USE OF FORENSIC ANALYSIS TO BETTER UNDERSTAND SHARK ATTACK BEHAVIOUR

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ABSTRACT

Shark attacks have primarily been analyzed from wound patterns, with little knowledge of a shark's approach, behaviour and intention leading to such wounds. For the first time, during a shark-human interaction project in South Africa, a white shark, *Carcharodon carcharias*, was filmed biting a vertically positioned person at the water surface, and exhibiting distinct approach patterns leading to the bite. This bite was compared to ten white shark attacks that occurred (i) in the same geographical area of South Africa, and (ii) where the same body parts were bitten. Close similarity of some of these wound patterns to the bite imprint of the videotaped case indicate that the observed behaviour of the white shark may represent a common pattern of approaching and biting humans.

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Key words: *White shark, Carcharodon carcharias, human being, exploratory behaviour*

INTRODUCTION

Shark bites on humans or inanimate objects result in considerable speculation as to how they occurred and the motivation of the animals. Although victims often recall certain phases of an incident, they rarely see the animal approaching. Understanding the approach behaviour of a shark explains the bite pattern later manifested in the wound structures. Interestingly, one of the most revealing records of a shark bite was recorded by sheer accident. A video of a white shark, *Carcharodon carcharias*, biting a human being was used to analyze the approach behaviour of the animal and its possible motivation, in connection with the actual bite pattern. The tooth imprint pattern was later compared with bite patterns of selected white shark attacks where comparable body areas were targeted.

MATERIAL AND METHODS

Setup during incident

In an ongoing shark-human interaction project, on September 10, 2000, near Dyer Island (34˚40'S, 19˚25'E), South Africa, white sharks were videotaped to examine how they approach and interact with human beings. During the project, one of the interactors was bitten by a shark. The targeted person was treading water, using snorkel equipment with a black wetsuit and turquoise colored Cressi-Sub "FROG" fins.* A second person was in the water during the experiment, acting as a cameraman, but stayed away from the interactor and the sharks. Two Sony VX 1000 PAL digital cameras,‡ with either Amphibico§ or Gates¶ underwater housings were used to record the interactions. The weather was rainy, with a slight swell of about 1 m. The water depth at the site was 8 m, with a visibility of 10 m. The water temperature averaged 14°C.

The terminology for the different approach and behaviour patterns of the interacting white shark is described in Tables 1 and 2, respectively, and used in italic form within the text. Relative swim speed was measured during the individual approach patterns (n=3 for each measurement) using iMovie 2.1.1** and expressed in tail beats per seconds (tbs/sec).

Bite pattern analysis of filmed incident

The size of the animal was estimated by the distances between tooth imprints on the interactor's fin and compared to teeth measurements[1] (crown apex distances) from jaw sets of known-sized white sharks from the collection of G. Hubbell, Gainesville, FL, U.S.A. Teeth numeration and abbreviation was according to the suggestion by Applegate & Espinoza-Arrubarrena.[2] Fin markings were enhanced using standardized photography techniques of bite wounds.

*Cressi-Sub USA, Westwood, NJ, U.S.A.
‡Sony Electronics, San Diego, CA, U.S.A.
§Amphibico, Quebec, Canada
¶Gates Underwater Products, San Diego, CA, U.S.A.
**Apple, Cupertino, CA, U.S.A.

Table 1: *Terminology of the different approach patterns*

Approach	Oriented pursuit of a bait or other object
Pass	Any traverse swim pattern in the visible area of the object
Frontal Checkout	Shark swims directly towards the object (upcoming leg), turns in front of the object (turning point), and returns to the point of original appearance (downgoing leg)
Lateral Checkout	Shark approaches the object diagonally (incoming leg), passes the object, turns towards the object (turning point), and returns to the point of original appearance (outgoing leg), passing the object again
Go around	Shark approaches from any direction, swims towards the object at a slight angle, circles around the object, and returns towards the point of appearance

Table 2: *Terminology of the different behaviour patterns*

Head shake	Quick sideways movements of the head to both sides without opening the mouth
Head turn	Coordinated head and eye movements toward an object, with or without changing general swim direction
Eye roll	Voluntary eye movement without an associated head movement
Pectoral lowering	Both pectoral fins are lowered at the same time to nearly vertical position
Roll	Rotational pattern along the longitudinal axis

Bite pattern analysis of selected attacks

The files of ten white shark attacks were selected from the archives of the Global Shark Attack File, Shark Research Institute, Princeton, NJ, U.S.A.[3-12] All attacks occurred between 1975 and 1990 along the South African coast between False Bay and Durban. These attacks occurred at the water surface, resulting in wounds to lower body parts. Criteria for comparison with this incident were (i) person's activity (1 = surfing, 2 = freediving); (ii) leg protection (1 = bare, 2 = wetsuit); (iii) leg position (1 = horizontal, 2 = vertical); (iv) lower limb motion at the time of incident (1 = yes, 2 = no); (v) number of bites (1 = single, 2 = multiple); (vi) primary damage of jaws (1 = upper jaw, 2 = lower jaw, 3 = severed, 4 = no visible difference); (vii) type of wound from lower jaw (1 = puncture [superficial], 2 = cut [deep], 3 = severed); (viii) type of wound from upper jaw (1 = puncture [superficial], 2 = cut [deep], 3 = severed); (ix) tissue loss (1 = yes, 2 = no); (x) wound affected by victim's action (1 = yes, 2 = no). A leg position [criteria (iii)] was considered vertical if a surfer was sitting on his board. Criteria (ix) does not express severity of wound with regards to survivorship of the victim,[13] but rather wound depth and structure, based on whether a wound could be surgically repaired without loss of tissue.[14] Criteria (x) depended on the presence or absence of a secondary wound (see Discussion for further details). Decisions for the individual categories of each criterion were based on the file reports and pictures, and comparison to other cases analyzed by the authors.

Since this study was a first attempt to compare different criteria of archived attacks and forensic wound analysis with an attack behaviour and outcome of a videotaped attack, no criteria were weighed. Due to the relatively small sample size, only a simple category comparison for each criterion between each archived attack and the videotaped one was used.

RESULTS

General approach pattern

Over a period of 15 minutes and 15 seconds, the white shark performed several *passes*, *go arounds*, *lateral* and *frontal checkouts*, focusing on the interactor before moving in and initiating the bite on his right fin. The majority of approach patterns were *passes* and *go arounds*. Relative swim speed did not change between the individual patterns, and ranged from 0.75 tbs/sec (SD = 0.11) to 1.02 tbs/sec (SE = 0.04). During *incoming* and *outgoing legs* of *lateral checkouts*, the animal always slightly descended to the interactor's fin level, focusing on them, and either performed *head turns*, *eye rolls*, *head shakes*, or a combination of these behaviour patterns. *Fin lowerings* were only observed close to *turning points*, without any other behaviour patterns during the respective *upcoming* and *downgoing* legs.

Bite approach

The animal was about two metres from the interactor during a *go around*, when it turned and moved directly toward him. As the shark neared the interactor's right fin, the animal lowered its left

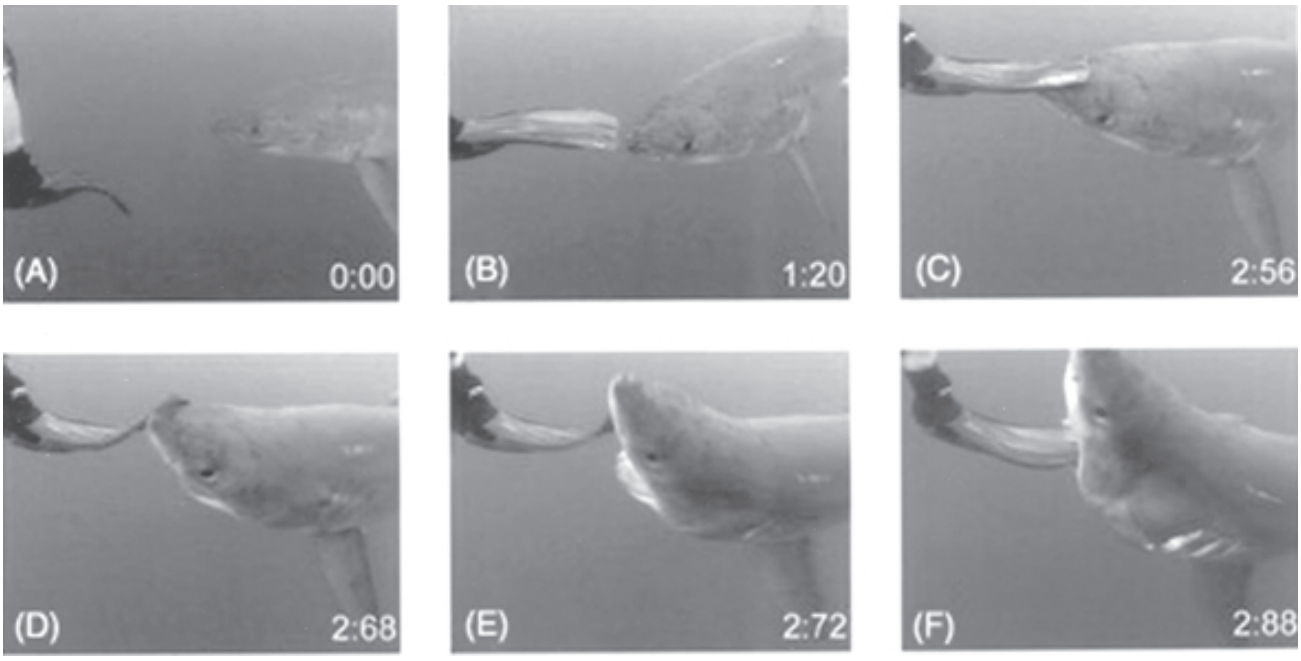

Fig.1: *Bite sequence in sequential frames. The numbers on the bottom right corner indicate the actual time in seconds.*

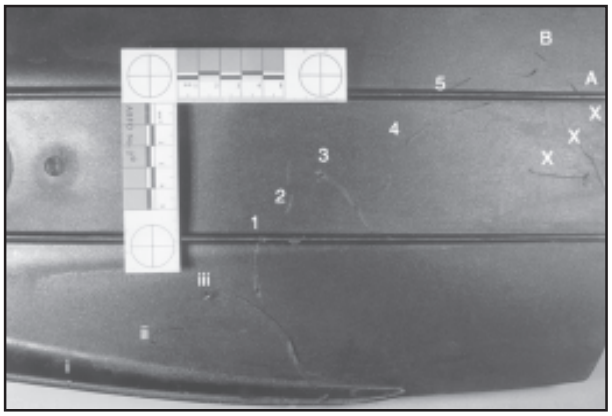

Fig.2: *White shark bite pattern on the bottom side of the interactor's right fin*

pectoral fin performing a *head turn* toward the interactor (Fig.1A). The shark's snout reached the interactor's right fin (Fig.1B) at the very moment the fin reached a horizontal position. The shark *rolled* slightly to its left to keep the object in right eyesight, and positioned its snout under the fin (Fig.1C), pushing it upward with the right half of the snout, while simultaneously opening its jaws (Fig.1D). The position of the interactor's leg, together with the shark's momentum, flipped the fin forward, placing it between the shark's jaws (Figs.1E and 1F). After the bite, the shark completed its *go around* pattern, without increasing swim speed, keeping the diver in sight without making any further *approaches*.

Teeth marks on fin

Fig.2 shows the bottom surface of the interactor's right fin with the tooth imprints of the left lower jaw. Anterior tooth marks are marked as i, ii, and iii, lateral tooth marks as 1-5. Main cuts were caused by iii, 3, and 4. X represents untraceable cuts and imprints, whereas A and B are end markers of cuts created by the lateral teeth 4 and 5. The upper surface of the fin shows similar cuts as well, but very irregular, caused by the lateral teeth of the left upper jaw. A comparison between crown apex distances of known-sized white shark jaws and imprints on the lower fin, indicated the animal (male) was between 3.5 and 4 m.

Comparison of the videotaped incident with archived attacks

Of the ten selected attacks, two occurred while freediving, the others during surfing activities (Table 3). The freediving attacks, 1983.08.20a and 1987.10.11, were assessed as most similar to the videotaped incident where either eight of ten or ten of ten criteria matched. The main difference for case 1983.08.20a was that the shark's upper jaw caused the primary damage. Independent of activity, six victims shared three criteria with the videotaped incident: single bite, puncture wound from lower jaw and no tissue loss.

Table 3: *Category listing of each criterion for all cases examined.*

Case	i	ii	iii	iv	v	vi	vii	viii	ix	x
1971.06.30	1	1	1	1	1	1	1	2	2	2
1975.08.17	1	2	1	1	1	1	1	2	2	2
1976.10.06	1	1	1	1	1	1	1	2	2	2
1980.01.31	1	1	1	2	1	3	3	3	1	1
1983.08.20a	2	2	2	1	1	1	1	2	2	1
1986.12.22	1	1	1	2	1	4	2	2	2	2
1987.10.11	2	2	2	1	1	4	1	1	2	1
1989.08.22	1	2	1	1	2	4	2	2	2	1
1990.04.14	1	2	1	1	2	4	1	1	2	2
1990.05.06	1	2	2	2	1	1	1	2	2	2
Video case	2	2	2	1	1	4	1	1	2	1

DISCUSSION

Although white shark attacks on humans have been well documented,[1,15,16] none were observed from underwater. Although this is a single incident and definitive conclusions cannot be made, observations were made that question how white sharks approach and bite humans, and how wound patterns can result.

Bite mechanics and injury patterns

The white shark's bite kinematics differs somewhat from the more well-studied carcharhinid sharks.[17] Although all higher evolved shark species use protrusion of the upper jaw – the palatoquadrate rotates forward and downward – probably to enhance the motion freedom of their jaws when biting,[18] the upper jaw protrusion of white sharks takes place well before the lower jaw is completely elevated. Different hypotheses exist about the advantage of such a mechanism.[19-21] The tips of white sharks' front teeth are angled inward, compared to the more out-turned teeth in carcharhinid sharks, allowing white sharks to more effectively grasp and hold larger prey. Nevertheless, it is the shark's motivation that influences the actual bite pressure and hence the type of wound, rather than the actual bite kinematics.

Of the other ten selected attacks, seven victims were bitten once without actual tissue loss. This is comparable with the videotaped incident. The superficial cuts on the interactor's fin indicate that the animal did not clamp its mouth shut but only slightly pinned the fin. The incisions were then created by the interactor himself, when he moved his fin to the right. Except for three incidents, all others wounds exhibited similar puncture imprints from the lower teeth.

Similarity to the videotaped incident refers to the appearance of the injury rather than the wound depth, since the videotaped shark clamped down on artificial material rather than human tissue. The lack of actual tissue loss should likewise not be equaled with the severity of a wound since a bite can, primarily when large animals are involved, still lead to moderate or deep incisions. Furthermore, the victim himself, when attempting to pull a body part away from the animal, can increase the severity of a wound or produce a secondary wound. In such a situation a more indistinct wound pattern is created, leading away from the initial teeth penetration. Margins of the incisions are much cleaner, with a more constant depth, when a shark just bites into a moving body part. Nevertheless, the clarity of both wound types and their patterns is further affected by the relative bite angle (angle between the vertical axis of jaws and the main axis of the targeted body area) in connection with Langer's lines of the targeted body area.[22]

Bite motivation

The videotaped incident showed that the shark's intention was not to bite through the fin or hold on to it. It has been argued that, to determine palatability, white sharks grasp an object as an exploratory bite.[23,24] This supports the observation that single white shark bites on humans are often superficial.[25,26] Considering the similarity between the fin imprints and some of the examined wound patterns, it is likely that the motivation was the same for most sharks that bit the surfers and freedivers. This can be supported by the fact that in seven cases the result was one bite, with no tissue loss.

Whether biting into a wetsuit or onto bare human skin has a different effect on their exploratory behaviour cannot be evaluated, due to the small sample size. Of the six victims whose legs were covered, two of them were bitten twice, while none of the bare legged victims was bitten a second time. Nevertheless, neither human skin nor artificial material is familiar to sharks.

Exploration is a function often suggested for object play in adult predatory species where the animal explores and learns about novel stimuli and to become familiar with objects that they are initially hesitant to approach.[27] Play behaviour as a bite motivation, particularly for white sharks, has also been suggested.[26]

Approach pattern and object recognition
Given that the shark was unfamiliar with the object as such, behaviour flexibility was needed to cope with the situation, and was demonstrated by a variety of patterns within the general approach strategy that involved an extensive period of time. White sharks often spend a considerable period investigating both known and unknown objects.[28] The shark kept its distance from the interactor during the initial approaches performing *passes* and *go arounds*. Neither of these two patterns limited the shark's escape routes. Contrary to *passes* and *go arounds, frontal* and *lateral checkouts* brought the shark very close to the interactor. This seemed to put the animal in a higher state of alertness based on observations of *pectoral lowerings*. Such behaviour patterns enhance maneuverability, and are considered essential survival behaviours.[29] Although the animal appeared to be in a higher state of alertness, no known agonistic displays were observed.[30,31]

Although white shark attacks on humans have often been interpreted as a result of mistaken identity, primarily in cases in which surfers were bitten,[32] no clear evidence has ever been offered to substantiate this hypothesis. A general seal shape resemblance to humans, as the reason for mistaken identity, is insufficient to support such a misidentification. Although a shape resemblance is unlikely, a motion resemblance could be possible, and dangling feet when sitting or laying on a surfboard, or the motion of a diver's fin as in this incident could have triggered some form of action pattern.[33]

In this case, the shark consistently reacted to these motions during its *outgoing legs* near the interactor. It is possible that this could be due to a shark's recognition of the water pressure as an object's propulsion system, detected by the lateral line system.[34,35] This sensory organ is only functional close to a source, supporting the observation that the animal only reacted during the *outgoing legs of lateral checkouts* or *close passes*, when closest to the interactor. Looking at the randomly selected cases, seven of the ten cases showed some form of motion by the victims as well. This could indicate that a moving object is indeed more prone to be investigated than a non-moving object.

Aside from water pressure detection, auditory, olfactory and bioelectrical clues cannot enhance the shark's understanding of an object such as a surfboard or a divesuit.[36] Therefore, vision is likely to be the primary sense used during these interactions.[28,37] The two different eye movement patterns, used during the closer approaches in this case, support this assumption. *Eye rolls* observed during the *outgoing legs* indicated a visual orientation, which occurred without a change in the shark's general swim direction but often with a slight *roll* along the longitudinal axis; whereas the *head turns*, an oriented response, used full vision to approach.[38] During an interview with a victim of one incident, he mentioned that he observed the shark slightly roll to one side immediately prior to the bite, which also supports this observation.

CONCLUSION

Shark incidents with humans have primarily been categorized based on theoretical evaluation or by surface observation of animate objects.[17,39] This incident, observed from below the surface, showed that a white shark's approach behaviour may be much more complex than assumed, and that the animal is capable of changing its tactics when approaching an unknown object. Determining the tooth imprint pattern and its occurrence from the videotaped case made it possible to compare this with wound patterns of selected attacks, suggesting that exploration was the likely motivation for most of those as well.

Forensic odontology primarily focuses on human teeth, but animal bites have also been analyzed.[40,41] Although shark attacks are usually highly publicized, their forensic analysis is still scarce. Knowledge of forensic odontology may be used not only to identify a shark species and size but also to understand wound pattern development and potential motivation. The analysis of this incident, and its similarity to other cases, indicates that the videotaped behaviour of this white shark might be a common pattern of approaching and exploring unfamiliar objects. In spite of the fact that this was a single event, new ideas that deserve further examination arose from these observations in comparison with earlier white shark attack cases where only post-incident pictures are available.

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