Dermal and mucous denticles of a female megamouth shark, Megachasma pelagios, from Hakata Bay, Japan.

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X-ray Observations on Vertebrae and Dentition of a Megamouth Shark, *Megachasma pelagios*, from Hakata Bay, Japan

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Key words: megamouth shark, *Megachasma pelagios*, X-ray, vertebrae, dentition

Abstract This study presents X-ray observations of vertebrae and dentition of a female megamouth shark, *Megachasma pelagios* (4710 mm TL, 790 kg BW). Radiographs of the vertebrae and dentition were taken from the specimen while it was frozen (−30℃) and additional radiographs of the dentition were taken after thawing the specimen. Vertebrae from the tip of the dorsal lobe of the caudal fin to the origin of the dorsal lobe of the caudal fin were visualized easily with radiography. However, vertebrae from the origin of the dorsal lobe of the caudal fin to the origin of the first dorsal fin were difficult to discern via radiography. We could count 125 vertebrae from the tip of the dorsal lobe of the caudal fin to beyond the origin of the first dorsal fin with certainty. Vertebrae 1 through 91 were clear and easily counted (82 of which were found in the dorsal lobe of the caudal fin), vertebrae 92 through 125 were unclear but countable. The vertebrae from the origin of the first dorsal fin to the spiracle were unclear and difficult to count with certainty. The vertebrae were found to possess a large uncalcified area (i.e., the notochord) in the center of the calcified portion of each cartilaginous centrum. This study suggests that it is very difficult to examine all vertebrae in large megamouth sharks via X-radiography. Four or five teeth were observed in each lingual to labial row of teeth in both jaws. No vestigial teeth were observed at the jaw symphyses. Lingual to labial tooth rows were separated from each other, although spacing between the rows was not uniform. A wider space occurs every third or fourth row in the anterior and posterior regions of both jaws. Teeth in each row form a line without overlapping each other.

On 29 November 1994, a bird watcher found a large, strange, freshly-dead shark at the water's edge on a beach on the northeast coast of Hakata Bay, Fukuoka, Japan. Staff members of Marine World umino-nakamichi identified this strange fish as the rare megamouth shark, *Megachasma pelagios*. It was the first female of the species ever seen, and the seventh specimen overall. At once, three individuals (K. Takada, Y. Yabumoto, and K. Yano) conferred at Marine World umino-nakamichi and decided to initiate the megamouth shark research project (which they opened to all interested scientists). They contacted many scientists and invited them to join the project. Several additional scientists heard of the stranding via the news media and also were granted permission to join the megamouth project.

On 21 January 1995, the frozen specimen was transported in a refrigerated car from Fukuoka to the Veterinary Teaching Hospital of Miyazaki University for X-ray observations of its vertebrae and dentition. These radiographic observations represented the first trial in the megamouth shark research project. This paper presents results of the radiographic study of the vertebrae and dentition of the female megamouth shark.

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Materials and Methods

The specimen examined was a female, 4710 mm in total length and 790 kg in body weight. The specimen was frozen at −30℃. The specimen was transported from Fukuoka in a refrigerated car (−25℃) to the Veterinary Teaching Hospital of the Faculty of Agriculture at Miyazaki University. Radiographs of the vertabrae and cleutition was made with the frozen specimen. In addition, radiographs of its dentition were made after thawing the specimen. Radiographs were prepared using standard procedures with a MS-15-3 (Hitachi Medical Corporation, Tokyo, Japan) for roentgenography of large animals (Fig. 1A) or an Atomscope-20s-ET portable X-ray generator (Mikasa X-ray Co., Ltd., Tokyo, Japan) (Fig. 1B). The portable X-ray machine was used to take radiographs of the dentition of the megamouth shark. Three types of screens (Fuji HR-3, HR-6, and Kyokko RE-Super) with single emulsion film (Fuji HR-s and RX) were used. Single or double grids (10 : 1 grid ration) were used in some radiographs. Films were developed with a Fuji FPM-700 film processor (Fuji Medical, Tokyo, Japan). The radiographs of the vertebrae of the megamouth shark were taken at 44-82 Kv and

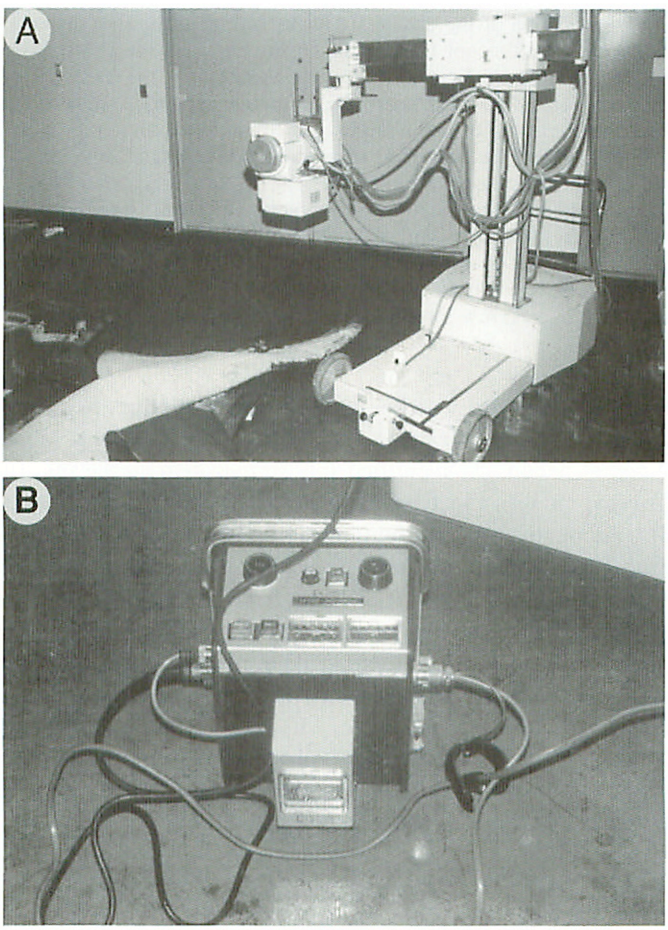

Fig. 1. X-ray machine for large animals, MS-15-3, (A) and portable X-ray generator, Atomscope-20s-ET, (B) used on the megamouth shark, *Megachasma pelagios*.

Table 1. Radiographic conditions used to observe the vertebrae of a megamouth shark, *Megachasma pelagios*, collected from Hakata Bay, Fukuoka, Japan

Pin number from tip of cuadal dorsal lobe	Voltage (Kv)	Electric current (mA)	Emission time (second)	Type of screen
0 (tip of caudal fin) - 1	44	100	0.16	HR-3
1 - 2	44	100	0.25	HR-3
2 - 3	44	100	0.40	HR-3
3 - 4	44	100	0.50	HR-3
4 - 5	44	100	1.00	HR-3
5 - 6 (upper caudal origin)	52	500	0.12	HR-6
6 - 7	60	500	0.20	Kyokko
7 - 8	72	500	0.32	Kyokko
8 - 9	62	500	0.32	Kyokko
9 - 10 (1st dorsal origin)	72	500	0.32	Kyokko
10 - 11	72	500	0.32	Kyokko
11 - 12	82	500	0.50	Kyokko
12 - 13	76	1000	0.50	Kyokko
13 - 14	80	1000	0.50	Kyokko
14 - 15	80	1000	0.50	Kyokko
15 - 16	82	1000	0.64	Kyokko
16 - 17	78	1000	0.64	Kyokko

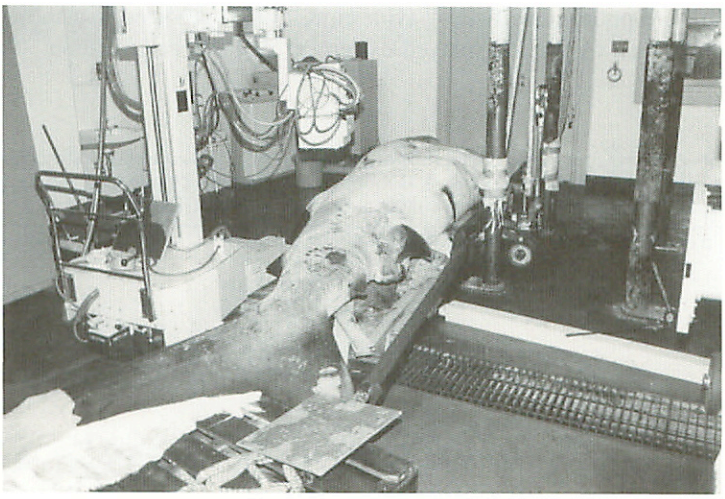

Fig. 2. The position of the body of the megamouth shark, *Megachasma pelagios*, while X-rays were being taken.

100-1000 mA for 0.12-1.00 sec emission time (Table 1), and 100 cm in plate focus distance. The roentgenograms of the dentition were taken at 70 Kv and 15 mA for 0.1-0.2 sec, and 60-70 cm in plate focus distance.

The radiographs of the vertebrae of the megamouth shark were taken laterally from the right side of the body (Fig. 2). Vertebral positions along the body of the megamouth shark were marked with pins of known separation during radiography.

Results and Discussion

Vertebrae

Thirty X-radiographs were taken for observation of vertebrae. Pin number, distance between pins, and number of vertebrae between pins are shown in Table 2. Vertebrae from the tip of the dorsal lobe of the caudal fin to its origin were visualized easily with radiography (Table 2). However, vertebrae from the origin of the dorsal lobe of the caudal fin to the origin of the first dorsal fin were difficult to discern via radiography, and those from the origin of the first dorsal fin to the spiracle were not observed by radiography (Table 2). We could count 125 vertebrae from the tip of the dorsal lobe of the caudal fin to beyond the origin of the first dorsal fin with certainly (Table 2). Vertebrae 1 through 91 were clear and easily counted (82 of which were found in the dorsal lobe of the caudal fin). Vertebrae 92 through 125 (located from the caudal peduncle to the origin of the first dorsal fin) were unclear but countable. Vertebrae from in front of the origin of the first dorsal fin to the spiracle (numbers 126-139) were difficult to count with certainty, hence the total number of vertebrae is questionable. The vertebrae were found to possess a large uncalcified area (i.e., the notochord) in the center of the calcified portion of each cartilaginous centrum. The average length of the vertebrae (between pins in each position) is shown in Fig. 3. The length of the vertebrae increased from the tip of the dorsal lobe of the caudal fin to the origin of the first dorsal fin. We could not distinguish monospondylous from diplospondylous vertebrae in the radiographs, and all the vertebrae of the megamouth shark were not observed by radiography. We suggest that the vertebrae of the megamouth shark are poorly calcified. Taylor et al. (1983) reported that the vertebrae of the first megamouth shark examined displayed extremely reduced calcification. Poorly calcified

Table 2. Pin number from the tip of the dorsal lobe of the caudal fin attached to the body as marks during X-ray observations, distance between the pins, and number of vertebrae counted by radiography of a female megamouth shark, *Megachasma pelagios*, collected from Hakata Bay, Fukuoka, Japan

Pin number from tip of caudal dorsal lobe	Distance between pins (mm)	Progressive increase of pin distance (mm)	No. of vertebrae	Progressive increase for no. of vertebrae
0 (tip of caudal fin) - 1	335	335	20	20
1 - 2	281	616	17	37
2 - 3	257	873	13	50
3 - 4	299	1172	12	62
4 - 5	290	1462	11	73
5 - 6 (upper caudal origin)	278	1740	9	82
6 - 7	294	2034	9	91
7 - 8	281	2315	8*	99
8 - 9	319	2634	7*	106
9 - 10 (1st dorsal origin)	257	2891	7*	113
10 - 11	261	3152	6*	119
11 - 12	289	3441	6*	125
12 - 13	242	3683	4**	129**
13 - 14	235	3918	4**	133**
14 - 15	208	4126	3**	136**
15 - 16	185	4311	3**	139**
16 - 17	190	4501	?	-

* Vertebrae were unclear but countable.
** Vertebrae were difficult to count with certainty.

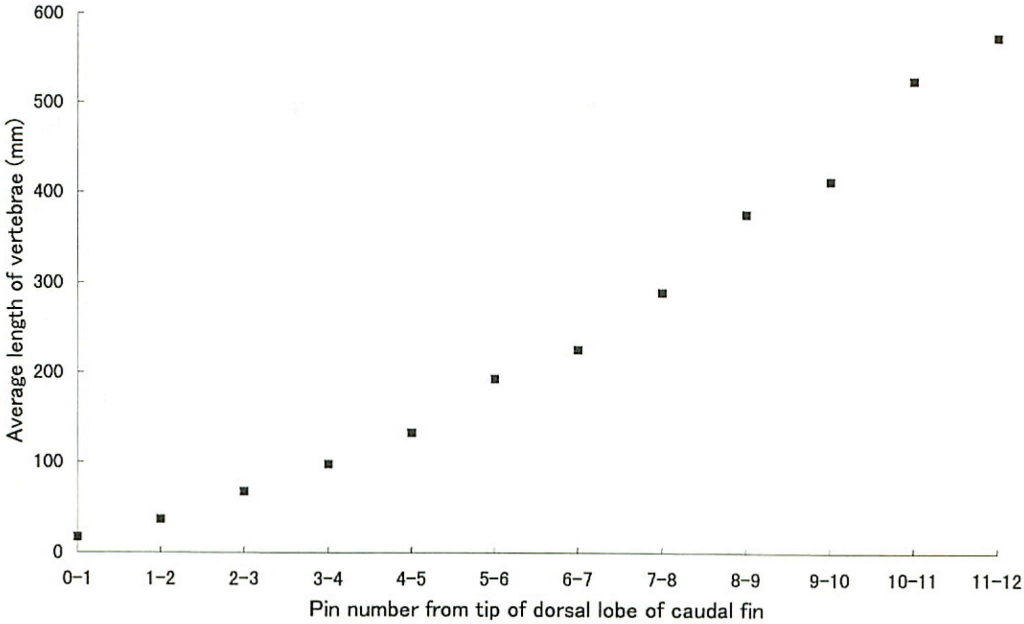

Fig. 3. The average length of vertebrae, between pins in each positon, of megamouth shark, *Megachasma pelagios*.

vertebral centra have been reported for *Somniosus microcephalus* and *S. pacificus* (Ridewood, 1921; Tanaka et al., 1982). Monospondylous and diplospondylous vertebrae also could not be distinguished in both species of *Somniosus* (Tanaka et al., 1982; Yano, pers. observ.), as in this megamouth shark.

The vertebrae were found to possess a large uncalcified area (i.e., the notochord) in the center of the calcified portion of each cartilaginous centrum. Taylor et al. (1983) stated that the holotype of the megamouth shark had poorly formed and calcified vertebral centra with a hypertrophication of notochordal tissue between the centra. Frilled sharks, *Chlamydoselachus anguineus*, differ in having the notochord partly constricted and not septate precaudally, and the squaloid *Aculeola nigra* has its entire vertebral column septate (Compagno, 1977). The poorly calcified vertebral centra of the megamouth shark is similar to the septate vertebral columns of other large species, such as *Somniosus* (Ridewood, 1921; Tanaka et al., 1982), as reported by Compagno (1973). Schaeffer (1967) stated that vertebral centra are usually well developed in living elasmobranchs but are lacking in cladodont-level sharks and most hybodont-level sharks. Living hexanchids, such as *Heptranchias perlo*, the chlamydoselachid *Chlamydoselachus*, and some squaloid sharks (e.g., *Aculeola, Echinorhinus*, and *Somniosus*) also have centra that are poorly developed or entirely absent, and a notochord that is only partially constricted or is totally unconstricted (Ridewood, 1921; Compagno, 1973, 1977; Tanaka et al., 1982; Yano, pers. observ.). Compagno (1973) was uncertain whether or not the absence of centra in these sharks is an adaptation to their deep-water environment. Megamouth sharks probably perform vertical migration routinely (Hutchins, 1992). The one individual that was tracked spent the daylight hours at a depth of about 170 m and then ascended at dusk to about 12 m below the surface where it remained throughout the night (Lavenberg, 1991; Hutchins, 1992). The megamouth shark swam slowly at about 0.95 km per hour, and maintained this swimming rate entire tracking time (Lavenberg, 1991).

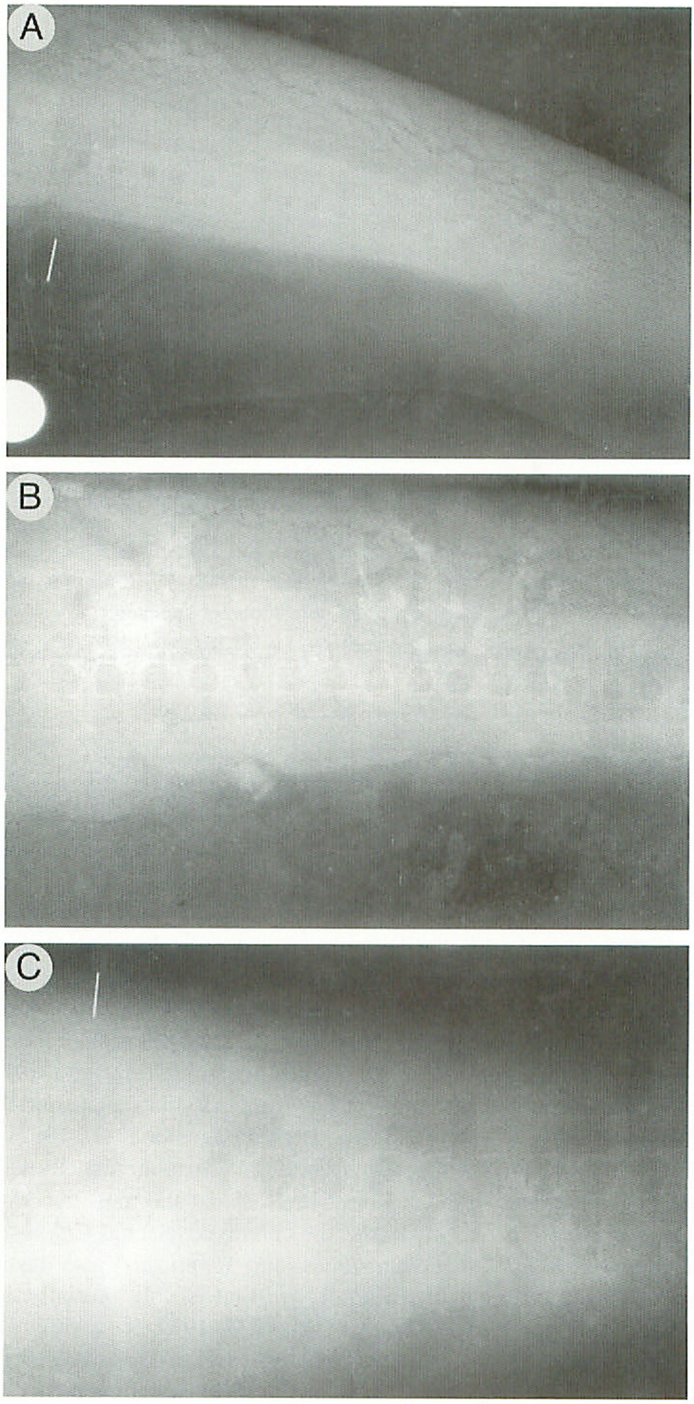

Fig. 4. Radiographs of vertebrae of a megamouth shark, *Megachasma pelagios*. A, tip of dorsal lobe of caudal fin to pin No. 1, 44 Kv, 100 mA, 0.16 sec, film HR-3; B, pin Nos. 1-2, 44 Kv, 100 mA, 0.25 sec, film HR-3; C, pin Nos. 3-4, 44 Kv, 100 mA, 0.50 sec, film HR-3.

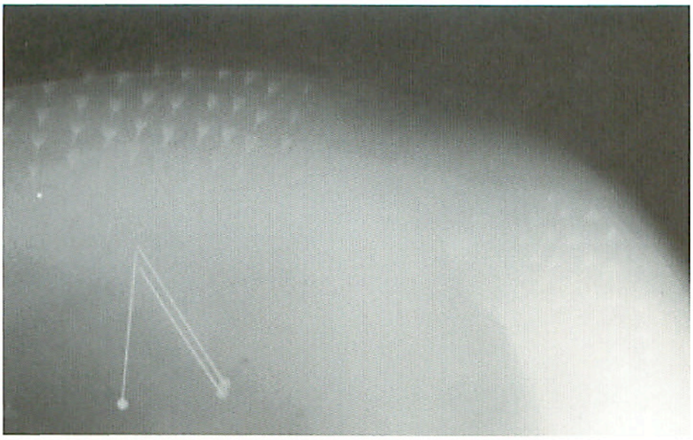

Fig. 5. Radiographs of the lower jaw symphysis of a megamouth shark, *Megachasma pelagios*, 70 Kv, 15 mA, 0.1 sec, 60-cm focal distance to plate, screen Kyokko RE-Super.

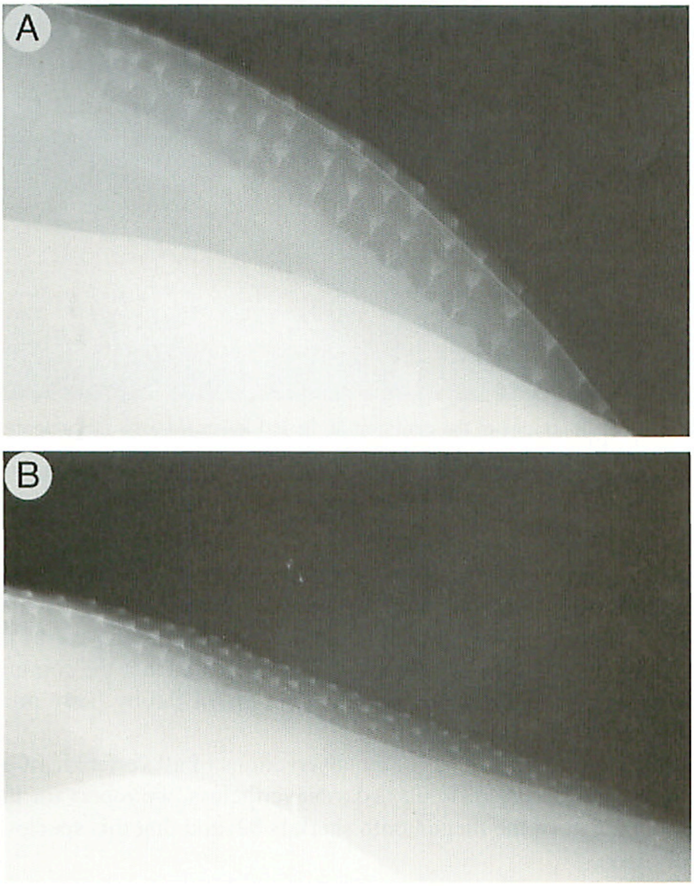

Fig. 6. Radiographs of the dentition on the right upper jaw of a megamouth shark, *Megachasma pelagios*. A, anterior teeth, 70 Kv, 15 mA, 0.2 sec, 70-cm focal distance to plate, screen HR-3; B, posterior teeth, 70 Kv, 15 mA, 0.1 sec, 70-cm focal distance to plate, screen HR-6.

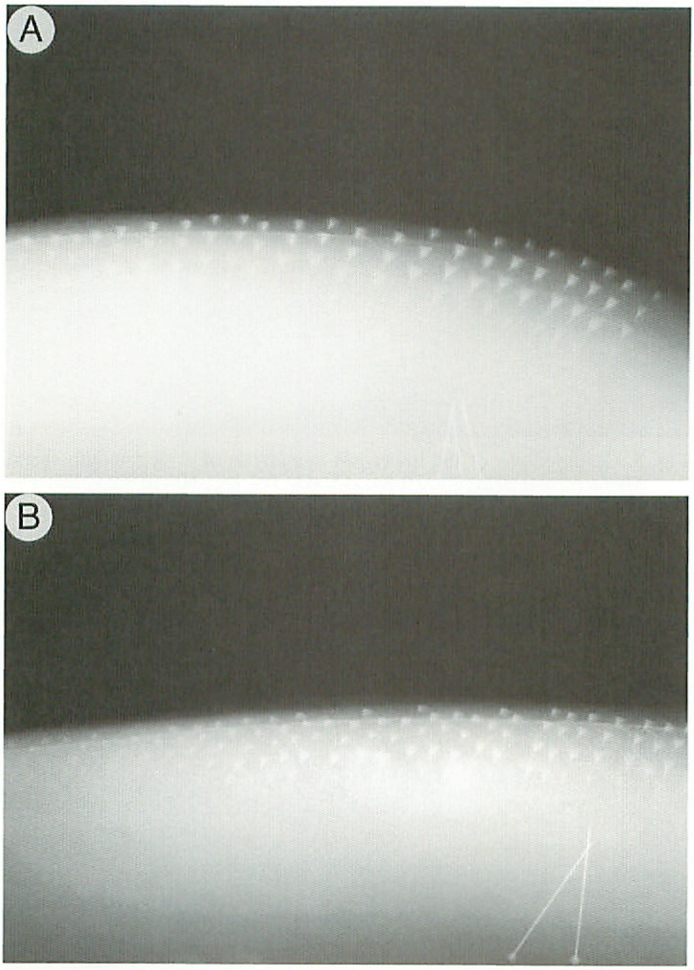

Fig. 7. Radiographs of the dentition of the left lower jaw of a megamouth shark, *Megachasma pelagios*. A, anterior teeth, 70 Kv, 15 mA, 0.2 sec, 70-cm focal distance to plate, screen HR-3; B, posterior teeth, 70 Kv, 15 mA, 0.2 sec, 70-cm focal distance to plate, screen HR-3.

We think the uncalcified vertebrae of the megamouth shark are a secondary adaptation (i.e., not a primary condition) to their swimming behavior, because they usually swim slowly (Compagno, 1990; Lavenberg, 1991), probably in mid-water where the sharks probably attempt to achieve neutral buoyancy. Last and Stevens (1994) suggested that the combination of a large liver high in low-density squalene, poor calcification, and a flabby body probably helps the megamouth shark achieve neutral buoyancy.

The results of this study suggest that X-ray observations of all vertebrae of a large specimen of the megamouth shark is a very difficult task. Nevertheless, we report for the first time that the caudal vertebral number of the megamouth shark is 82, and that this species has at least 125 vertebrae (probably 139).

Dentition

Twenty-four radiographs were taken for observation of the dentition. The films were placed under the ventral surface of the upper jaw, touching the teeth, while taking radiographs of the upper jaw dentition. For taking radiographs of the lower jaw dentition, films were set under the lower jaw, away from the teeth.

Four or five teeth were observed in each lingual to labial row in both jaws, but vestigial teeth were not observed at the symphyseal space (Fig. 5). The tooth rows are separated from each other. The spacings of the rows are not uniform. For example, the spaces between the 1st and 2nd, the 4th and 5th, the 5th and 6th, and the 8th and 9th rows are broader than the spaces between the 2nd and 4th and the 6th and 8th rows on the right side of the upper jaw (Fig. 6A), and the spaces between the 1st and 2nd, the 4th and 5th, the 8th and 9th, the 9th and 10th, and the 10th and 11th rows are broader on the left side of the lower jaw (Fig. 7A). A wider space occurs every third or fourth row in the anterior and posterior regions of both jaws (Figs. 6 and 7). The spacings of rows 13 to 17 of the upper jaw are narrow and about the same width. The spacings of rows 9 to 13 of the lower jaw are wide and about the same width. Teeth in each row form a line from the lingual to labial sides without overlapping each other. The spaces between teeth in each posterior row are wider than those of the lateral and anterior rows because the lengths of the rows are the almost same, but the sizes of the teeth are smaller in the posterior rows than in the anterior and lateral rows (Figs. 6B and 7B).

Acknowledgments

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