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CASE REPORT

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Postmortem Changes of Human Bodies on the Bathyal Sea Floor—Two Cases of Aircraft Accidents Above the Open Sea

ABSTRACT: Forensic taphonomy in the marine context recently received growing attention. However, only limited information is available about the fate of human bodies at greater sea depth. Following two fatal aircraft accidents (west of Namibia, south of Sicily) human remains were recovered from a depth of 540–580 m (both cases) after 3 months (Namibia)/34 days (Sicily). In the Namibia case fully skeletonized bones were lifted. In the Sicily case a complete, dressed body was found exhibiting a partially skeletonized skull, starting adipocere formation and pink teeth. The rate and mode of decomposition of human bodies in the deep sea varies considerably and is mainly influenced by the local faunal composition. Of special relevance for the understanding of both cases was the oceanographic observation that the highly efficient necrophageous lyssianassids are abundant off Namibia but are rare in the Mediterranean, emphasizing the importance of collaboration of forensic and marine scientists in such case work.

KEYWORDS: forensic science, forensic taphonomy, aircraft accident, open sea, bathyal

In the past years German Forces lost two aircraft in accidents in two different regions of the world above the open sea. In both cases the wreckages were found at a similar depth of about 540–580 m on the continental slopes ("bathyal" in terms of marine science). One case was a mid-air jet collision at an altitude of 35,000 ft of a German Air Force *Tupolev* TU-154 and a U.S. Air Force C-141 *Starlifter* with a total of 33 persons on board of both aircraft and nobody surviving. The other case was a crash of a MK-88 helicopter in which two of the three crewmembers survived. For accident investigation purposes in the jet aircraft crash the recovery of the flight data recorders and the cockpit voice recorders was the main goal of efforts. This was achieved and human remains were spotted and recovered. In the other case the helicopter wreckage and the missing crewmember could be lifted from the seabed. Preparation and debriefing of both missions revealed that forensic taphonomy in the marine context recently received growing attention (1–3). However, there is only limited information available about the fate of human bodies in the marine environment if the bodies remained at a depth inaccessible for divers or outside dredge-fishing zones. The purpose of this report is the presentation of the taphonomic findings in relation to such information and in the context of the marine life at greater depth.

Recovery of Remains, Findings, and Further Observations

Jet Aircraft Case

The jet aircraft mid-air collision happened off the Namibian coast (latitude 18°S). Initial search and rescue efforts revealed only floating aircraft debris and one floating human body that was recovered 2 days after the crash. Following side scan sonar exploration of the sea bottom, in a joint operation of German and U.S. military authorities a remotely operated vehicle (ROV, US Navy *Deep Drone 7200* [4]) equipped with a color video camera and two manipulator arms was employed. The video images were continuously monitored by forensic science personnel on board a vessel used as platform for the ROV. On day 89 after the crash a set of bones lying on the sea floor could be identified including a pair of trousers. The bones were found in the vicinity of larger wreck parts originating from the *Tupolev*. In the legs of the trousers, bony structures consistent with tubular bones could be seen. Other identifiable bones included the cranium, vertebrae, ribs, pelvis, and limb bones. It appeared that the bones were fully skeletonized and disarticulated. Within the set, the bones were lying according to their location in the human body. Numerous trout-sized fish, later classified as the deep-water cape hake *Merluccius paradoxus* (Dr. Friedhelm Krupp, personal communication) were swimming near the bottom but seemed not to be attracted by the bones. Also nearby, a crab, later classified as the deep-sea red crab *Chaceon maritae* was detected. For the recovery of as many bones as possible they were transferred in a basket that was finally lifted to the surface. The bones were yellow-greyish, partly dotted blackish, greasy and free of soft tissue and joint cartilages and delivered a slightly muddy but no putrefactive odor. In the joint regions some tubular bones were pink. Reddish fluid oozed from some long bones. The surface of the bones was smooth or showed a pronounced relief at muscle or tendon insertions but no signs of abrasion, rasping, boring, dissolution, or encrustations. On a vertebra a tiny osteophyte was preserved. No rib was complete and some rib fragments exhibited bulks consistent with healed rib fractures. Some anterior segments revealed a cartilaginous yellowish core. Cranium, pelvis, and some long bones showed fractures with parts missing. The color of the fracture surfaces was similar to the other parts of the bones indicating that the fractures were crash-related and not caused on

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recovery. Open bone marrow cavities were empty. The facial portions of the cranium including parts of the orbitae, the complete maxilla, and the mandible were missing, the cranial cavity was widely open and empty. On the outside the fronto-temporal sutures were partly gaping and blackish. Identification was achieved by radiological comparison of several skeletal features and was facilitated by a wallet with personal documents found in the trousers and a variety of X-rays taken at life time of the assumed person including head, chest, and spine radiographs (5).

Helicopter Case

The helicopter accident occurred in the Mediterranean Sea (latitude 37°N). After hitting the water, two of the crew managed to escape the rapidly sinking aircraft and were rescued. The third crew-member was assumed to be immersed with the helicopter. Following sonar exploration of the seabed, the airframe of the helicopter was found and the video images of the ROV used (*Super Achille* [6]) showed that it was lying upside-down and almost complete. Still strapped to his seat by the belts the missing crewmember was partly hanging outside the helicopter through an open door with his head resting on the sea floor. His flight suit seemed intact, the so-called survival vest was in place and he was wearing his pilot's boots. The flight helmet was missing, this being in line with the foregone recovery of a floating helmet assigned to him. The skull was skeletonized with some remains of what seems to be soft tissue. Parts of the facial bones of the right side were missing giving view into the oral cavity. No soft tissues were observed and dental restorations were seen on the crowns of the lower left molars. At times a crab, later identified as the deep-sea brachyuran crab *Paromola cuvieri* was seen close gnawing on the head. An animal, assumed to be *Todarodes sagittatus*, the European Flying squid (Dr. Uwe Piatkowski and Dr. Jürgen Guerrero-Kommritz, personal communications) was once observed on the leg of the flight suit. In the proximity of the wreck a few deep sea corals were visible and a bluntnose sixgill shark (*Hexanchus griseus*) scoured close to the sea floor but was never seen close to the body. On day 34 after the crash, the body was recovered. At autopsy the skull was found to be fully skeletonized at the outside with exception of the occipital parts where the head had been seen lying on the sea floor. There, the edge of the preserved scalp in this region was irregular in shape with no hints of bruising and adipocere had formed. The surface of the bone showed no abrasion, bioerosion, dissolution, or encrustations. In the right suborbital area bone structures were missing including parts of the maxilla and some teeth, parts of the nose, and part of the zygomatic. The capsule and cartilage of the jaw joint was gone as well as most of the soft tissue, with the remaining looking reddish-brown. All remaining teeth were complete and had pink roots. Dental identification was accomplished easily. The right orbit was empty, the left showed wrinkled greyish-white tissue. Inside the cranium the dura lining was loose from the bone and engulfed the liquefied brain. No fracture lines were detectable and the sutures were firm. Haemorrhages were found in the petrous temporal bones. Taphonomic findings of the rest of the body include slippage of the skin of the glove-wearing right hand, partly skeletonization of the unprotected left hand, loss of the soft tissue under the skin of the left forearm, gas crepitation under the greyish-white to greenish-dark skin, few small roundish skin lesions and a larva at the lower leg, waterlogged skin at the feet, a flaccid heart with hemolytic staining of the endocardium and the large vessels, and a softened brown to greenish liver. The overinflated lungs released reddish foamy fluid on incision. Rib and sternum fractures with surrounding hemorrhages were judged crash-related.

Discussion

Taking into account the postmortem interval both recovered remains showed significant taphonomic findings. Most noticeable in the jet case is the complete skeletonization of the body including the loss of cartilage after remaining 3 months in the water. These changes are far more advanced than reported for bodies having been lain in a lacustrine or riverine environment: In a study of the fate of human remains in German lakes and rivers covering a postmortem interval up to several months (7) and in case studies from North America (8) a complete skeletonization of a body was never observed. In a case report of two corpses found in a lake after 50 years at a depth of 50 m (ca. 166 ft) in a car one body was fully skeletonized while the other exhibited extended adipocere formation (9). However, in coastal environments skeletonization can occur within the first month and is mainly caused by scavenging fish, arthropods, and molluscs. In a case series of bodies from the Gulf of Maine (depth mainly not exceeding 150 m) (1), one body recovered 1 month after death by ground net fishing showed intact clothing and a complete loss of soft tissue but not of cartilage. Cartilage loss was first observed in one case 10 months after death but in other cases cartilage could be found until 18 months after death.

In our jet case the remains were found after 3 months at a depth of 580 m on the continental slope (bathyal). Ecologically this part of the sea floor belongs to the tropholytic zone where no photosynthesis occurs because of the lack of enough light. Without any primary production the fauna either depends on organic matter originating in the euphotic (trophogenic) zone close to the surface or has to migrate actively towards the surface layer for feeding. Food ingression into the deep sea can be in the form of particulate matter, like faeces or corpses of small pelagic animals. For the present case the fate of large food falls is more interesting. Experimental work has been carried out with baited cameras (10–12). It was found that the speed of consumption can vary considerably depending on depth, latitude, and kind of bait. While larger animals are usually seen close to carcasses, the main element of the necrophagous fauna are lysianassoid amphipods. Fish observed near large food falls do not necessarily feed on the carcass, but can also be attracted by the amphipods (13). In our case the obviously undisturbed arrangement of the bones and the absence of any bite marks or erosions on the bone surfaces point to such small scavengers capable, e.g., to move underneath the trousers but unable to dislocate bones or to rasp the cortical surface. At the time of video-recording all soft tissue was already gone and the amphipods had probably already largely left the scene. The frequently seen hake *Merluccius paradoxus* is not known to be a scavenger. The crab *Chaceon maritae* which was seen once near the bones occurs in a density of about one animal per 100 m^2 (14) and scavenges but the crab seems to be too big to be charged for the complete consumption of tissue, e.g., of the cloth-covered legs. The time scale of the reduction to a skeleton is in accordance with current knowledge. Jones et al. (12) state that a 50–100 kg small whale carcass is typically reduced to a skeleton during 15 days. The experiments of these authors have been performed at abyssal depths of 4000–4800 m in the North Atlantic. The reduction speed can even be quicker in upper bathyal depths and also taking into account that the Namibian bathyal is influenced by strong upwelling processes in the Benguela current system. In such nutrient rich areas of the sea the scavenging fauna is richer than in more oligotrophic areas, where scavengers have to travel longer distances towards the food items.

In the helicopter case the head of the victim was partly skeletonized, omitting regions lying on the sea bottom and the rest of the body being covered by the tight-fitting flight suit. The still existing organic parts point towards a less active destruction process. In fact, in the Mediterranean the necrophagous fauna is completely different from that in the Atlantic ocean. Baited camera experiments and trap catches have shown that lysianassid amphipods are scarce and oceanic genera like *Eurythenes* are lacking altogether. In this environment predominantly decapods and fish feed on carcasses (15,16). Such communities are less efficient in the breakdown of organic matter than oceanic ones which results in slower degradation. Our finding is fully compatible with these oceanographic observations. In our case a deep-sea brachyuran crab, *Paromola cuvieri,* was seen gnawing on the unobstructed parts of the head. During the recordings there was always only one individual present and no other benthic arthropods around. A squid, probably *Todarodes sagittatus,* only observed once, is known to feed on live prey so that it cannot be brought in connection with the destruction of the corpse. The bluntnose sixgill shark (*Hexanchus griseus*) scouring around the wreck site is a facultative scavenger. It rests at the bottom at depths up to 2000 m during the day and moves to shallow waters or swims close to the surface at night to feed (17). Though it is quite conceivable that the shark was attracted by the deceased there were no bitemarks found, indicating that the shark might not have fed on the body. This is in line with the observations of Jones et al. (16); also these authors state that sharks do not account for the total consumption of large carcasses. We therefore conclude that the crab and other decapods might have chiefly contributed to the loss of tissue of the head. The relatively small amount of flesh missing correlates well with the slow feeding behavior of *Paromola cuvieri* and other decapods. In this connection the time of 34 days for which the corpse was on the sea bottom is of interest, because this is the period for which it was exposed to necrophageous fauna. To date there are no long-term experiments in connection to organic matter breakdown in the Mediterranean deep sea. The present case clearly shows that even body tissues freely exposed to the environment (and not only the body encased in a flight suit inhibiting access by fauna) still have flesh on them after 34 days. This observation is in perfect accordance with knowledge about the composition of the necrophagous communities in which the highly efficient lysianassids are absent or rare.

The loss of boney parts of the face may be explained by crash-related fractures and subsequent loss of fragments on postmortem withering of the soft tissue: Scratches and patterned impressions on the outside of the deceased's helmet together with crash reconstruction considerations suggested an impact to the right side of his face when the helicopter hit the water and the possibility of fractures of the facial bones.

The teeth clearly showed pink roots, a phenomenon reported mainly on bodies from humid or freshwater environments (18–20) where it may occur as early as 1–2 weeks after death but reported only once in a saltwater environment after 8 months and there seen in only one body out of seven (21). The underlying mechanism is seepage of hemoglobin or its derivates into the dentinal tubules after extravasation and hemolysis of the erythrocytes. It is fostered by congestion or a head-down posture as it was given in our case. Experiments showed that it took up to 10 days to get pink teeth if intact erythrocytes were instilled in the root canal instead of haemolysed ones (18). Since there is no immediate hypo-osmolaric hemolysis in saltwater as there is in freshwater one may conclude that the first appearance of pink teeth in saltwater can be delayed for up to 10 days compared to freshwater and therefore results in an occurrence time of 2.5–3.5 weeks in saltwater. Our finding of pink teeth 5 weeks postmortem fits in this time line.

At the rim of the preserved parts of the scalp and the neck skin formation of adipocere has commenced. Recently in a laboratory study the role of bacterial enzymes for fat hydrolysis as an initial step and the environmental conditions for the course of adipocere formation are described (22). Adipocere formation of bodies in coastal waters is well known and is reported previously (2). Our findings show that adipocere can also form in a depth of nearly 600 m (tropholytic zone) despite the considerably different environmental conditions regarding light, substrate, and oxygen compared with those of the trophogenic zone near the surface. In a case where the ambient sea water temperature (10–12°C) was similar to our case (13°C according to [23]) but the bodies were recovered from inside a shipwreck at a shallower depth of 65–85 m (likely to be tropholytic if no uncommon conditions were present) onset of focal adipocere formation is reported after a comparable immersion time of 25–38 days (24).

Conclusion

The findings in our cases together with the findings of the other mentioned reports suggest that under the conditions of the tropholytic zone of the deep sea, the rate and mode of decomposition can vary considerably. Composition of the local fauna and accessibility of the tissue seem to play a major role. If scavenging is restricted by wreckage structures or tight-fitting clothes the course of decomposition may be similar to that known from bodies in lakes or coastal waters.

The observations presented in this study show clearly that the degradation of larger biogenic objects (including human bodies) in the sea is not just a matter of ambient parameters and bacterial floras, but that the speed and time scales are mainly influenced by the specific faunal composition of the necrophageous communities which we just start to understand. The interpretation of evidences in such cases can thus only be done appropriately on the background of oceanographic knowledge.

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