboat propeller injury.

The patient was informed that the data concerning his case would be submitted for publication, and he provided consent.

Case Report

A 20-year-old man presented to the emergency department after sustaining a major laceration to his right forefoot when he jumped off a boat into a saltwater river and cut his foot on the boat's spinning propeller. He had no relevant medical history. His surgical history was notable for open reduction and internal fixation of his right lateral malleolus during adolescence.

On initial presentation, he was in severe pain. He had a 15- to 20-cm laceration extending from the base of the fifth metatarsal across the dorsum of the foot to the great toe with exposed subcutaneous tissue and apparent tendon lacerations (Figure 1). He had no dorsal sensation to light touch distal to the laceration and decreased strength in the flexor hallucis longus and tibialis anterior, with no appreciable function of the dorsal foot extensors. His dorsalis pedis and posterior tibial pulses were palpable but weak, his capillary refill was less than 3 seconds, and his toes were warm and well perfused. Radiographs of the right foot showed fractures at the head of the first metatarsal, the great toe proximal phalanx, and the distal diaphysis of the second, third, and fourth metatarsals. There was also subluxation of the fourth and fifth tarsometatarsal joints with the distal cuboid visualized in the wound. There was also a corticated fragment proximal to the base of the fifth metatarsal (Figure 2a-c).

Immediately on arrival to the emergency department, the patient was given intravenous cefazolin (2 g), gentamicin (300 mg; 4 mg/kg/dose), and doxycycline (100 mg), as well as a tetanus booster. His wounds were irrigated with 2 L of

[1] Department of Orthopaedic Surgery, The Johns Hopkins University, Baltimore, MD, USA

Corresponding Author:
Casey J. Humbyrd, MD, Department of Orthopaedic Surgery, The Johns Hopkins University/The Johns Hopkins Bayview Medical Center, 4940 Eastern Avenue, Suite A660B, Baltimore, MD 21224, USA.
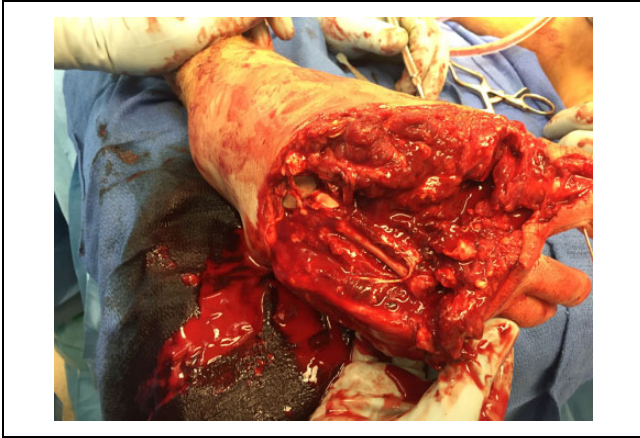Email: casey.humbyrd@jhu.edu

Figure 1. Intraoperative photograph of a near-complete amputation of the right forefoot of a 20-year-old man after a motorboat propeller injury.

normal saline mixed with betadine and covered with betadine-soaked gauze. A temporary posterior slab splint was applied.

He was then taken promptly to the operating room, where the wound was carefully debrided and thoroughly irrigated with 12 L of antibiotic solution (consisting of 40 mg of neomycin and 200,000 units of polymyxin B) using cystoscopy tubing. Attention was then turned to reduction of the open fractures. Starting with the great toe, the proximal phalanx was reduced with a point-to-point reduction clamp. Two Kirschner wires (K-wires) were used to hold the reduction. For the second metatarsal, a K-wire was first placed antegrade out of the metatarsal at the open fracture site and then sent retrograde into the proximal portion of the second metatarsal after reduction was performed. The same procedure was used to achieve and maintain reduction of the third metatarsal. The fourth toe was found to be subluxated at the fourth metatarsophalangeal joint. As described above, a K-wire was first sent antegrade from the base of the proximal phalanx to the tip of the toe, reduction was performed, and the K-wire was then passed retrograde into the fourth metatarsal base to stabilize the reduction. This K-wire in the fourth metatarsal base stabilized the patient's fourth tarsometatarsal joint dislocation by sending it retrograde into the cuboid with the cuboid-metatarsal articulation held reduced. Further stabilization of the cuboid–fifth metatarsal was achieved with a K-wire that was passed retrograde from the lateral aspect of the fifth metatarsal base into the cuboid. The patient's great toe metatarsophalangeal joint was also grossly unstable, and a K-wire was passed antegrade from the proximal phalanx out of the medial cortex and then retrograde into the first metatarsal. Intraoperatively, it was noted that there was significant bone loss from the first metatarsal head. Intraoperative fluoroscopy was used to confirm adequate positioning for all of the reductions described above (Figure 3a-c).

After open reduction and pinning of the fractures, the patient's second, third, fourth, and fifth extensor digitorum

longus and extensor digitorum brevis tendons were repaired with 4-0 Prolene sutures (Ethicon, Somerville, NJ). A Bunnell-type suture augmented with a running epitendinous suture was used, and the ankle was held in dorsiflexion while the extensor tendons were repaired. Intraoperatively, the patient was given prophylactic cefazolin, gentamicin, and doxycycline.

The wound was first grossly reapproximated with 2-0 Nylon vertical mattress sutures to relieve tension. The edges were then slowly reapproximated, first with 2-0 Monocryl and then with 3-0 Nylon sutures. The wound was completely closed at the conclusion of the case, and no skin tension was noted. After wound closure, the patient was given a right ankle block for postoperative pain control. His wound was then dressed with Xeroform petrolatum wound dressing (DeRoyal Industries, Powell, TN), 4-in^2 gauze pads, and sterile soft-roll gauze. A posterior slab splint with a stirrup was then applied with the ankle held in neutral dorsiflexion.

The patient recovered well after surgery and continued treatment with cefazolin and gentamicin for 24 hours for his open fractures and doxycycline for 96 hours for *Vibrio* prophylaxis. On postoperative day 1, he reported substantial pain that was not alleviated by multiple breakthrough doses of intravenous hydromorphone hydrochloride. A popliteal nerve catheter was placed by the anesthesia team. The popliteal nerve catheter, in combination with oral hydromorphone hydrochloride, provided symptom relief, and his pain was well controlled by postoperative day 4. He was discharged on postoperative day 4 with the popliteal nerve catheter in place and was advised to remain nonweightbearing for 6 to 8 weeks. The popliteal nerve catheter was discontinued on postoperative day 7, at which time the patient's pain level had decreased considerably.

At his 2-week postoperative visit, darkened eschar was visible over the great toe wound, although no sign of infection was noted. He was insensate to the dorsal foot distal to the laceration at that time. His splint was changed to a cast at that time, and he was advised to remain nonweightbearing. He was followed in clinic every 2 weeks, and at 8 weeks after the initial procedure, he returned to the operating room for removal of the pins and debridement of the great toe eschar. He was again placed in a posterior slab splint with a stirrup and advised to remain nonweightbearing for an additional 2 weeks, which was determined in consultation with the plastic surgery service for optimal healing of the great toe wound. He recovered without complication. Two weeks after pin removal (10 weeks after the initial procedure), his splint was changed to a boot and he began bearing weight. He also began physical therapy twice weekly for 8 weeks. Physical therapy sessions included an evaluation of ankle range of motion/sensation/strength, manual therapy (massage), electrical stimulation, gait training, and stretching/strengthening exercises. Active plantarflexion of the toes was encouraged, as well as active dorsiflexion, actively assisted dorsiflexion, and passive dorsiflexion. Passive plantarflexion was permitted at 3 months after
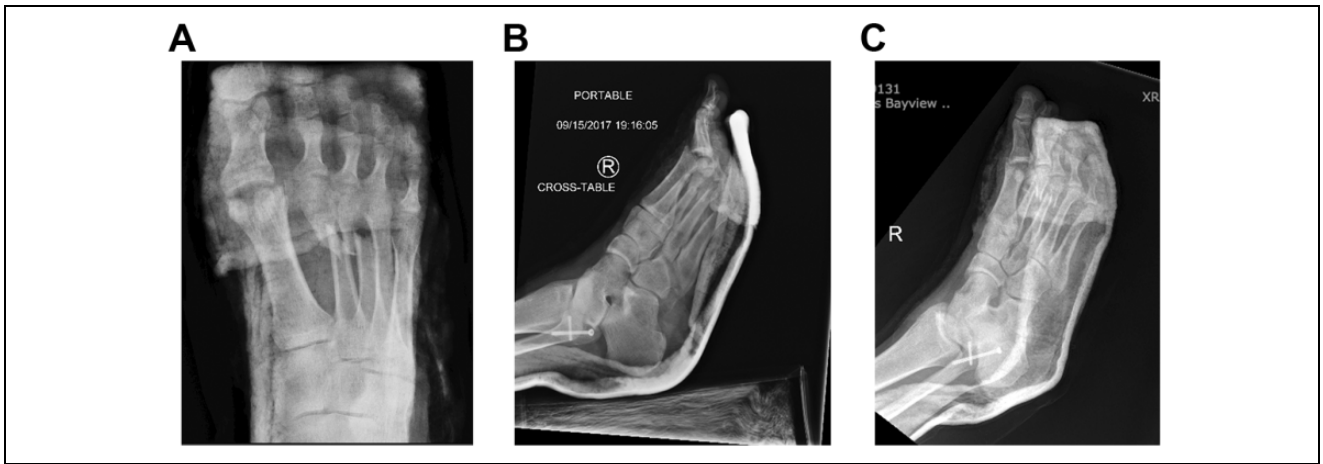
Figure 2. (A) Preoperative nonweightbearing anteroposterior radiograph of the right foot in a splint after a motorboat propeller injury. (B) Preoperative nonweightbearing lateral radiograph of the right foot in a splint after a motorboat propeller injury. (C) Preoperative nonweightbearing oblique radiograph of the right foot in a splint after a motorboat propeller injury.
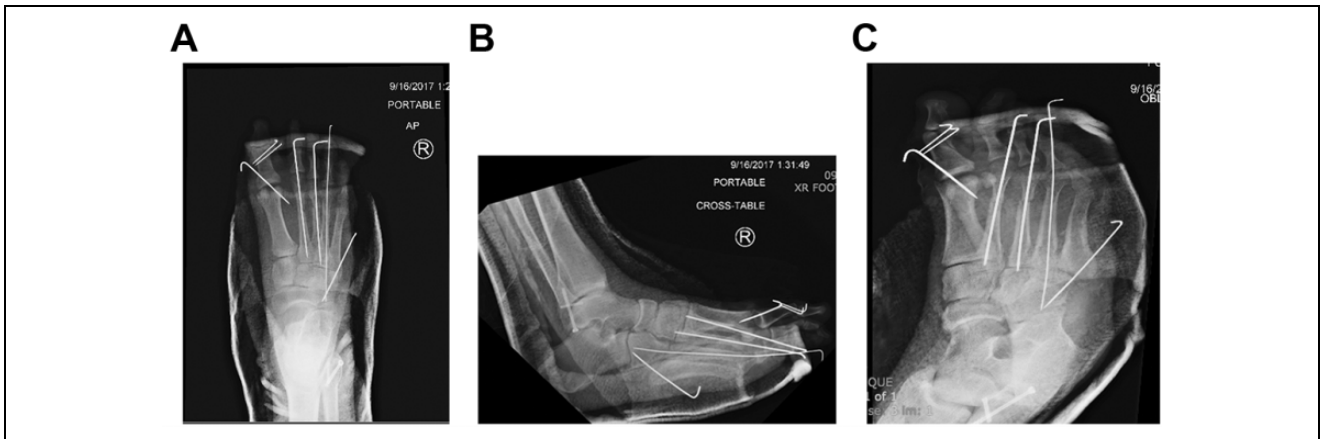

Figure 3. (A) Immediately postoperative nonweightbearing anteroposterior radiograph of the right foot in a splint. (B) Immediately postoperative nonweightbearing lateral radiograph of the right foot in a splint. (C) Immediately postoperative nonweightbearing oblique radiograph of the right foot in a splint.

surgery. His great toe wound ultimately healed with local wound care.

Three months after the initial procedure, he was transitioned from a boot to a postoperative shoe. At the 5-month postoperative visit, his wounds were healed (Figure 4) and he had good strength with ankle dorsiflexion and plantarflexion, although he had limited range of motion and weakness of his toes in dorsiflexion (extensor hallucis longus/extensor digitorum longus strength of 2/5, with a score of 5 indicating maximum strength). He continued to remain insensate to the dorsal foot distal to the laceration. Radiographs at the 9-month postoperative visit showed progression of healing of the fractures (Figure 5a-c). At this visit, he was cleared to return to his regular activities, including competitive weightlifting.

Figure 4. Five-month postreconstruction photograph of the right forefoot after a motorboat propeller injury.
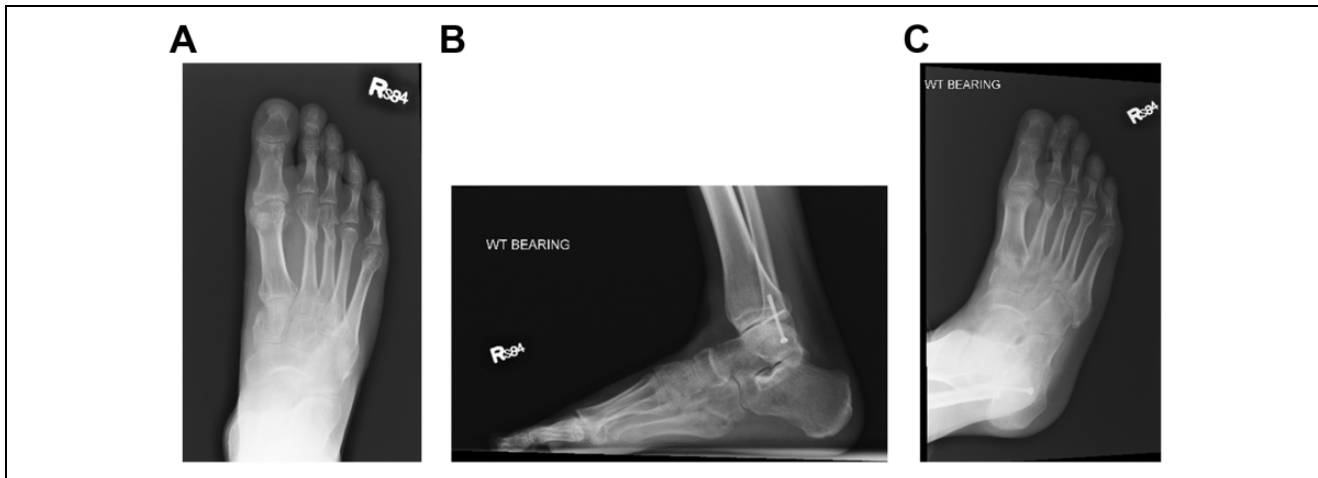
Figure 5. (A) Anteroposterior weightbearing radiograph of the right foot 9 months after surgery for a motorboat propeller injury. (B) Lateral weightbearing radiograph of the right foot 9 months after surgery for a motorboat propeller injury. (C) Oblique weightbearing radiograph of the right foot 9 months after surgery for a motorboat propeller injury.
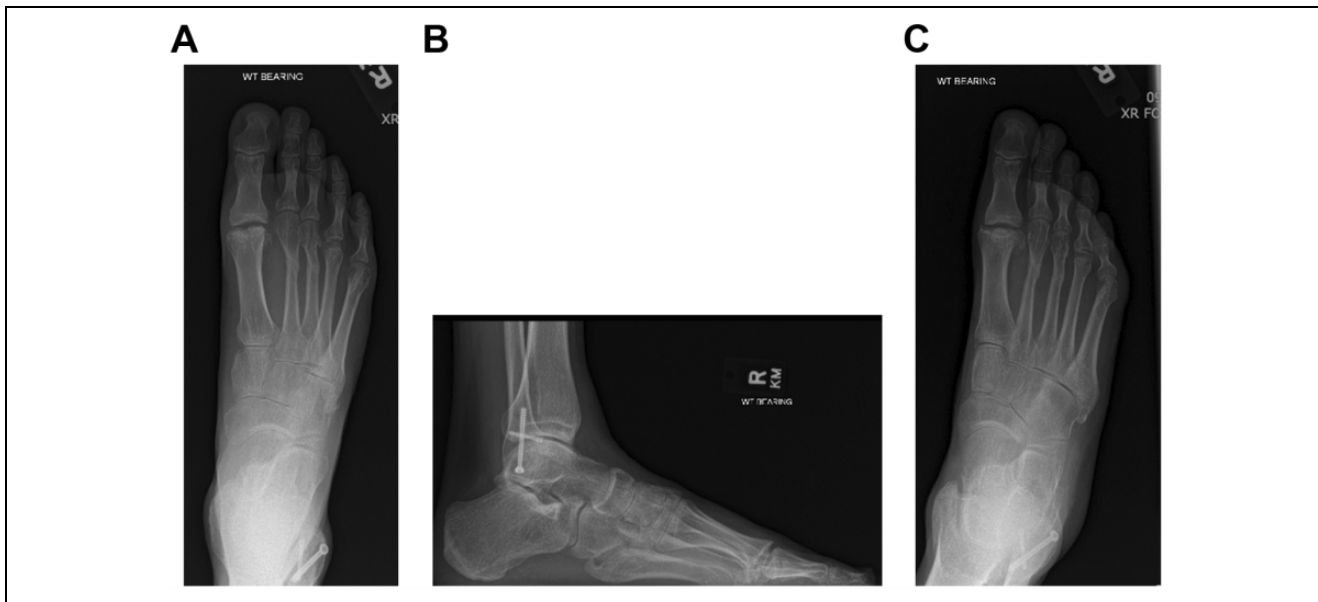

Figure 6. (A) Anteroposterior weightbearing radiograph of the right foot 1 year after surgery for a motorboat propeller injury. (B) Lateral weightbearing radiograph of the right foot 1 year after surgery for a motorboat propeller injury. (C) Oblique weightbearing radiograph of the right foot 1 year after surgery for a motorboat propeller injury.

At his 1-year postoperative visit, he reported continued stiffness and pain in his great toe. Although the pain did not prohibit him from participating in his regular activities, he had extremely limited active and passive range of motion at the first metatarsophalangeal joint. Otherwise, he had full strength in ankle dorsiflexion and plantarflexion, and the sensation of his dorsal foot distal to the laceration had returned. His toe extensors had 20 degrees less extension than those of the contralateral side, but he reported no functional deficits in his activities of daily living. Radiographs showed complete healing of the metatarsal shaft fractures with arthritis of the first metatarsophalangeal joint (Figure 6a-c). Given his persistent pain and stiffness, he was

interested in potential surgical treatment. On the basis of imaging findings and his limited range of motion, a metatarsophalangeal joint arthrodesis was presented to him as an excellent option for pain relief. He plans to undergo surgery in the near future.

Discussion

In patients who present with limb-threatening injuries as a result of contact with a motorboat propeller, surgeons are presented with the difficult task of determining whether to attempt salvage or proceed with amputation. The Mangled Extremity Severity Score was created to help surgeons

Table 1. Motorboat Propeller Injuries Reported in the Literature.

First Author	Year	No.	Patient Age(s), y	Injury Types (Locations)	No. of Patients With Isolated Injuries to Foot or Ankle	No. of Traumatic Amputations (Body Part)	No. of Deaths
Hummel[13]	1982	5	21, 24, 24, 27, 27	Lacerations (buttock, thigh, calf, foot); open fractures (calcaneus, tibia/fibula/MTs, ankle, midfoot); traumatic amputation (foot); open injury (head)	3	1 (foot)	1
Di Nunno[6]	2000	1	30	Deep parallel lacerations (head/neck/back); near-complete amputation (arm at elbow)	0	1 (arm at elbow)	1
Semeraro[24]	2012	2	NA	Parallel lacerations (head, posterior leg, head/neck/torso, elbow, occipital defect, rib); comminuted fractures (proximal radius/ulna, distal tibia/fibula, radius with butterfly fragment); fractures (rib, cranium)	0	0	2
Ihama[14]	2009	3	22, 53, 60	Parallel lacerations (side); amputation (leg at mid-thigh); fractures (rib/scapula/humerus/femur, skull, ribs/pelvis/lower extremity); parallel chop wound (side); open exposure caused by laceration of cranial cavity (cranium)	0	1 (leg at mid-thigh)	3
Mendez-Fernandez[18]	1998	1	38	NA (knee)	0	0	0
Hoexum[11]	2017	4	10, 14, 21, 48	Traumatic amputation (medial malleolus); open fractures (calcaneus/talus/navicular; calcaneus/talus/lateral cuneiform/second MT/third MT); subtotal traumatic amputation (distal tibia)	4	2 (medial malleolus; distal tibia[a])	0

Abbreviations: MT, metatarsal; NA, not available.
[a]Subtotal traumatic amputation of distal tibia was salvaged operatively.

determine which patients who present with limb-threatening injuries are candidates for limb salvage.[16] The criteria for the Mangled Extremity Severity Score include limb ischemia, patient age, shock, and injury mechanism. Whereas some studies have determined that scores greater than 7 are highly predictive of amputation,[7,10] others have found that the low sensitivity and specificity of these scores make them a less useful measure for predicting amputation.[3] Yet, other factors that have been shown to accurately predict the need for amputation after high-energy injuries to the forefoot or midfoot include the following: fractures of all 5 metatarsals (increased risk of amputation by a factor of 10), open fractures (increased risk of amputation by a factor of 16), open injury to the plantar or dorsal surfaces (hazard ratios of open plantar vs dorsal surfaces are 8.0 and 12, respectively), higher Gustilo grade, and vascular injury.[33]

Our patient presented with several risk factors for amputation, including open fractures of all 5 metatarsals, extensive open injury to the dorsal surface of the forefoot, and high Gustilo grade (IIIa). Despite this patient's risk factors for amputation, limb salvage was performed. This decision was made after a detailed discussion with the family and a shared decision-making process in which the risk of amputation was discussed. Although limb salvage/reconstruction has been associated with higher rates of complications, including nonunion, wound infection, osteomyelitis, and the

need for additional surgery, 2 studies have found no differences in outcomes at 2 years after surgery in patients who underwent amputation vs those who underwent limb salvage.[4,9]

A variety of motorboat propeller injuries have been reported in the literature (Table 1). Most patients sustain multiple, deep, longitudinal parallel lacerations of the cranium and distal extremities. Comminuted, open fractures of the tibia/fibula and radius/ulna are also commonly reported. With regard to complete and near-complete amputations, 4 cases of traumatic amputations and 1 case of a near-complete amputation have been reported. The near-complete amputation involved the ankle,[11] and there are no previous reports of near-complete amputation involving the forefoot.

In the case of the patient with a near-complete amputation of the ankle,[11] limb salvage was performed with a good result; however, the patient continued to experience significant functional impairment when not using a brace 1 year after surgery. Although our patient continued to experience pain and stiffness of his first metatarsophalangeal joint, he was very pleased with his results overall. He explicitly stated at one of his postoperative visits that he was very grateful that limb salvage was performed instead of amputation. Weightlifting and body building are important to him, and he has been able to return to these activities.
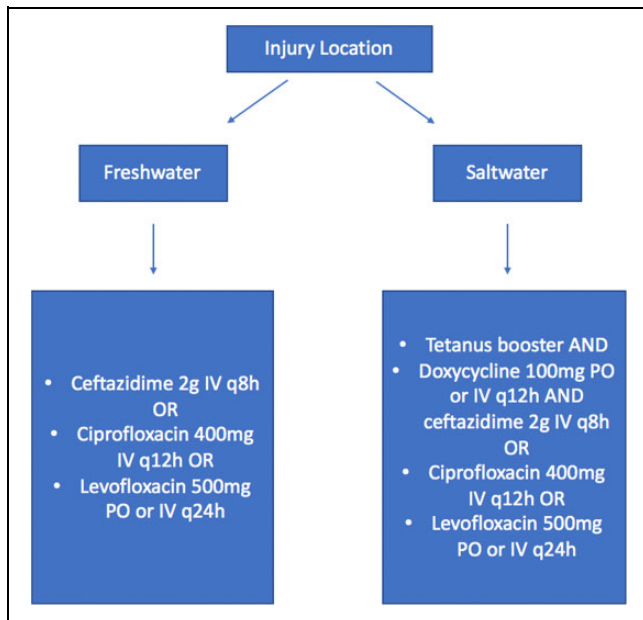
Figure 7. Flowchart with antibiotic considerations for freshwater vs saltwater injuries. Adapted from Noonburg.[21] IV, intravenous; PO, per os.

There have been reports of patients undergoing amputation as a result of infection months after limb salvage as a result of motorboat propeller injuries. Infections caused by *Staphylococcus aureus*, *Pseudomonas*, *Acinetobacter*, *Achromobacter*, and *Vibrio* have been reported, and some have postulated that waterborne bacteria become deeply injected into the tissues at the time of injury because of the high velocity of the spinning motorboat propeller, making infection after this type of injury highly likely.[2,20] Recommended antibiotic prophylaxis includes the use of fluoroquinolones or a third/fourth-generation cephalosporin for freshwater injuries.[20] For saltwater injuries, doxycycline plus a third/fourth-generation cephalosporin or fluoroquinolone is recommended, in addition to a tetanus booster to cover *Clostridium* species (Figure 7).[20] Another study made similar recommendations for antibiotic prophylaxis in patients with freshwater or saltwater injuries.[23]

Our patient's injury occurred in saltwater; therefore, he was treated with broad-spectrum antibiotics for coverage of saltwater-borne bacteria, including *Vibrio*. He was placed on cefazolin and gentamicin for 24 hours and doxycycline for 96 hours. He was also given a tetanus booster in the emergency department.

With regard to optimal duration of antibiotics for an open fracture, there is no consensus in the literature. Some studies recommend 24 hours of antibiotic coverage for Gustilo types I and II and 72 hours of coverage for Gustilo type III fractures,[1,12] whereas others have found no differences in infection rates for open fractures (including Gustilo type III)

treated for 72 hours compared with shorter treatment regimens (<72 hours).[5,19] Our patient received cefazolin and gentamicin for 24 hours and did not develop a wound infection.

Although there is no consensus regarding the optimal duration of antibiotic treatment for open fractures, the most important factor in decreasing infection risk is early administration of antibiotics.[21] Our patient immediately received a tetanus booster, cefazolin, gentamicin, and doxycycline in the emergency department, which likely played a critical role in decreasing his infection risk.

There are established guidelines for the duration of antibiotic treatment for *Vibrio* soft tissue infections,[20] yet to our knowledge, no information is available in the literature with regard to the appropriate duration of antibiotic prophylaxis for *Vibrio* in adults. The Children's Health Queensland Hospital recommended intravenous ciprofloxacin (10 mg/kg every 12 hours) plus intravenous lincomycin (15 mg/kg every 8 hours) for 5 to 7 days for *Vibrio* prophylaxis in children[15]; however, there are no established guidelines for duration of antibiotic prophylaxis in adults. Our patient received doxycycline for 4 days. Although it is possible that a shorter duration of antibiotics would have been sufficient, it was determined that it was better to err on the side of caution with a longer course of antibiotics to ensure that he received adequate *Vibrio* coverage. *Vibrio* soft tissue infections present as cellulitis, which can quickly progress to necrotizing fasciitis (in <12 hours), bacteremia, and septicemia.[8] Once patients with *Vibrio* infections become septic, the mortality rate is greater than 50%.[17] Therefore, we felt it was reasonable to continue *Vibrio* coverage for 4 days, especially given that there are no established guidelines for the duration of *Vibrio* prophylaxis and that disseminated *Vibrio* infections can have devastating and often fatal consequences.

In the case presented, we successfully reconstructed a near-complete amputation caused by a motorboat propeller through pin fixation of the metatarsal fractures and soft tissue repair. We recommend antibiotic coverage for waterborne bacteria, including *Vibrio* for those exposed to saltwater, to decrease the chance of infection.

ORCID iD

Casey Jo Humbyrd, MD, ![ORCID] https://orcid.org/0000-0001-9623-4212

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