Bite Motivation of Sharks Reflected by the Wound Structure on Humans

Erich Kurt Ritter, PhD, and Marie Levine

Abstract: Bite wounds on humans have rarely been comparatively analyzed, and the behavior leading to such bites is virtually unknown. Nevertheless, the behavior of a shark is reflected in the bite structure and should be an essential part of shark-accident analysis. This paper compares 3 nonfatal accidents on humans, caused by bull sharks, *Carcharhinus leucas*, that occurred within a 12-month period in the same area of the Bahamas. Examination focused on wound analysis and accident reconstruction to determine the most likely bite motivation of the sharks. Two sharks targeted the left calf areas of the victims; another one bit the back area of a person. Although both calf bites had a very similar appearance, examination concluded that one of them showed the same triggering behavior as for the shark who inflicted the very different-looking back bite. Those 2 bites were competitive, whereas the other calf bite was initially of exploratory nature, turning into a stress-related bite.

Key Words: bite motivation, bull shark, wound structure

(*Am J Forensic Med Pathol* 2005;26: 136–140)

In the past, shark bites on humans hardly revealed more information beyond the place of accident, the victim's activity, and the damage the shark caused. But even if the species could be determined, the likely behavior leading to the accident was unknown. Nevertheless, the bite motivation of a shark is reflected in the structure of a wound and must be an essential part of a shark accident analysis.[1] This paper compares 3 nonfatal accidents with bull sharks, *Carcharhinus leucas*, that occurred in the same area of the Bahamas within a 12-month period between August 2001 and 2002. The most likely bite motivation of the animals is discussed based on wound analysis and accident reconstruction.

Manuscript received October 30, 2004; accepted January 10, 2005.
From the Shark Research Institute, Princeton, New Jersey.
Reprints: Erich Kurt Ritter, PhD, Shark Research Institute, Florida Office, 5970 Osprey Place, Pensacola, FL 32504. E-mail: erichritter@bellsouth.net.

ISSN: 0195-7910/05/2602-0136
DOI: 10.1097/01.paf.0000164231.99750.2b

MATERIALS AND METHODS

Between the 12-month period of August 2001 and 2002, 3 people were bitten by bull sharks, *C leucas*, in the Bahamas. The bites were nonfatal. The size of the animals was estimated by comparing the curvature of the individual wound margins with jaws from known-sized animals and rounded to the nearest 10 cm. Each wound was photographed prior to surgery or treatment. Wound examination focused on number of bites, margin structure, tooth imprints, wound depth, and tissue loss.[2,3] Wound reconstruction determined the relative bite angle (RBA) and symphyseal axis projection (SAP). RBA is defined as the angle between the vertical axis of jaws when positioned onto the affected area and the main axis of the targeted human body area (rounded to the nearest 10°), where 0° is with the body or limb axis, 180° against it. SAP is defined as the vertical line between the upper (palatoquadrate) and lower jaw (Meckel cartilage) symphyseal articulation, to estimate (1) theoretical bite volume and (2) bite center. RBA and SAP are determined by using sets of the estimated jaw sizes on victim-sized mannequins. Wound margins of upper and lower jaws are referred to as bite top and bite bottom, respectively. Figure 1 shows SAP of a bull shark that was 240 cm in length, including individual upper and lower teeth. Upper teeth of this species are broad, triangular, and strongly serrated, with erect or slightly oblique cusps, and their bases overlap with each other; lower teeth are slender with broad serrated cusps, but no overlapping with adjacent teeth bases occurs.[4] Upper teeth are primarily used to cut and saw (sideways movement along a surface when embedded in it, with ongoing perpendicular pressure); lower teeth are primarily used to puncture and hold a structure in position, with a limited capability of cutting and sawing. A tooth series is defined as the active teeth of a longitudinal jaw axis; a row is defined as the in-line teeth of any individual tooth of the active series.[5]

RESULTS

Case 1

Figure 2A and B shows the posterior and lateral side of the lower left leg of a 177-cm man. The affected muscles included the gastrocnemius, soleus, and peroneus longus. The

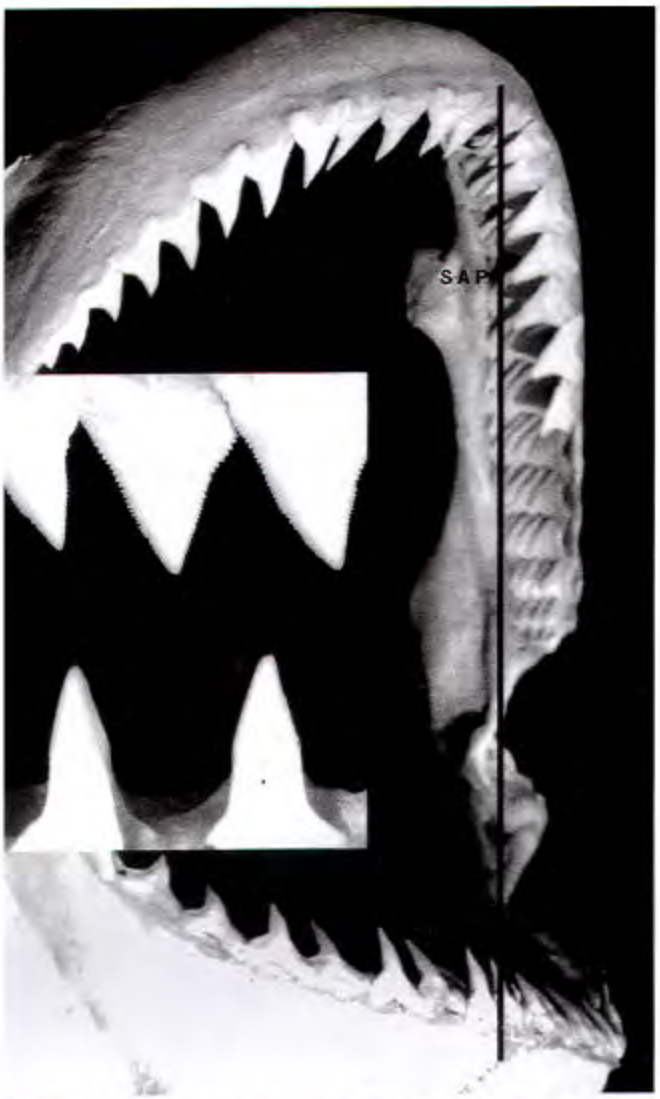

FIGURE 1. Symphyseal axis projection (SAP) of a bull shark jaw set, together with individual upper and lower teeth.

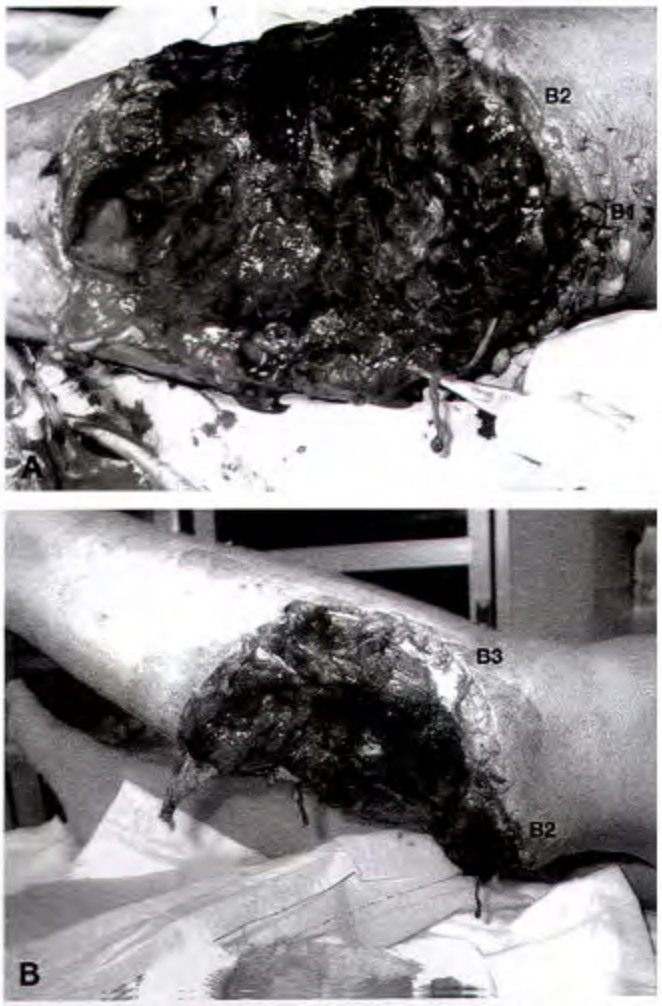

FIGURE 2. Posterior (A) and lateral (B) side of the lower left leg of case 1. B1-3 represent imprints and cuts of the respective bites.

180-cm (approximate length) shark bit the lower leg of the victim 3 times. The first bite (B1) is represented by a superficial puncture wound of the lower jaw around its symphyseal area, with a very slight sideways motion (Fig. 2A). The second bite (B2) is visible by a small segment of a margin created by the right upper jaw (Fig. 2B), with an RBA of approximately 130°. The third bite (B3) consists of the primary bite with an RBA of 80°. Its curvature margin shows extensive sawing (Fig. 2B). SAP excluded tibia and fibula for any of the 3 bites.

Case 2

Figure 3A and B shows the left lateral and medial side of the lower left leg of a 179-cm man. The affected muscles included the gastrocnemius, soleus, peroneus (longus, and brevis), extensor digitorum longus, and tibialis anterior. The external component shows a clear-edged bite top, with a well-defined sawing motion (Fig. 3A), and an RBA of 90°. The nearly severed gastrocnemius matches the upper jaw curvature. The bottom area shows cuts and puncture wounds. The tissue flaps show a slight change of the RBA during the bite. A second much smaller and only partially visible bite (X) exists as well (Fig. 3B). SAP included tibia and fibula (which was severed). The length of the shark was 240 cm.

Case 3

Figure 4 shows the back area of a 183-cm man. The approximately 300-cm-long shark approached the victim with a 0° RBA. The bite top is seen by the superior puncture wound, the bite bottom by the inferior one. Both teeth sets caused superficial imprints, with a very light closing motion of the upper teeth towards the bite center (but without

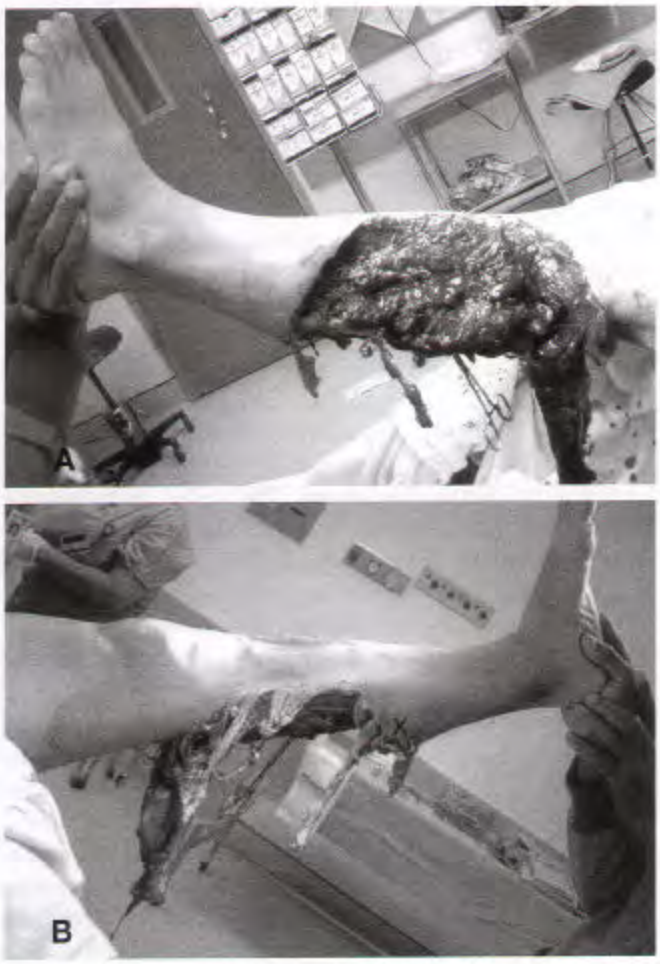

FIGURE 3. Lateral (A) and medial (B) side of the lower left leg of case 2. X represents the bite bottom of a second bite.

FIGURE 4. Back area of case 3. Teeth of the active series are marked with an A; in-row teeth are marked with an I.

protraction of the palatoquadrate). Some upper-tooth imprints show bending ends due to a slight body turn of the shark or the victim. Wound diameters of individual teeth indicated midlevel tooth penetration for both upper and lower teeth. Upper jaw wound shows 7 tooth imprints of the active series and 2 imprints from in-row teeth; the lower one shows 9 tooth imprints of the active series and 5 imprints from in-row teeth.

DISCUSSION

The motivation for sharks to bite humans is poorly understood and primarily of theoretical nature.[6–8] Hardly any case studies exist where a shark was observed approaching and biting a human being to connect the resulting bite pattern with the triggering behavior.[1] Nevertheless, the wound structure can reveal important hints to the antecedent motivation of the animal to initiate and execute a bite, even when no information from the victim or a witness is available. Cases 1 and 2 show a very similar bite structure. Nevertheless, these 2 bites show differences, pointing to unrelated bite motivations. In case 1, the shark bit 3 times. The first bite is represented by a few very superficial and irregular tooth imprints. Only a lower jaw in the symphyseal area where several rows of teeth are often active can create such a pattern. This first bite was created without great force, suggesting a slowly approaching animal whose initial bite was interrupted. This was most likely due to a reaction of the victim at first contact or due to the large RBA, nearly against the target area axis, making a forceful bite impossible and necessitating a change of RBA. The bite top of this first bite lies within the main bite and was destroyed during the process. The second bite was more forceful. This is indicated by the well-developed upper jaw margin, which is clean-edged. This bite was also interrupted. The reason remains unclear, but since the animal readjusted its RBA, the still-large RBA could have been a reason, or the victim moved his leg. The third bite was executed without interruption. Despite the victim's tissue loss, the bite pattern does not show a hunger-motivated behavior with the victim as the primary target, since SAP reveals a much larger theoretical bite

volume than what was actually removed. Nevertheless, a hunger-oriented motivation is likely but with the human as the secondary target, and the person was seen as a competitor (eg, being too close to a potential prey). Since the shark applied several bites in quick order without the intent to remove tissue, its motivation points indeed toward competition. Since human beings are unknown objects to sharks,[1] it is crucial to look for similar bite patterns in their biology to understand and explain such a scenario and its triggering behavior. Biting without causing damage is known among sharks when they, for example, compete for food.[9] At close range to a food source, they hit and bite each other prior to initiating a bite, should another shark be too close.[9] The rather severe damages to the victim's leg occurred because the shark used a similar force that it would also apply for conspecifics that have a much tougher skin than humans, even when wearing dive suits, and so this particular animal just followed a general action pattern for such a situation.[10] When the bites occurred, the person was certainly in a vertical position. A horizontal position would have triggered the initial bite in the 90° RBA area and not against the leg axis.

Although the wound of case 2 shows close visual similarity to case 1, it shows a different motivation. The wound pattern even indicates a motivation change during the incident itself. This victim was bitten twice, as seen by the 2 different bite bottoms. The first bite (X) is only manifested by a few lower jaw imprints. The rest of this bite is erased by the main bite. Both bites were terminated early. It cannot be determined by the wound pattern if the first interruption was caused by the person through pulling the leg away or by the animal readjusting its bite. But it is clear that the second bite was terminated early due to a reaction of the victim. Three facts support this conclusion: (i) the still partially attached muscle flap that follows the margin of the upper jaw, (ii) the tissue flaps created by the lower teeth, and (iii) the change of RBA within the second bite structure. For unknown reasons, the shark attempted to remove muscle tissue during the second bite by applying a sawing motion. When sharks gouge (removing tissue from an object that exceeds the bite volume of the feeding animal), they normally do not terminate the bite until the piece is removed; hence, the still partially attached muscle flap points towards an interruption. That the interruption was indeed caused by a leg motion of the victim is also evidenced by the tissue strips from the lower teeth. Sharks cannot swim backwards, and such a pattern can only occur if the person moved the leg. The changing RBA supports this conclusion as well. RBA rarely changes if the object does not move when a bite occurs. Since the bites were initiated from behind the person, visual contact of the animal prior to the bite was not likely. The RBA of the second bite showed a 90° angle and suggests that the victim could have been in either a horizontal or vertical position when bitten. However a horizontal position is unlikely due to the large size of the animal. If being bitten at the surface, the victim would have laid on his back and been able to lift his left leg out of the water with the animal attacked. The size of the animal makes such a scenario impossible, and a vertical position is more favorable where the person could pull the weight of the shark within the water. Exploratory behavior, as the initial motivation suggests by the superficial imprints of the lower jaw during the first bite, then seemed to have evolved into a stress-related bite, suggested by the upper-jaw damage of the second bite. That a competitive bite was not the case is indicated by the much greater bite volume of the second bite with clear edges.

Case 3 showed a completely different wound picture, but its analysis groups it with case 1. The shark swam into the victim with a fully open mouth. The upper jaw was not in protraction[11] at the time of impact, since it would have created more and deeper imprints with the upper-jaw teeth and created different imprint angles. No sawing motion was detectable, indicating that the animal's intention was not to remove tissue from the person but to only trigger a reaction. Although the same motivation occurred for the first case, the wound picture of case 1 and case 3 shows a very different appearance, what is due to (i) body area of the person and Langer lines,[12,13] (ii) body motion of the shark or the person at impact, and (iii) much larger size of the involved animal. Considering the large size of the shark in case 3, the midlevel tooth imprints indicate a slow swimming animal at impact as well. The 0° RBA indicate the victim was ascending or descending but not floating. On a person, floating horizontally in the water, facing skywards, a bite would be located closer to the lateral side of the rib cage or hip area, with an RBA around 90°, or even more likely, bites to the limbs. The latter would also be most likely if a person would be in a vertical position at the surface. Such a position requires sculling with arms or treading water, and bites would certainly occur to the moving parts of a body.[1] The person was not at the surface during the bite but either diving down or ascending towards the surface. That the shark hit the person only 1 time and not repeatedly, as in case 1, is likely due to its much larger size relative to the person. The way the shark hit the person, with fully open jaws at impact, prevented the shark from closing its jaws and removing tissue, indicating that the motivation was indeed competition in which hitting rather than biting is a means to initiate a reaction from the target.

CONCLUSIONS

The analysis of bite marks from sharks can determine the likely motivation of the animal to initiate and execute a bite and the position the victim was in when being bitten. The findings suggest that older cases of shark bites should be reevaluated where motivational reasons of a shark or victim

position were of importance to understand the structure of the wound picture.

REFERENCES

1. Ritter E, Levine M. Use of forensic analysis to better understand shark attack behavior. *J Forensic Odon Stomatol*. 2004;22:40–46.
2. Byard RW, Gilbert JD, Brown K. Pathologic features of fatal shark attacks. *Am J Forensic Med Pathol*. 2000;21:225–229.
3. Davies DH, Campbell GD. The aetiology and clinical pathology and treatment of shark attack. *J R Nav Med Serv*. 1962;68:1–27.
4. Compagno LJM, ed. *FAO Species Catalogue, Vol. 2: Sharks of the World*. Rom: Food and Agriculture Organization of the United Nations; 1984:479.
5. Nambiar P, Brown KA, Bridges TE. Forensic implications of the variation in morphology of marginal serrations on the teeth of the great white shark. *J Forensic Odon Stomatol*. 1996;14:3–9.
6. Collier RS. Recurring attacks by white sharks on divers at two Pacific sites off Mexico and California. *Environ Biol Fish*. 1992;33:319–325.
7. Lea RN, Miller DJ. Shark attacks off the California and Oregon coasts: an update, 1980–84. *South Calif Acad Sci Mem*. 1985;9:136–150.
8. Levine M. Unprovoked attacks by white sharks off the South African coast. In: Klimely AP, Ainley DG, eds. *Great White Sharks: The Biology of Carcharodon carcharias*. San Diego: Academic Press; 1996:435–448.
9. Ritter E. Food-related dominance between two carcharhinid shark species, the Caribbean reef shark, *Carcharhinus perezi*, and the blacktip shark, *Carcharhinus limbatus*. *Mar Fresh Behav Physiol*. 2001;34:125–129.
10. Barlow GW. *Modal Action Patterns: How Animals Communicate*. In: Sebeok TA, ed. Bloomington: Indiana University Press; 1977:98–134.
11. Motta PJ, Wilga CD. Advances in the study of feeding behaviors, mechanisms, and mechanics of sharks. *Environ Biol Fish*. 2001;60:131–156.
12. Ridge MD, Wright V. The directional effects of skin: a bio-engineering study of skin with particular reference to Langer's lines. *J Invest Dermat*. 1966;46:341–346.
13. Gibson T, Kenedi RM, Craik JE. The mobile micro-architecture of dermal collagen: a bio-engineering study. *Br J Surg*. 1965;52:764–770.