3,000-year-old shark attack victim from Tsukumo shell-mound, Okayama, Japan

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ABSTRACT

Modern shark attacks are uncommon and archaeological examples are even rarer, with the oldest previously known case dating to ca. AD 1000. Here we report a shark attack on an adult male radiocarbon dated to 1370–1010 cal BC during the fisher-hunter-gatherer Jōmon period of the Japanese archipelago. The individual was buried at the Tsukumo site on Japan's Seto Inland Sea where modern shark attacks have been reported. The victim has at least 790 peri-mortem traumatic lesions characteristic of a shark attack, including deep, incised bone gouges, punctures, cuts with overlapping striations and peri-mortem blunt force fractures. Lesions were mapped onto a 3D model of the human skeleton using a Geographical Information System to assist visualisation and analysis of the injuries. The distribution of wounds suggests the victim was probably alive at the time of attack rather than scavenged. The most likely species of shark responsible for the attack is either a white shark (*Carcharodon carcharias*) or a tiger shark (*Galeocerdo cuvier*). Shortly after the attack most, though not all, of his body was recovered and buried in the Tsukumo cemetery.

Keywords: shark attack, trauma, radiocarbon, 3D, GIS, radiocarbon

Highlights:

1. Oldest recorded shark attack in the world
2. Adult male victim likely alive at the time of attack
3. Victim suffered fatal injuries
4. 3D modelling of the pattern of injuries

1. Introduction

Sharks rarely attack humans or scavenge their remains, yet when they do attack the danger they pose is considerable. One prehistoric man from the Japanese archipelago learned this all too well. The deep and sharp incised linear marks that cover a majority of the remaining skeleton of individual No. 24 from Tsukumo Shell-mound, Okayama Prefecture, Japan, are arresting. Despite having been excavated in the early 20th century (Kiyono, 1969), a comprehensive explanation for their cause has not yet been presented. The authors (JAW, RJS) conducting the re-examination of this skeleton as part of a larger project on violence in prehistoric Japan were initially quite puzzled by the shape, depth, and distribution of the lesions found on this individual. It was not clear how, or why, another human would cause them, either via a violent encounter or through post-mortem processing, or how commonly reported animal attacks would be able to produce such marks. The wounds to Tsukumo No. 24 number in the hundreds and vary considerably in size, shape (at times curving along the bone), and severity. Their incised, sharp edges and slightly curved shape are not consistent with the kinds of marks that would be made by the stone tools available at the time (Fernández-Jalvo and Andrews, 2016; Robb et al., 2015).

On further examination of the remains and literature, the authors realised that the lesions were remarkably similar to reports of shark attack injuries found on modern and archaeological remains (Allaire et al., 2012; Byard et al., 2006; Ihama et al., 2009; İşcan and McCabe, 1995; Keegan and Carlson, 2008; Nakaya, 1993; Stock et al., 2017). This paper presents the circumstantial and direct evidence for what is now the oldest recorded shark attack on a human, significantly pre-dating 5th century Greek writings and 8th century BC illustrations of shark attacks (Burgess, 1970; Coppleson, 1962), as well as known archaeological cases (Keegan and Carlson, 2008).

2. Background

2.1. Site details

The Jōmon period of the Japanese archipelago spans more than 10,000 years, beginning with some of the earliest pottery production in the world. The period is marked by a fisher-hunter-gatherer economy with some plant cultivation. The Jōmon culture in Kyūshū lasted until ca. 900 BC and was followed by the Yayoi period, which saw the introduction of agriculture and bronze tools. Yet, the Jōmon culture persisted much longer eastwards, with the Yayoi culture never fully taking hold in Tōhoku and Hokkaidō (Mizoguchi, 2013). Tsukumo shell-mound is located 3 km from the Seto Inland Sea, in Kasaoka City, Okayama Prefecture, Japan (Fig. 1). Found during construction work in the 1860s, the site was first excavated in 1915 and has produced more than 170 human skeletons (Kanaseki and Tabata, 1930; Kiyono, 1969). The pottery from the site dates primarily to the Late–Final Jōmon periods, spanning ca. 2540 to 435 cal BC (Kobayashi, 2017).

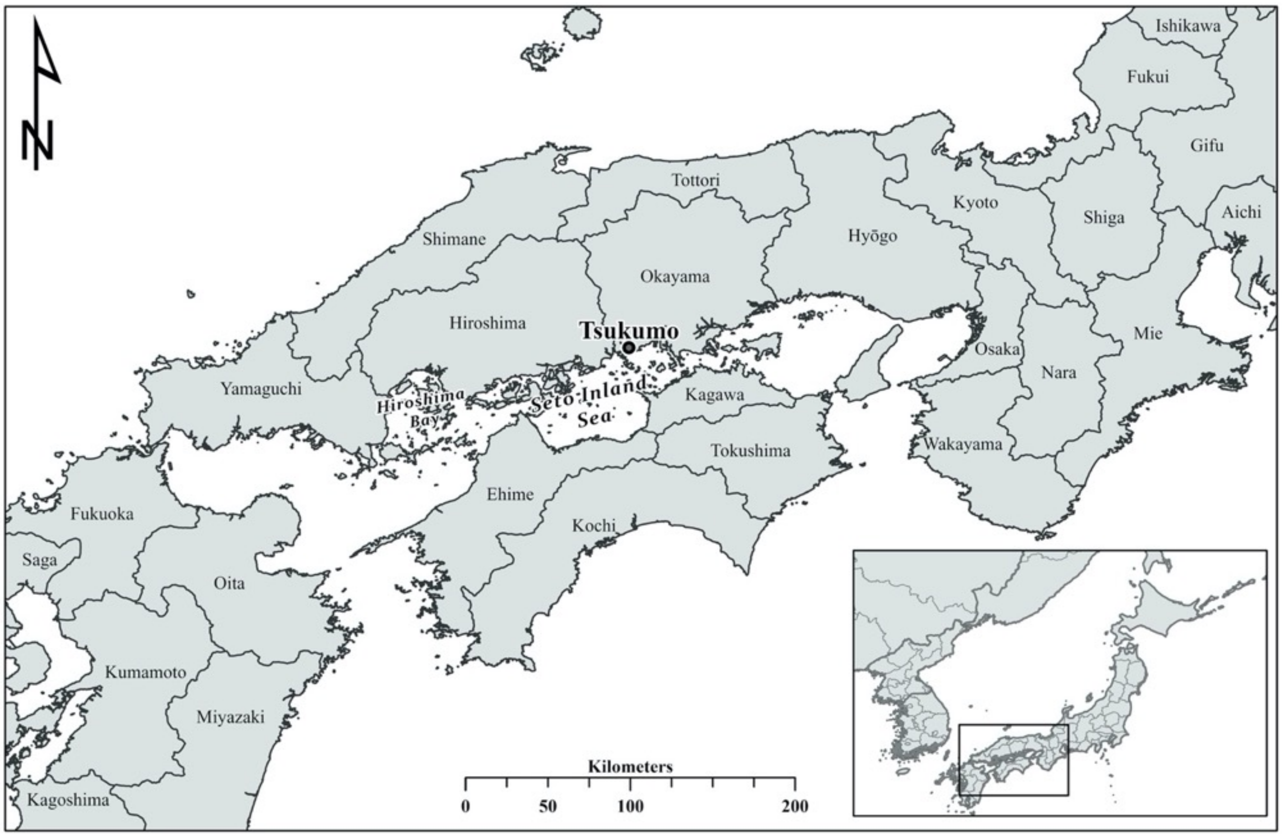

Fig. 1. *A map of the location of Tsukumo Shell-mound in Okayama Prefecture. The administrative boundaries map data source is GADM (https://gadm.org/data.html).*

2.2. Jōmon period sharks

The Late-Final Jōmon saw increased use of marine environments around the Japanese archipelago (Bausch, 2017; Hudson et al., in press). Frequent voyaging to offshore islands is matched by evidence for specialised exploitation of deepwater fish and abalone (Komoto, 1999). Increased incidences of auditory exotoses from this time are thought to relate to diving for fish and shellfish (Katayama, 1996), a custom mentioned in the *Wei zhi*, a third-century AD Chinese account of Japan (Kidder, 2007).

Sharks are largely cartilaginous vertebrates (Chondrichthyes), and cartilage does not tend to preserve well in the archaeological record. This is not the case for their dentition, which has mineralised components, along with some isolated ossification foci, including some vertebral bodies, which are more likely to be preserved (Steel, 1985). Although not common, shark teeth and vertebrae have been found in coastal and inland Jōmon sites from Okinawa to Hokkaido (Kōchi Prefecture Archaeological Center, 2004; Nagabaka Archaeology Project, 2013; Nakazawa, 2017). An incised hammerhead shark (*Sphryna* sp.) on a Final Jōmon bowl from Yama-no-kami (Nagano) may be the oldest such illustration found anywhere in the world (Takahashi, 1972) (Fig. 2). The inland location of some Jōmon sites with shark remains raises the possibility that shark meat was traded, a custom known ethnographically in Japan (Hashiguchi, 1999). Jōmon shark teeth were often perforated as ornaments, but finds deposited with other animal remains suggest sharks were also eaten (Shimane Prefecture, 2019).

Fig. 2. *Photograph of a Jōmon potsherd from Yama-no-kami with an incised depiction of a hammerhead shark (Takahashi, 1972). The ceramic dates to the Final Jōmon ca. 700 BC. Courtesy of the Iiyama City Board of Education.*

Shark hunting was carried out by prehistoric societies worldwide (Charpentier et al., 2020), possibly including the Jōmon, for whom social prestige may have been symbolised by shark teeth (Nakazawa, 2017; Watanabe, 1990). Evidence from fishhooks (Tajima, 2015) and stable carbon and nitrogen isotope analysis of human remains (Kusaka et al., 2010) supports the consumption of high-trophic-level fish in the Inland Sea area during the Late-Final Jōmon. Within Okayama Prefecture alone, shark remains have been reported at four Jōmon sites (Tajima, 2015), though at Tsukumo only one Galeomorphii or Squalomorphii bone has been recovered (Tomioka, 2020), making it unlikely that it was a specialised shark-hunting village.

2.3. Shark attacks

Most sharks do not attack humans without provocation, but among those that do the most dangerous are white (*Carcharodon carcharias*), tiger (*Galeocerdo cuvier*), and bull (*Carcharhinus leucas*) sharks (Burgess, 1991; Burgess and Callahan, 1996; Caldicott et al., 2001; Clua et al., 2014; Coppleson, 1962; Davies and Campbell, 1962; Howard and Burgess, 1993; İşcan and McCabe, 1995; Nakaya, 1993). Unprovoked shark attacks tend to follow three patterns – ‘hit-and-run’, ‘bump-and-bite’, and ‘sneak’ attacks (Burgess, 1991). Hit-and-run attacks usually occur in the surf zone, entail a single bite, and tend to be non-fatal. It is thought that these are due to the misidentification of humans as prey. The other two patterns are more likely to result in severe injuries and occasional mortality. They are believed to be the result of the shark actively targeting humans as appropriately-sized prey. In bump-and-bite attacks, the shark circles and bumps the victim prior to attack, while no prior warning is given in the case of 'sneak' attacks (Allaire et al., 2012; Auerbach and Burgess, 2007; Caldicott et al., 2001; Howard and Burgess, 1993; Lentz et al., 2010; Stock et al., 2017). Almost half of all known shark attacks in the first half of the 20th century were fatal before advances in medical treatment and the advent of beach safety initiatives (Fig. 3), though there is likely to be a bias towards more serious attacks in early reports.

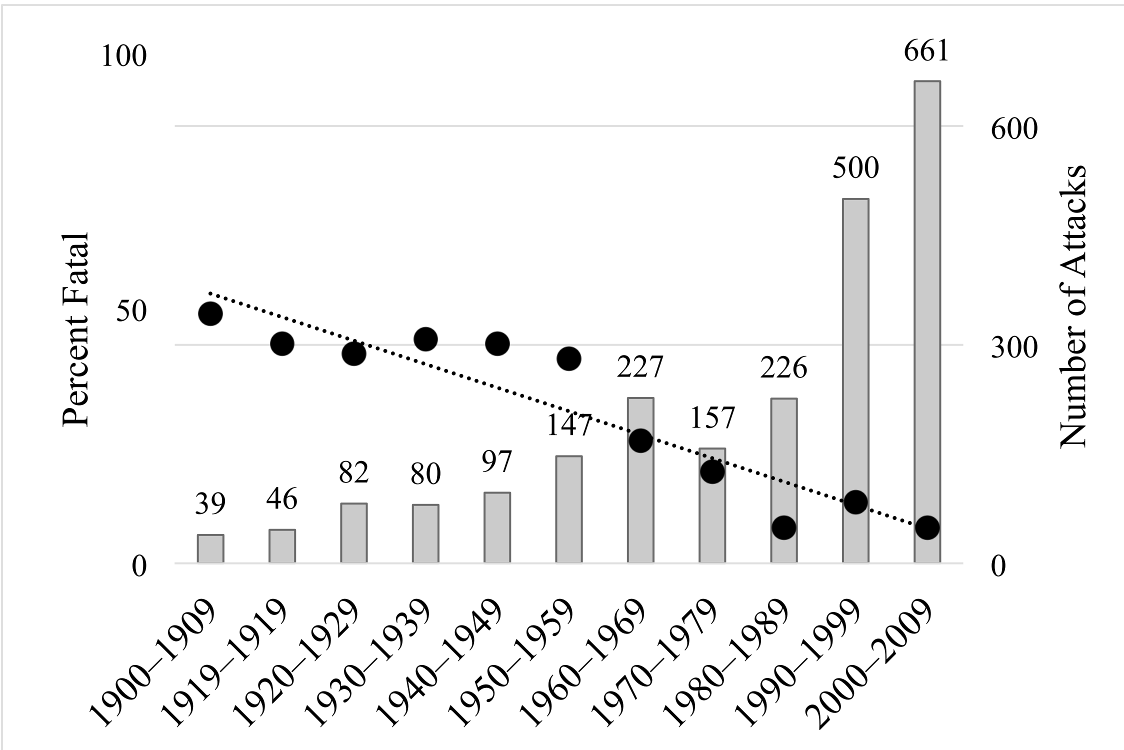

Fig. 3. *Graph of unprovoked shark attack trends worldwide over the past century. Figure reproduced from data available through the International Shark Attack File (ISAF; https://www.floridamuseum.ufl.edu/shark-attacks/trends/fatalities/).The number of shark attacks is influenced by the activity of the ISAF per decade and by how likely it was that attacks were reported per decade.*

Injuries from sharks are categorised by cutting, crushing and tearing (Davies and Campbell, 1962). The areas most often injured in such attacks are the upper and lower extremities, especially the legs extending to the buttocks. 'Degloving' injuries to the arms and hands, in which the flesh is stripped off the bone, may occur as a victim tries to fend off the shark. 'Bite-and-spin' tactics employed by the tiger shark may result in spiral gouges on long bones. Another common area of attack is the thorax, often resulting not only in the loss of flesh and bone but also fracturing of the ribs (Auerbach and Burgess, 2007; Coppleson, 1963; Davies and Campbell, 1962; Lentz et al., 2010). Osseous traumatic lesions diagnostic of a shark attack include: punctures with or without radiating and associated blunt force fractures, as the jaws of the shark exert considerable force; striations with bone shavings; overlapping striations as the teeth – serrated in the case of white, bull, and tiger sharks – drag across the bone; and incised bone gouges (Allaire et al., 2012). As shark skin is covered by placoid scales with a dentine pulp cavity encased in an enamel-like structure, shark skin and fins can also severely abrade and lacerate the skin of victims (Coppleson, 1963; Steel, 1985), although of course these injuries will not be recorded on the skeleton. Sharks less commonly scavenge human remains and the pattern of scavenging when it does occur is not well understood. Tiger and cookiecutter (*Isistius brasiliensis*) sharks are among the few species that regularly engage in post-mortem scavenging of human remains (Davies and Campbell, 1962; Ellingham et al., 2017; Higgs and Pokines, 2013; Ihama et al., 2009; İşcan and McCabe, 1995; Rathburn and Rathburn, 1984; Schultz and Malin, 1963; Stock et al., 2017).

2.4. Modern shark attacks in Japan

Japan falls within the 'Northern Seasonal Zone' of shark attacks, where attacks tend to occur in warmer months (Coppleson, 1963), although half of the attacks in the Seto Inland Sea documented since the 1950s were in winter (Table 1) (Nakaya, 1993; Schultz and Malin, 1963). One confirmed fatal attack was by a white shark, and white sharks were found to make up approximately 9% of identified sharks in the Inland Sea between 1992 and 1998 (Teshima et al., 2001). Japanese waters are also within the modern range of tiger sharks, but not bull sharks.

Table 1. *Modern unprovoked shark attacks in the Seto Inland Sea and associated straights. Based on Nakaya (1993) and Schultz and Malin (1963).*

Date	Fatal?	Species	Common Name	Details
July 1959	Yes	Unknown		
Aug. 1959	Yes	*Prionace glauca*	Blue	Swimmer attacked; Left thigh bitten
Aug. 1964	No	Unknown		Swimmer attacked; Leg bitten
Aug. 1967	Yes	Unknown		
Jan. 1992	No	Unknown		
Feb. 1992	No	Unknown		Diver attacked; Diving helmet bitten; No injuries
March 1992	Yes	*C. carcharias*	White	Professional diver attacked
March 1993	No	*C. carcharias?*	White?	

3. Methods

The age and sex of Tsukumo No. 24 have been previously estimated, but are re-evaluated here using current bioarchaeological protocols (Buikstra and Ubelaker, 1994; Igarashi et al., 2005; Smith, 1984). Stature was calculated using Fujii's method (Fujii, 1960; Kouchi, 1987). Forensic and bioarchaeological analyses of trauma (Fernández-Jalvo and Andrews, 2016; Dettmeyer et al., 2014; Loe, 2017; Lovell, 1997; Wedel and Galloway, 2014) were carried out and only those injuries that were at least 'highly consistent' with a traumatic aetiology as defined in the Istanbul Protocol (UN, 2004) were used in the analysis. CT scans were taken at Kyoto University with an Alexion TSX-023A/3R (Toshiba Medical Systems, Tokyo).

3D 'maps' of the completeness of the skeleton and distribution of lesions were created by JAW and JP using ArcGIS Pro 2.4.1. Skeletal maps were based on a 3D model of the human body

(BodyParts3D, licensed under creative commons (BY-SA); http://lifesciencedb.jp/bp3d/) adapted for use in forensics and palaeopathology. Each bone was divided into recording zones (Knüsel and Outram, 2004), which were used to visualise and quantify how much of the skeleton was present for examination and each zone on the 3D skeleton was attributed with this data. The skeletal trauma was mapped onto the model of the skeleton by creating 3D line features for the smaller, shallower lesions and 3D multipatch features in the case of larger wounds to account for the area and depth impacted. Additionally, the 3D line features were extruded from the bone surface to increase visibility. Blood vessels that may have been impacted by the trauma were identified through their co-location with the skeletal lesions. A search radius (using the Intersect 3D tool) equal to the width of the area of the body being analysed was applied to the skeletal lesions to estimate the extent of the impacted soft tissue. A generous search radius was applied to account for errors in the 3D model and to approximate the likely range of movement of the body.

4. Tsukumo Shell-mound Individual No. 24

Skeleton No. 24 from Tsukumo is that of a young–middle adult male with an estimated stature of 157.9 cm. The largely complete skeleton exhibits deep, sharp incisions covering the majority of the elements and has excellent surface preservation (Fig. 4). Radiocarbon dating of Tsukumo No. 24 returned a date of 3090 ± 25 BP (TKA-17598) calibrating to 1370–1010 cal BC, taking a marine reservoir effect into account (see Supplementary Information (SI)).

Fig. 4. *The original excavation photograph of Tsukumo No. 24 and a photograph of the extant skeleton: Left: No. 24 excavation photograph showing the irregular placement of the left leg (inverted and on top of the upper body) and missing right leg and left hand (courtesy of Laboratory of Physical Anthropology, Kyoto University). Right: Photograph of the extant skeleton available for examination. Photograph by JAW, courtesy of Kyoto University.*

4.1. Types of injuries present

The wounds on Tsukumo No. 24 number in the hundreds and vary in size, shape, and severity. There are extensive injuries over the majority of the skeleton, with the upper and lower extremities showing the highest concentration (Fig. 5).

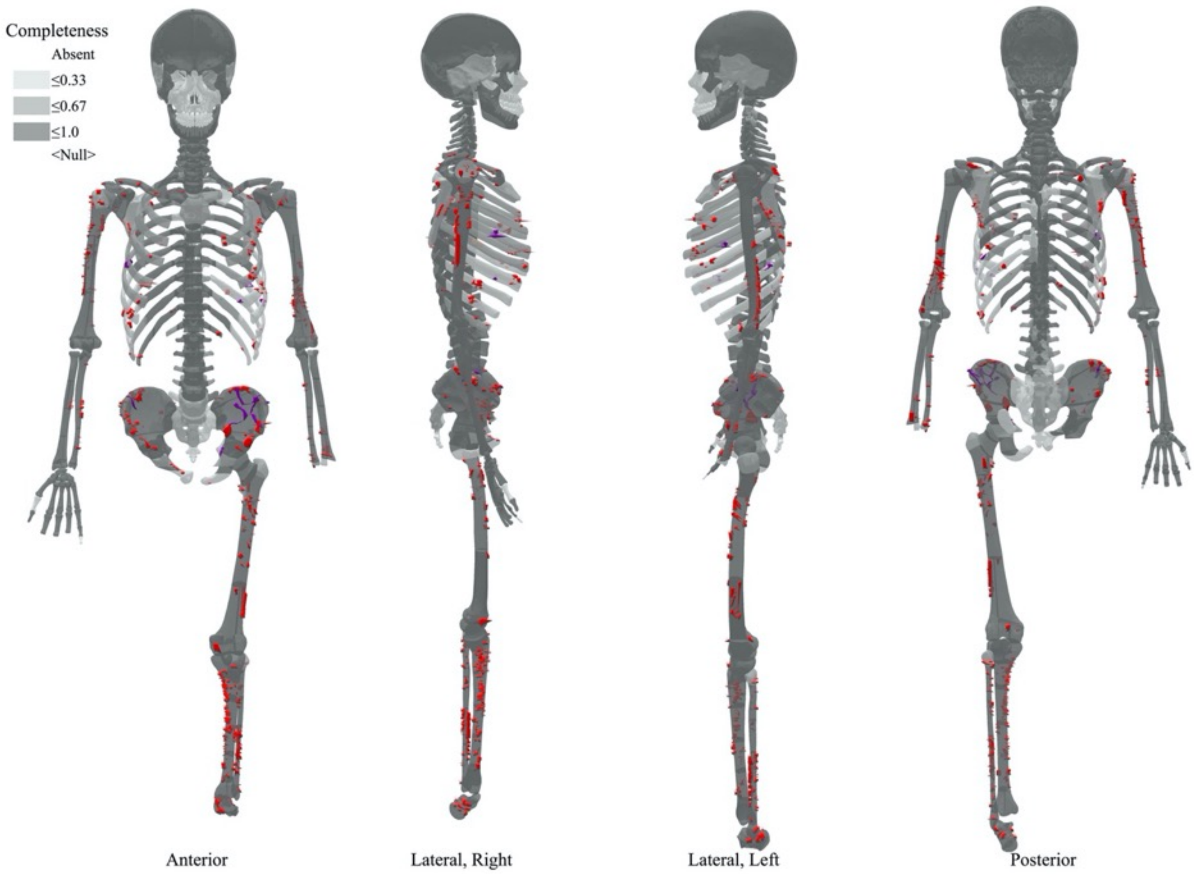

Fig. 5. *A complete distribution map of the traumatic injuries found on Tsukumo No. 24. The red features represent wounds caused by bite marks, the orange are overlapping striations (sparsely located on the axial skeleton), and the purple are fracture lines.*

Tsukumo No. 24 has at least 790 peri-mortem traumatic linear lesions (thoroughly documented in SI Figures S1–S66.). These injuries have sharp, V-shaped patinated edges without any sign of the initial osseous stages of healing (i.e., rounding of margins, macroscopic polishing, or pitting) (Barbian and Sledzik, 2008; Galloway et al., 2014; Maples, 1986). Additionally, there is evidence of peri-mortem fracturing, with patinated, smooth fracture lines on the os coxae and ribs. The remains were not exposed in a marine environment over a prolonged period, which would have resulted in taphonomic alterations to the bone as well as differential element representation (Pokines and Higgs, 2015). On the medial diaphysis of the left femur there are two small groups of parallel, overlapping U-shaped marks which differ from the others, and do not resemble documented instances of marine scavenging by creatures such as crabs or lobsters (Fig. 6) (Anderson and Bell, 2014; Erkol and Hösükler, 2018; Higgs and Pokines, 2013; Koseki and Yamanouchi, 1964; Möttönen and Nuutila, 1977); they are possibly caused by post-mortem rodent gnawing in the terrestrial burial environment (Fernández-Jalvo and Andrews, 2016). Excluding these, all of the linear marks show the same striated pattern, the largest and deepest of which cuts into the greater sciatic notch of the left os coxa (Fig. 7). Although all of the peri-mortem injuries are similar in character, they vary widely in depth and extent (Fig. 8). On the extremities and their associated joints in particular there are areas that show rows of linear marks (often associated with triangular-shaped punctures), linear marks which drag across the bone, and clusters of overlapping striations.

Fig. 6. A photograph of the medial diaphysis of the left femur showing overlapping U-shaped striations possibly caused by rodent scavenging. Photograph by JAW, courtesy of Kyoto University.

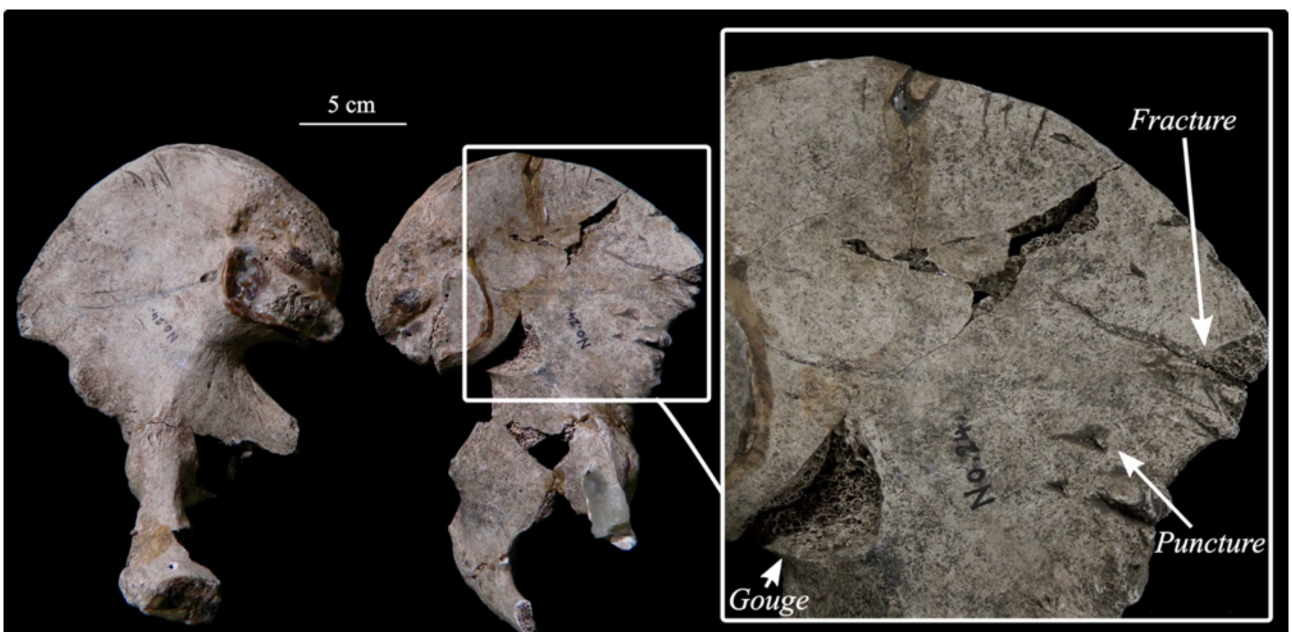

Fig. *7. Photographs of the right and left os coxae of No. 24 showing deep bite marks along the iliac crest, fracturing originating at the superior iliac spine, punctures throughout the ilium (largest: 10.9 x 5.3 mm), and a gouge with an anteriorly scalloped edge cutting into the greater sciatic notch (33.2 x 20.2 mm and 21.3 mm deep). Photographs by JAW, courtesy of Kyoto University.*

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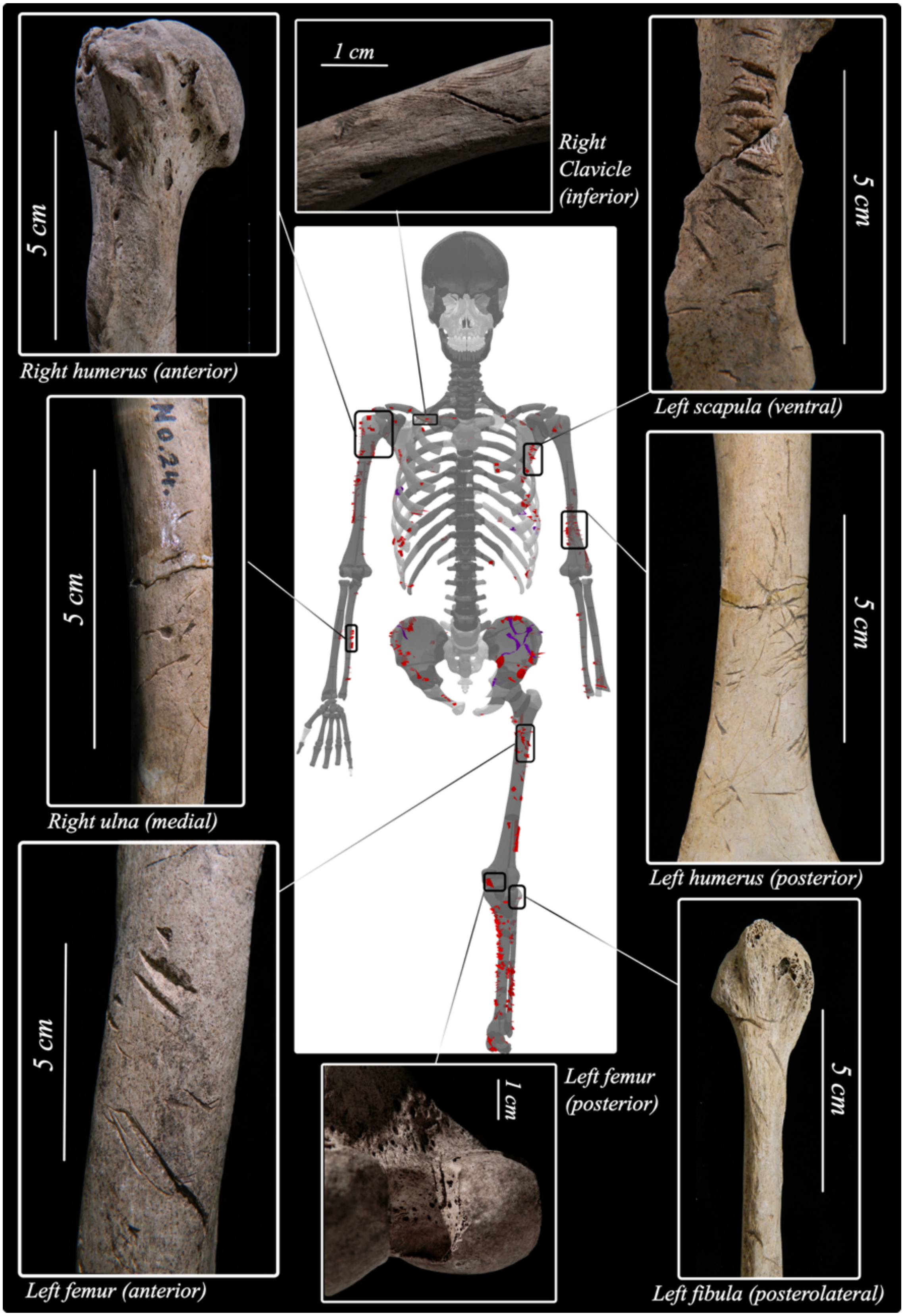

267 ***Fig. 8.*** *Photographs and a distribution map of a selection of striated lesions throughout the skeleton.*
268 *Photographs by JAW, courtesy of Kyoto University.*

Terrestrial carnivores tend to cause abrasion, fractures, disarticulation, gouges, U-shaped linear marks, notches, pits, punctures, and rounding to bone to varying degrees depending on the species and its feeding habits (Fernández-Jalvo and Andrews, 2016). The linear marks on Tsukumo No. 24 match several of these patterns (i.e., disarticulation, fractures, gouges, and punctures), but are remarkable in their depth, V-shape, and striations. These lesions are characteristic of those caused by sharks (Allaire et al., 2012; Stock et al., 2017), including the negative impressions of bone shavings that can be observed on the surviving elements. CT scans of the left os coxa and tibia, the bones with the deepest bite marks, did not reveal the presence of any embedded shark tooth fragments (Nakaya, 1993, Stock et al., 2017, Davies and Campbell, 1962, Lowry et al., 2009). Nevertheless, the pattern of lesions, although more extensive than the majority of known shark attack or scavenging cases, is consistent with shark feeding behaviours, as will be demonstrated in the discussion. The high and widespread degree of trauma suggests that the victim remained in the sea for some period of time sufficient to allow the shark to feed on the body after death.

5. Patterns of injury

The majority of injuries to Tsukumo No. 24 are concentrated on the pelvis, left leg, and arms and shoulders. There also are numerous bite marks, fractures, and overlapping striations on the ribs. The vertebrae and skull were unaffected. The skull and vertebrae are less commonly involved than the extremities and anterior body in shark attacks, likely because the skull and back do not contain as much flesh (Auerbach and Burgess, 2007; Coppleson, 1963; Ihama et al., 2009; Schultz et al., 1961). It is clear that the lower limbs of Tsukumo No. 24 were disarticulated at the time of burial, with the right leg missing along with the left hand (Fig. 4). There are signs of trauma on the remaining adjacent bones, with the left lower ulna and radius providing evidence consistent with the loss of the hand during the attack (Fig. 9). Defensive wounds to the arms are common in shark attacks. It is probable that the missing right leg was entirely separated from the body by the shark, and either consumed or not recovered. Given the concentration of wounds to the left hip and leg and the lack of injury to the right hand, it is likely that the left hand was lost in an attempt by the victim to defend himself from the shark during an attack to his legs. Such a defensive motion could easily have resulted in the shearing off of the hand by the shark. It is impossible to irrefutably prove that the victim was alive at the time of attack, but the loss of the left hand and the concentration of injuries to the pelvis and left leg strongly support an initial attack on a living victim.

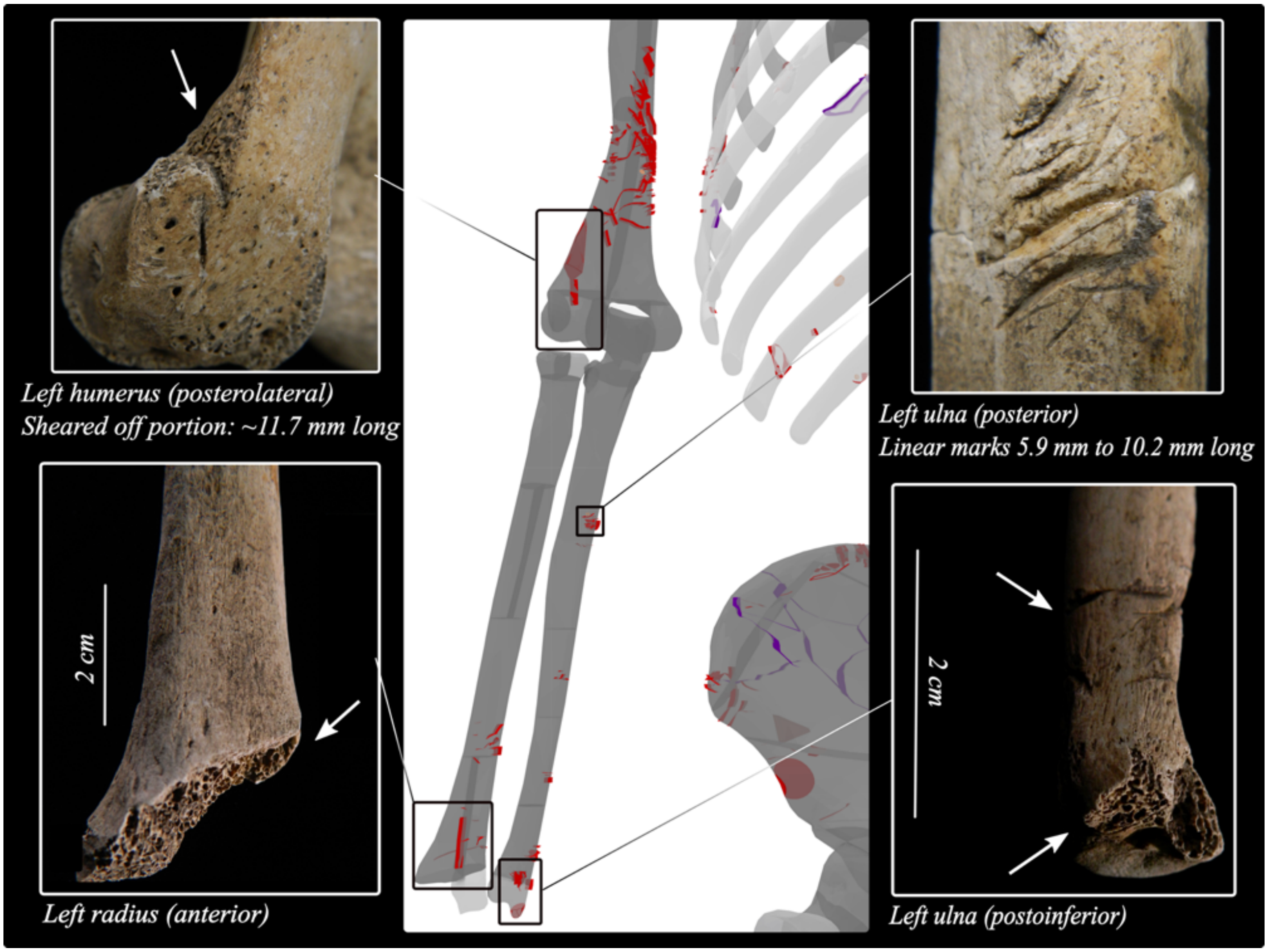

Fig. 9. *Photographs and a distribution map of the lower left arm showing deep bite marks. Photographs by JAW, courtesy of Kyoto University.*

The bone with the greatest concentration of multiple deep bites is the left tibia (Fig. 10). Evidence of trauma to Tsukumo No. 24's torso can be seen in bite marks and fractures to almost all extant ribs (Fig. 11) as well as the manubrium and pelvic region. The chest cavity and abdomen may have been eviscerated. It is unlikely that the chest was the site of large bites, as the ribs (~65% extant) would have been easily been torn away.

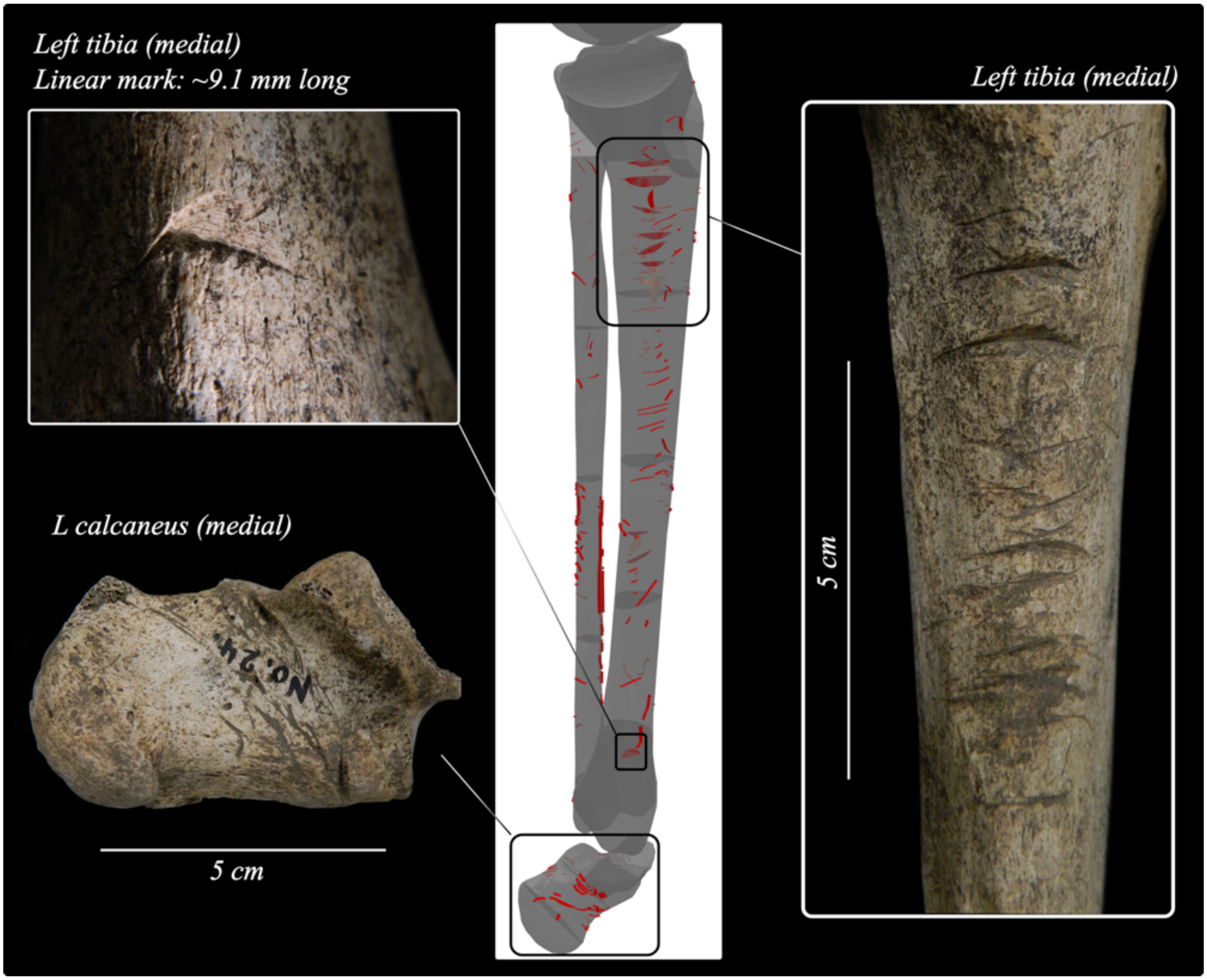

Fig. 10. *Photographs and a distribution map of the deep rows of linear marks and overlapping striations to the left lower leg. Photographs by JAW, courtesy of Kyoto University.*

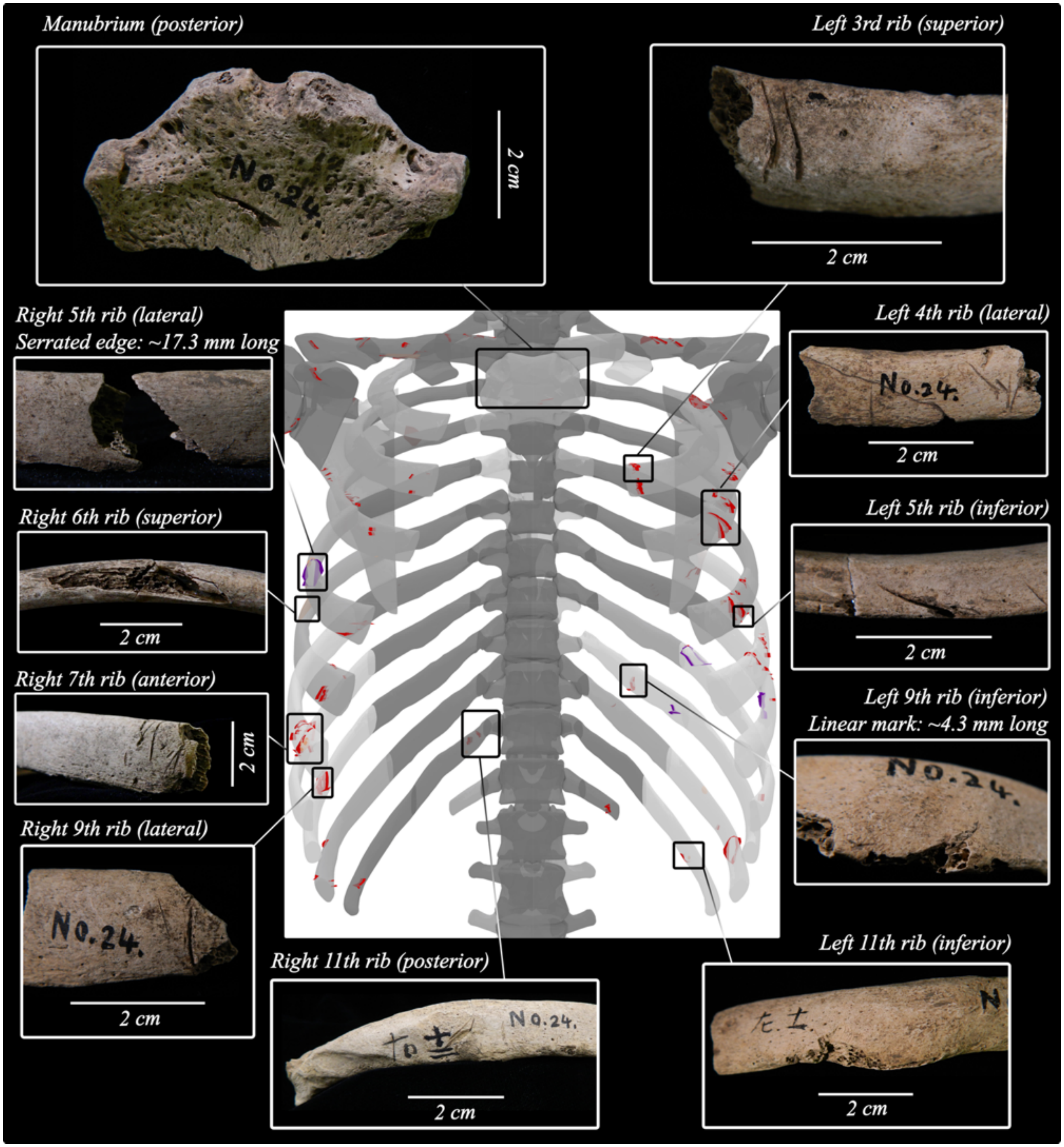

Fig. 11. *Photographs and a distribution map of the bite marks and fractures to the chest cavity. Note that most of the ribs are fractured at the point of injury. Photographs by JAW, courtesy of Kyoto University.*

The overlapping bite marks oriented in different directions, which are especially prevalent on the long bones, suggest continued consumption of the body after death by the shark. It is not easy for a shark to bite a bobbing, floating corpse. The shark would have had to reorient its position repeatedly and would, at times, have been unable to capture the limbs, helping to explain the number of shallower, diversely oriented lesions and dense clusters of overlapping lesions found on the skeleton. Shark teeth are largest medially, decreasing in size laterally towards the corners of the jaw, which may result in differing lesion and puncture sizes depending on which part of the shark's mouth was involved in the bite.

If alive at the time of attack, as argued here, the victim undoubtedly would have expired from exsanguination and shock. During the initial attack(s) the victim likely lost his left hand, his femoral arteries probably would have been severed shortly thereafter, and he would have quickly lost consciousness (Fig. 12). By any criteria, the injuries to this person were fatal (Davies and Campbell, 1962; Lentz et al., 2010). While the shark likely continued mauling the corpse, the skeleton shows no signs of having been in the water for a prolonged period. It is likely that his companions recovered as much of his body as they could shortly after the attack, implying that they were in the vicinity. Bodies in marine environments go through a predictable series of taphonomic processes, beginning with the disarticulation of the extremities (hands and feet) and the skull (Haglund, 1993). For Tsukumo No. 24, most of the bones of the right hand are present (Fig. 4 and 5), while the absence of the left hand is explained by being sheared off during the attack. Similarly, the missing feet are more parsimoniously explained by the traumatic removal of the legs during the attack, with the left suffering heavy damage to the extent that it was placed in the grave in an inverted position, and the right not being recovered at all. Finally, the victim's body was accorded a normative burial rite in the cemetery at Tsukumo, which was presumably a part of his home village.

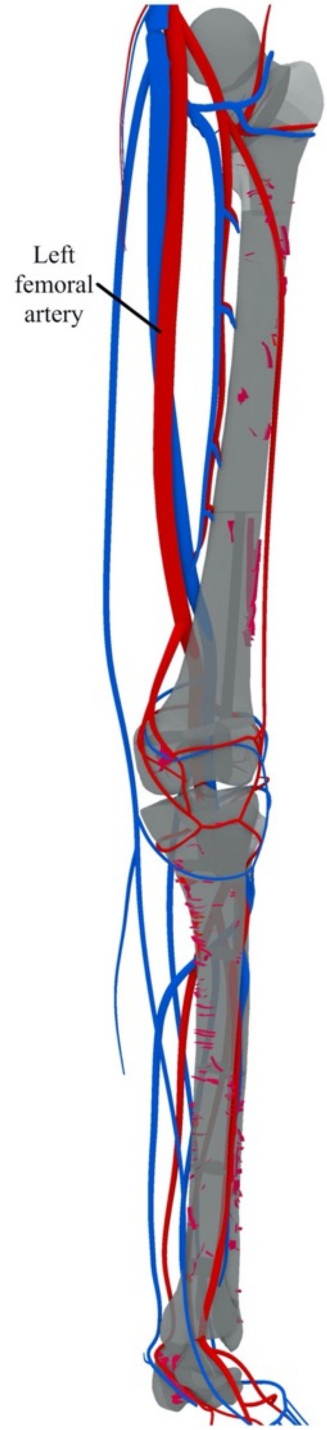

Fig. 12. A distribution map of all of the arteries (red) and veins (blue) that would have most likely been impacted by the bites which caused osseous traumatic lesions on the left leg (medial, anterior orientation).

5.1. Evaluation of shark species

Remains of both tiger and white sharks have been found in Jōmon period sites (Table 2). In some cases these seem to be fossil shark teeth, but in others contemporaneous. White sharks appear to have been more common around mainland Japan during the Jōmon, whereas tiger sharks were more common around Okinawa. A particularly a large collection of tiger shark teeth from layers dating to ca. BC 800 – AD 800 was found at Nagabaka on Miyako Island, Okinawa (Nagabaka Archaeology Project, 2013). Nevertheless, there have been sightings of tiger sharks as far north as Aomori in recent years (Sakiyama and Senou, 2009) and tiger shark teeth are known from Jōmon sites as far north as Hokkaidō, although these could have been traded in from further south. Unfortunately, it is difficult to say anything in more detail about shark remains from the Jōmon period as most site reports and studies do not identify the species of shark.

Table 2. Possible white and tiger shark finds from the Jōmon period *(Komoto, 1999, Nakazawa, 2017, Nagabaka Archaeology Project, 2013, Suzuki, 2018).*

Site	Prefecture	Period	Shark Classification	Source
Kurobashi	Kumamoto	Middle – Late Jōmon	Lamnidae	Komoto (1999)
Matsubashi Ōno	Kumamoto	Late Jōmon	Lamnidae	Komoto (1999)
Kakiwara	Kumamoto	Late Jōmon	Lamnidae	Komoto (1999)
Take–no–shita	Kumamoto	Late Jōmon – Late Yayoi	Lamnidae	Komoto (1999)
Mizuko	Saitama	Early, Late Jōmon	*Carcharodon carcharias, Isurus oxyrinchus, Carcharhiniformes* sp.	Suzuki (2018)
Ariyoshikita	Chiba	Middle Jōmon	*Carcharodon carcharias* or *Isurus hastalis*; *Carcharodon carcharias* fossil?	Suzuki (2018)
Minou	Chiba	Late Jōmon	*Carcharodon carcharias*	Suzuki (2018)
Miyauchiidosaku	Chiba	Middle – Late Jōmon	*Carcharodon carcharias* fossil	Suzuki (2018)
Shimoota	Chiba	Middle – Final Jōmon	*Carcharodon carcharias* fossil*?*	Suzuki (2018)
Hiraka	Akita	Final Jōmon	*Carcharodon carcharias*?	Suzuki (2018)
Hinoki	Aomori	Late – Final Jōmon	*Carcharodon carcharias* fossil	Suzuki (2018)
Yooanji	Chiba	Middle Jōmon	*Carcharodon carcharias* fossil?	Suzuki (2018)
Hamanasuno	Hokkaido	Early – Middle Jōmon	*Carcharodon carcharias*	Nakazawa et al. (2017)
Satsukari	Hokkaido	Final Jōmon	Carcharhinidae	Nakazawa et al. (2017)
Misawa 1	Hokkaido	Final Jōmon	Carcharhinidae	Nakazawa et al. (2017)
Bibi 4	Hokkaido	Final Jōmon	*Carcharodon carcharias*	Nakazawa et al. (2017)
Shibi 4	Hokkaido	Final Jōmon	Carcharhinidae	Nakazawa et al. (2017)
Midori ga Oka	Hokkaido	Final Jōmon	*Carcharodon*	Nakazawa et

			carcharias?/Carcharhinidae	al. (2017)
Kussharo Kotan	Hokkaido	Early Jōmon	*Carcharodon carcharias*	Nakazawa et al. (2017)
Hira	Akita	Final Jōmon	*Carcharodon carcharias*	Nakazawa et al. (2017)
Dōno	Niigata	Middle Jōmon	*Galeocerdo cuvier*	Nakazawa et al. (2017)
Yōchi	Hiroshima	Middle Jōmon	Carcharhinidae	Nakazawa et al. (2017)
Nagabaka	Okinawa	Neolithic (Late-Final Jōmon equivalent)	*Galeocerdo cuvier*; *Carcharhinus plumbeus*	Nagabaka Archaeology Project (2013)

The Seto Inland Sea, between 32 and 35°N, falls within the temperate zone. A recent study estimated summer sea surface temperatures (SST) in Hiroshima Bay (Fig. 1) from 1220–920 cal BC (3170–2870 cal BP) to be between 23.3 and 22.3°C (Kawahata et al., 2017). By comparison, the same study noted that mean SST in Hiroshima Bay between 1999 and 2010 ranged from 10.3°C in February to 26.6°C in August. White sharks are endothermic cool water predators, whereas tiger shark are ectothermic and prefer warmer water. Recent catch studies on the eastern coast of Australia demonstrate that tiger shark catch rates were highest when water temperatures were approximately 22°C, whereas white shark catch rates were highest at ~19°C or lower. Additionally, both species were found between 16 and 34°S (Payne et al., 2018). The Seto Inland Sea SST during the 1st millennium BC would have been ideal for tiger sharks in the summer months, but certainly habitable for white sharks as well. The cooler seasons with lower temperatures would have been more suitable for white sharks.

Due to the extensive overlapping and different angles of bite marks on Tsukumo No. 24, it is difficult to distinguish single bites, much less ones that are large enough to allow an estimation of the jaw morphology. Hence, it is not possible to determine the shark species based on interdental distance measurements (cf. Lowry et al., 2009). Additionally, no evidence of spiral lesions (so-called ‘candy caning’), typically associated with tiger shark attacks, was found (Stock et al., 2017); however, such lesions do not always occur.

Modern shark attacks in the area (Table 1) have largely been attributed to white sharks. Yet, given the current distribution of white and tiger sharks and based on the archaeological record and the likely SST during the Final Jōmon, we can only conclude that the most likely aggressor could have been either a tiger or white shark. The pattern, style and sizes of tooth impressions on bones suggest a single shark, but an alternative scenario involving multiple sharks cannot be entirely ruled out. Multiple sharks attacking or scavenging is far less likely if the attacker was a white shark as they are solitary predators.

6. Conclusions

Our results suggest that around three thousand years ago Tsukumo No. 24 was attacked by either a tiger or white shark in the Seto Inland Sea. He most likely lost his right leg and left hand in the attack, and his wounds would have been fatal as they totalled at least 790 tooth marks that reached to the bone. Although numerous blood vessels and organs would have been impacted, it is likely that at least his larger lower limb arteries would have been severed early in the attack. This would have resulted in a relatively quick death from hypovolemic shock. His body was recovered and he was buried according to normative Jōmon funerary practices in a shell-mound, which helped to preserve his body in such excellent condition that we can understand in great detail the unusual and tragic circumstances leading to his death.

The attack on Tsukumo No. 24 highlights the risks of marine fishing and shellfish diving or, perhaps, the risks of opportunistic hunting of sharks drawn to blood while fishing. Humans have a long, shared history with sharks, and this is one of the relatively rare instances when humans were on their menu and not the reverse.

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