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Fluoride Concentration in the Teeth of Perciform Fishes and Its Phylogenetic Significance

Shoichi Suga, Yasuhiko Taki and Koji Wada

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Abstract Fluoride concentration in the teeth of 78 perciform species from both marine and freshwater environments was investigated by means of quantitative analysis using electron microprobe. In almost all the species examined, the fluoride concentration was more than 2.0% in enameloid and less than 0.6% in dentin and bone. This level of concentration in the enameloid is almost equal to that in the enameloid of balistoid species and much higher than in the enameloid of tetraodontoid species and the cypriniform *Cyprinus carpio* (less than 0.2%). The fluoride concentration in the perciform enameloid showed no siginificant difference associated with salinity conditions of the habitats of these fishes, and between zoogeographical positions in the case of freshwater forms, i.e., primary, secondary and vicarious freshwater species. There is no correlation between the fluoride concentration in the enameloid and the shape and size of teeth which show diverse morphological adaptation.

These facts suggest that the fluoride concentration in enameloid is related to phylogeny of the fishes rather than the fluoride concentration in environmental water, and that the evolution of chemical composition of fish enameloid is independent of the morphological adaptation of teeth.

Fish teeth comprise enameloid and dentin. The enameloid is analogous to the enamel of teeth of amphibians, reptiles and mammals and is similarly very highly mineralized, though its organic matrix is composed of ectodermal and mesodermal products unlike the enamel of tetrapods containing only ectodermal products. Suga et al. (1980, 1981a) reported that bony and cartilaginous fishes may be classified into two groups in terms of fluoride content in the enameloid of teeth; one group containing fluoride more than about 2.3% and the other containing less than about 0.2%.

The fluoride concentration in the enamel of mammals is generally considered closely related to that in drinking water and diet. In fishes, however, quantitative analyses of fluoride by electron microprobe thus far made of various forms from both marine and freshwater environments have suggested that the fluoride concentration in the enameloid is related to fish phylogeny rather than the fluoride concentration in environmental water (Suga et al., 1978a, 1979, 1980, 1981a, b).

In the present study, the fluoride concentration in the teeth of perciform fishes occurring in various salinity conditions was investigated by means of quantitative analysis using electron microprobe, in order to obtain more precise information on the relationships between the fluoride concentration in enameloid, fish phylogeny and environmental water.

The Perciformes, one of the largest orders of fishes, include a considerable number of freshwater species in addition to the predominant marine forms. These freshwater species can be classified into several groups which differ in the process of establishment as freshwater forms, e.g., primary freshwater fishes which are strictly intolerant of saline environments, secondary freshwater fishes which are rather strictly confined in freshwater but may be tolerant of sea water to a certain extent, and vicarious freshwater fishes that are strictly freshwater representatives of primarily marine groups (Myers, 1951). The fishes of this order bear teeth on the upper and lower jaws, upper and lower pharyngeals, gill arches, and, in some species, on the tongue, palate and mouth floor. The jaw and pharyngeal teeth exhibit a remarkable diversity in form and size, associated with feeding habits, ranging from the beak-like teeth of oplegnathids to the heterodont teeth of sparids in the jaws, and from the molars of cichlids to

Table 1. Fluoride concentration (%) in the enameloid, dentin and bone of the Perciformes. Suborders and families are arranged in alphabetical order. *** Primary freshwater fish; ** vicarious freshwater fish; * secondary freshwater fish. (J), jaw teeth; (P), pharyngeal teeth.

Suborder/Family	Species	Region	Enameloid	Dentin	Bone
Acanthuroidei					
Acanthuridae	*Acanthurus bleekeri*	(J)	3.89	0.45	0.36
	A. dussumieri	(J)	3.98	0.33	0.36
	A. gahhm	(J)	4.01	0.37	0.35
	Prionurus microlepidotus	(J)	3.67	0.34	0.40
Siganidae	*Siganus fuscescens*	(J)	3.12	0.42	0.20
Anabantoidei					
Anabantidae	****Anabas testudineus*	(J)	2.40	0.13	0.17
Channoidei					
Channidae	****Channa striata*	(J)	2.11	0.30	0.18
Echeneidoidei					
Echeneididae	*Remora albescens*	(J)	2.34	0.23	0.31
Gobioidei					
Gobiidae	*Cryptocentrus filifer*	(J)	1.97	0.17	0.34
	Glossogobius celebius	(J)	2.70	0.29	0.36
	Sicyopterus japonicus	(J)	2.75	0.30	0.35
Labroidei					
Labridae	*Choerodon schoenleinii*	(P)	3.82	0.26	0.37
	Halichoeres trimaculatus	(P)	4.84	0.26	0.13
	Hemigymnus melapterus	(P)	4.50	0.25	0.51
Scaridae	*Bolbometopon muricatus*	(P)	4.41	0.35	0.37
	Calotomus japonicus	(P)	3.02	0.28	0.28
	Scarus bowersi	(P)	3.77	0.28	0.48
	S. gibbus	(P)	4.06	0.33	0.38
	S. rhoduropterus	(P)	3.75	0.26	0.38
	S. rubroviolaceus	(P)	3.85	0.24	0.41
Mugiloidei					
Atherinidae	*Allanetta bleekeri*	(J)	1.87	0.18	0.26
Percoidei					
Apogonidae	*Apogon lineatus*	(P)	2.22	0.19	0.25
	A. semilineatus	(P)	2.52	0.17	0.22
Carangidae	*Caranx* sp.	(P)	3.45	0.39	0.63
Centrarchidae	****Ambloplites rupestris*	(P)	1.55	0.43	0.21
	****Lepomis macrochirus*	(P)	2.08	0.25	0.22
	****Micropterus dolomieu*	(P)	2.47	0.41	0.43
	****M. salmoides*	(P)	2.25	0.49	0.21
Chaetodontidae	*Heniochus acuminatus*	(J)	3.37	0.25	0.11
Cheilodactylidae	*Goniistius zebra*	(P)	2.57	0.31	0.11
Cichlidae	**Aequidens* sp.	(P)	2.65	0.15	0.19
	**Cichlasoma bimaculatum*	(P)	3.04	0.28	0.25
	**Crenicichla sexatilus*	(J)	3.50	0.17	0.15
	**Geophagus surinamensis*	(P)	2.74	0.19	0.19
	**Haplochromis mloto*	(P)	2.17	0.14	0.16
	**Labidochromis exasperatus*	(P)	2.09	0.19	0.36
	**Lamprologus lemairei*	(P)	1.70	0.16	0.17
	**Petrochromis trewavasae*	(J)	3.23	0.21	0.17
	**Tilapia mossambica*	(P)	2.68	0.26	0.40
	**T. nilotica*	(J)	3.14	0.28	0.28
		(P)	3.27	0.32	0.29

Table 1. (Continued)

Suborder/Family	Species	Region	Enameloid	Dentin	Bone
	**T. zillii*	(P)	3.52	0.24	0.52
	**Tropheus duboisi*	(P)	3.42	0.18	0.16
Coryphaenidae	*Coryphaena hippurus*	(J)	5.45	0.44	0.20
Embiotocidae	*Neoditerma ransonetti*	(J)	2.79	0.19	0.13
Kyphosidae	*Kyphosus cinerascens*	(P)	2.59	0.33	0.15
Lethrinidae	*Lethrinus nebulosus*	(J)	3.42	0.29	0.18
Lobotidae	***Datnioides microlepis*	(J)	2.59	0.23	0.18
Lutjanidae	*Etelis carbunculus*	(J)	2.86	0.22	0.29
Mullidae	*Mulloidichthys vanicolensis*	(P)	2.23	0.27	0.28
	Upeneus bensasi	(P)	1.72	0.13	0.18
Nandidae	****Nandus nandus*	(P)	2.62	0.26	0.29
Nemipteridae	*Scolopsis inermis*	(P)	2.67	0.75	0.24
Oplegnathidae	*Oplegnathus fasciatus*	(J)	3.27	0.48	0.34
Pentacerotidae	*Pentaceros japonicus*	(J)	2.86	0.19	0.16
Percichthyidae	***Coreoperca kawamebari*	(J)	2.75	0.31	0.35
	Lateolabrax japonicus	(J)	2.62	0.22	0.48
	Morone americanus	(P)	2.80	0.47	0.34
	Synagrops japonicus	(J)	2.34	0.41	0.21
Percidae	****Perca flavescens*	(J)	3.22	0.37	0.35
Pomadasyidae	*Plectorhynchus chaetodontoides*	(P)	3.61	0.38	0.36
Priacanthidae	*Priacanthus macracanthus*	(P)	2.69	0.70	0.10
Sciaenidae	***Pseudosciaena soldado*	(J)	2.21	0.25	0.18
Scombropidae	*Scombrops boops*	(J)	4.08	0.18	0.12
	S. gilberti	(J)	3.66	0.16	0.13
Scorpididae	*Microcanthus strigatus*	(J)	2.96	0.38	0.33
Serranidae	*Chelidoperca hirundinacea*	(J)	3.98	0.28	0.21
	Epinephelus fasciatus	(J)	2.83	0.44	0.34
	E. latifasciatus	(J)	2.47	0.19	0.31
Sillaginidae	*Sillago japonica*	(J)	2.76	0.19	0.38
Sparidae	*Acanthopagrus schlegeli*	(J)	5.22	0.66	0.36
	Pagrus major	(J) canine	4.21	0.27	0.21
		(J) molar	4.34	0.31	0.17
Scombroidei					
Gempylidae	*Promethichthys prometheus*	(J)	3.03	0.24	0.10
Scombridae	*Sarda orientalis*	(J)	2.36	0.48	0.33
	Scomberomorus sp.	(J)	2.04	0.20	0.23
	Thunnus thynnus	(J)	1.44	0.17	0.19
Trichiuridae	*Trichiurus lepturus*	(J)	2.87	0.25	0.13
Sphyraenoidei					
Sphyraenidae	*Sphyraena* sp.	(J)	2.83	0.30	0.14

the flat pavements of scarids on the pharyngeals. In view of such great diversities in number of species, living conditions and nature of teeth, the Perciformes can be regarded as one of the most suitable groups to determine relationships between fluoride concentration, fish phylogeny and environmental water.

Materials and methods

The specimens used for the present study represent 78 species falling into 40 families in 10 suborders (Table 1) from various marine and freshwater environments. The scope of this order and the classification of suborders followed Greenwood et al. (1966) with the following modification: the Channidae and the Echeneididae are included as suborders. Freshwater species are divided into primary, secondary and vicarious divisions according to Myers' (1951) zoogeographical classification.

Fig. 1. Microradiograms of undemineralized longitudinal ground sections of teeth of perciform fishes (1). a: *Oplegnathus fasciatus* (J), ×9. b: *Scarus gibbus* (J), ×9. c: *Pagrus major* (J), ×18. d: *Hemigymnus melapterus* (P), ×18. J, jaw teeth; P, pharyngeal teeth.

The specimens were stored in isopropyl alcohol and/or 10% formalin. Jaw and/or pharyngeal teeth and their surrounding tissues including bone were embedded in polyester resin after dehydration in an ascending series of concentration of alcohol. Planoparallel ground sections about 60～70 μm thick showing a longitudinal plane of teeth were made with a grindstone after sectioning with a hard tissue sectioning machine equipped with a diamond saw.

The ground sections were first microradiographed using soft X-ray apparatus to examine the mineralization pattern of teeth and bone, and then mounted on a polished surface of aluminum block with epoxy resin. After applying a thin coating of carbon to the polished surface of specimens by evaporation in a vacuum to form a conducting layer, electron microprobe

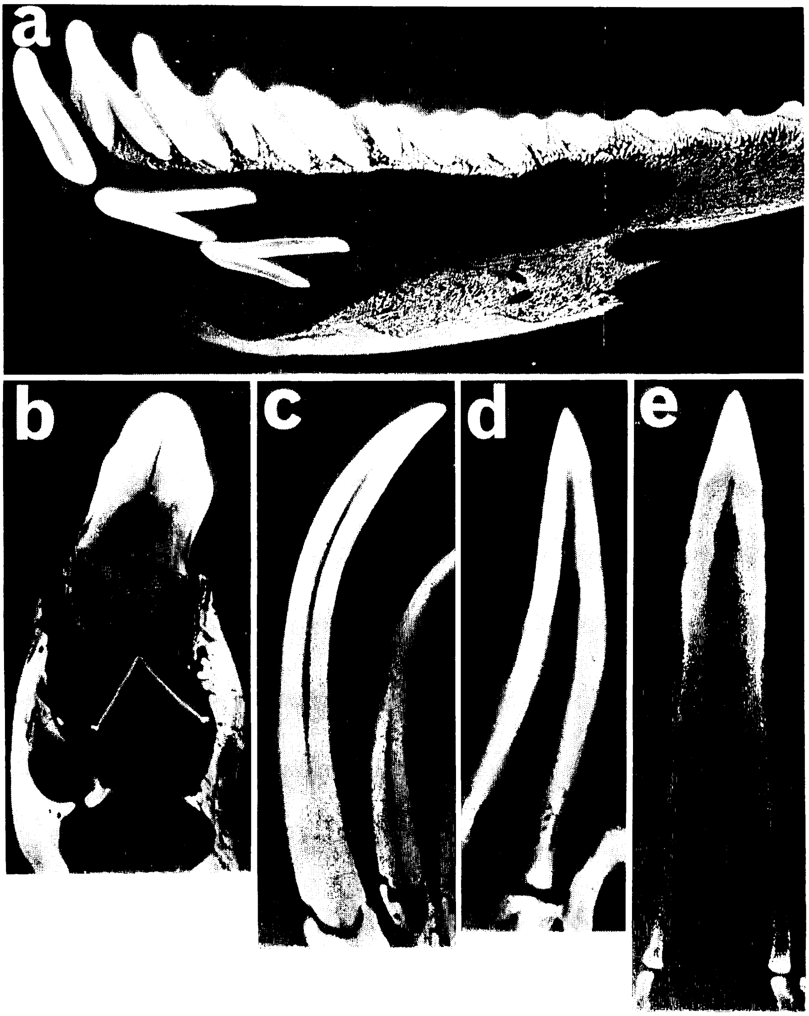

Fig. 2. Microradiograms of undemineralized longitudinal ground sections of teeth of perciform fishes (2). a: *Scarus bowersi* (P), ×11. b: *Lethrinus nebulosus* (J), ×21. c: *Microcanthus strigatus* (J), ×84. d: *Epinephelus latifasciatus* (J), ×84. e: *Pseudosciaena soldado* (J), ×84. J, jaw teeth; P, pharyngeal teeth.

quantitative and line scan analyses were performed. The electron microprobe apparatus used for this study is Shimadzu-ARL, type EMX-SM, equipped with a wave-length dispersive monochrometer (WDX). The analyses were performed with an accelerating voltage of 15 kV and a specimen current of 0.15 μA. The curved single crystals used are a 4-inch RAP crystal for the detection of FKα, a 4-inch LiF for CaKα, and a 4-inch ADP for MgKα (Suga, 1972).

Quantitative fluoride analysis was conducted by measuring the intensity of FKα emission obtained by the mode of point analysis, using the convergent method with fluorapatite (Durango in Mexico; fluoride concentration measured by the fluoride solid membrane electrode method was 2.82%) as a standard sample, as described in Suga et al. (1980, 1981a). The patterns of elemental distributions revealed by the line scan analysis were compared in detail with the microradiograms showing mineralization patterns.

Point analysis was made mainly at the surface

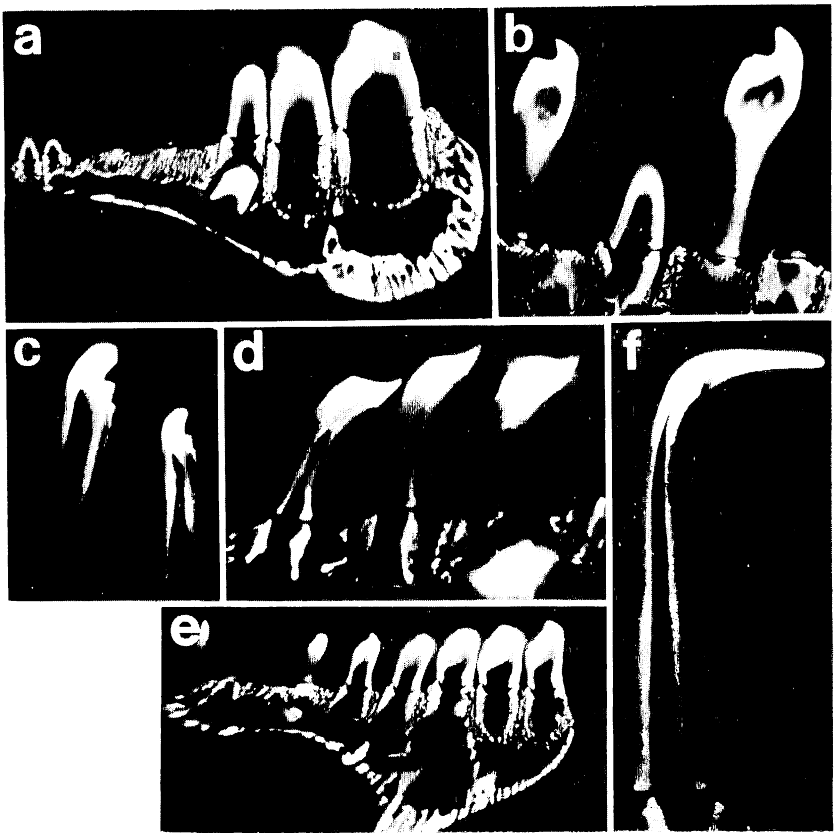

Fig. 3. Microradiograms of undemineralized longitudinal ground sections of perciform fishes (3), Cichlidae. a: *Cichlasoma bimaculatum* (P), ×24. b: *Tilapia nilotica* (P), ×24. c: *Tilapia zillii* (P), ×44. d: *Labidochromis exasperatus* (P), ×24. e: *Geophagus surinamensis* (P), ×24. f: *Petrochromis trewavasae* (J), ×96. J, jaw teeth; P, pharyngeal teeth.

layer of enameloid at the tip of newly erupted cusps, the middle layer of dentin and the alveolar bone. The fluoride concentration determined by the electron microprobe is the value of weight per volume bombarded by an electron beam of a very small diameter and is not weight per weight of apatite.

Results

Morphological and histological observations of teeth. In the microradiograms of undemineralized ground section, the enameloid was readily distinguished from the dentin and bone by its much higher radiodensity. The enameloid did not necessarily cover the entire surface of the erupted portions of teeth. For example, both incisal and molar teeth of the Sparidae had thick enameloid covering the entire surface of the erupted portion (Fig. 1c), whereas in some scombrids the enameloid was noticed as a very small cup only at the tip of long canine-like teeth (Fig. 4).

The sharp-edged, beak-like plate in the jaw of the Scaridae and Oplegnathidae were composed of successive rows of arrowhead-like teeth, which were surrounded firmly by bone and which move from the bottom towards the incisal edge, and the teeth had thick enameloid from the early stage of tooth formation (Fig. 1a, b). The flat pavement-like plate on the pharyngeals of the scarids consisted of double rows of successive layers of developing and fully formed teeth which move anteriorly, and each tooth had thick enameloid covering the entire surface of the tooth crown and underlying thin dentin (Fig. 2a).

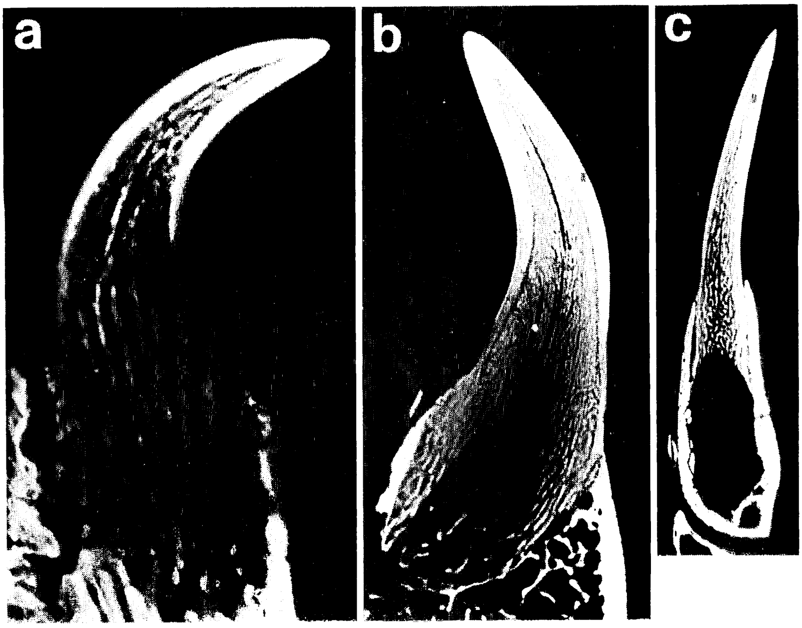

Fig. 4. Microradiograms of undemineralized longitudinal ground sections of teeth of perciform fishes (4). Jaw teeth. a: *Thunnus thynnus*, × 96. b: *Sarda orientalis*, × 24. c: *Trichiurus lepturus*, × 24.

Herbivorous species of the Cichlidae had slender chisel-like jaw teeth whose crowns were covered by a thin layer of enameloid (Fig. 3f). However, there was no correlation between the thickness of enameloid and the degree of mineralization, not only in all the cichlids examined, but in all the other perciform species examined as well (Figs. 1 ~ 5).

The dentin of the perciforms examined represented several different histological features. Most species had the so-called orthodentin which contains numerous dentinal tubules running radially from the pulpal side towards the peripheral part (Figs. 1 ~ 3). In some scombroids (Fig. 4) and a channid (Fig. 5a), the pulpal layer of dentin matrix contained a fine network of blood capillaries (the vasodentin).

Elemental analysis by electron microprobe. The results of line scan and point analyses made along a line crossing both enameloid and dentin layers at the tip of fully formed teeth showed that the fluoride concentration was much higher in the enameloid than in the dentin (Figs. 6, 7). Since high concentrations were observed in developing enameloid at early stages of mineralization as well as in erupted enameloid as in the

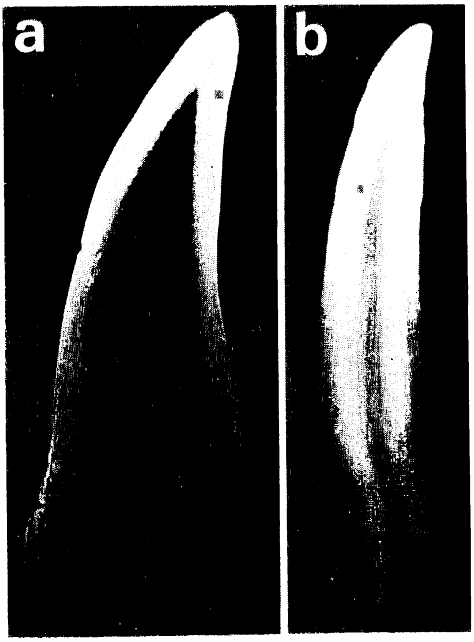

Fig. 5. Microradiograms of undemineralized longitudinal ground sections of teeth of perciform fishes (5). Jaw teeth. a: *Channa striata*, × 27. b: *Sicyopterus japonicus*, × 108.

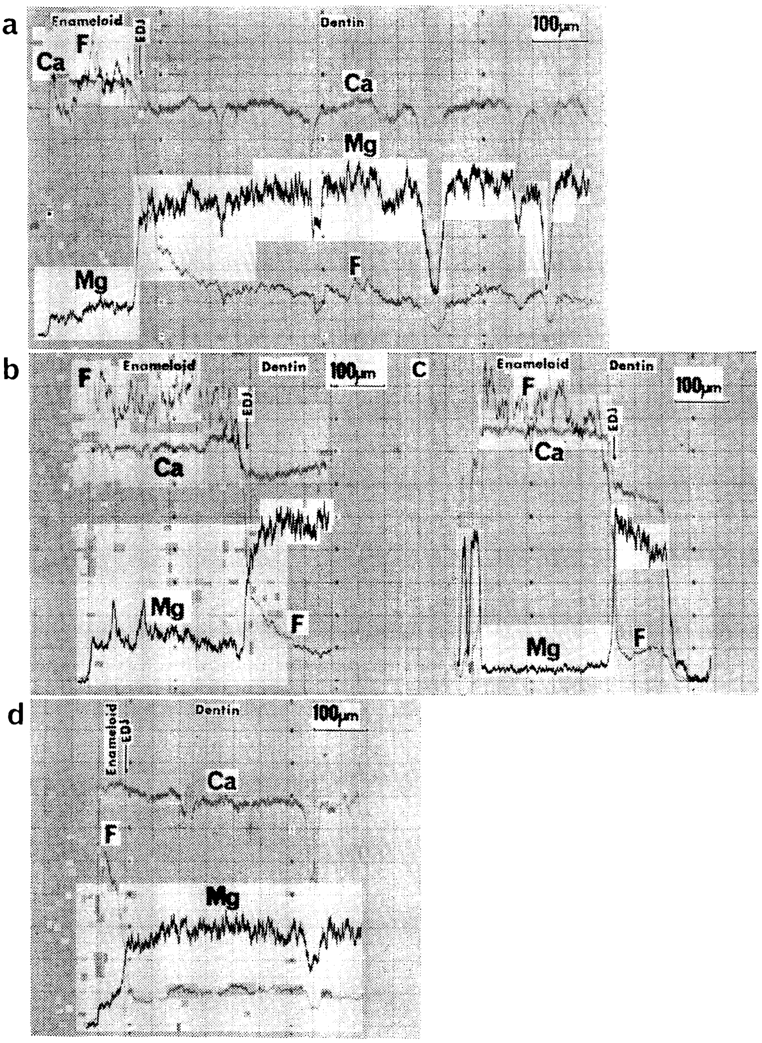

Fig. 6. Distribution patterns of fluoride, magnesium and calcium in the teeth of four marine species of the Perciformes, revealed by line scan analysis by electron microprobe. Line scan analysis was performed at the cusp of the crown of newly erupted jaw teeth. a: *Prionurus microlepidotus*, b: *Pagrus major*, c: *Bolbometopon muricatus*, d: *Sarda orientalis*.

Fluoride concentration is much higher in the enameloid than in the dentin, and magnesium concentration is lower in the enameloid than in the dentin. ES, enameloid surface; EDJ, enameloid-dentin junction.

Oplegnathidae, as previously reported by Suga et al. (1981a), the high deposition of fluoride into the enameloid is considered to have occurred during the process of tooth formation.

Although the fluoride levels were very low in the dentin compared with the enameloid, the fluoride in the narrow dentin layer adjacent to the enameloid-dentin junction tended to increase slightly in concentration from the pulpal side towards the junction (Figs. 6, 7).

Since no significant difference in fluoride concentration was observed between enameloid and dentin from different regions of the mouth (see values of *Tilapia nilotica* and *Pagrus major* in Table 1), teeth with suitable forms and sizes for preparing ground sections were chosen for investigations.

The fluoride concentrations determined by point analysis from the surface layers of enameloid, middle layer of dentin and alveolar bone of 78 species are shown in Table 1. The fluoride concentrations in the teeth of *Cyprinus carpio* and *Takifugu rubripes rubripes* (*Fugu rubripes rubripes* in original paper) and in human mature enamel and fluorapatite (Suga et al., 1980, 1981a, b) are shown in Fig. 8 for comparison.

The enameloid of all the perciform species presently examined contained rather high fluoride ranging from 1.44% to 5.45%, whereas the dentin and bone contained fluoride lower than 0.75% and 0.63%, respectively. The fluoride concentrations of this order are much higher than in human enamel and in the enameloid of *Cyprinus carpio* and *Takifugu rubripes rubripes.* The distribution of fluoride concentrations in the enameloid, dentin and bone for the 78 species is plotted in Fig. 8. It is readily recognized from the figure that there is no significant difference in fluoride concentration among marine and freshwater species of different divisions.

Discussion

The fact that the enameloid of sharks contains fluorapatite, unlike the mammalian enamel which contains hydroxyapatite, was first detected by Trautz et al. (1952). Glas (1962) found that the shark enameloid contains fluoride as high as 3.3% in the form of fluorapatite. Such high fluoride concentrations in shark enameloid were further confirmed by chemical and physical quantitative analyses (Büttner, 1966; Suga et al., 1978b; Daculsi and Kérebel, 1980). As for the fluoride concentration in the teeth of bony fishes, no investigation had been made until an electron microprobe analysis using electron beam of very small diameter was applied by Suga et al. (1976).

Previous studies on the teeth of teleostean fishes using electron microprobe suggested that the fluoride concentration in the enameloid is closely related to the phylogeny of these fishes rather than the fluoride concentration in environmental water (Suga et al., 1976, 1977, 1978a, 1979, 1980, 1981a, b). For example, marine forms of the Tetraodontoidei (order Tetraodontiformes) contain very low fluoride (lower than 0.22%), whereas marine species of the Balistoidei of the same order contain very high fluoride (higher than 2.31%) (Suga et al., 1981b). On the other hand, preliminary investigations have indicated that the fluoride concentration in enameloid is rather high in some freshwater, as well as marine, species of the Perciformes (higher than 1.55%) (Suga et al., 1978a, 1981a) and very low in some species of the freshwater order Cypriniformes (lower than 0.17%) (Suga et al., 1978a, 1979, 1981a).

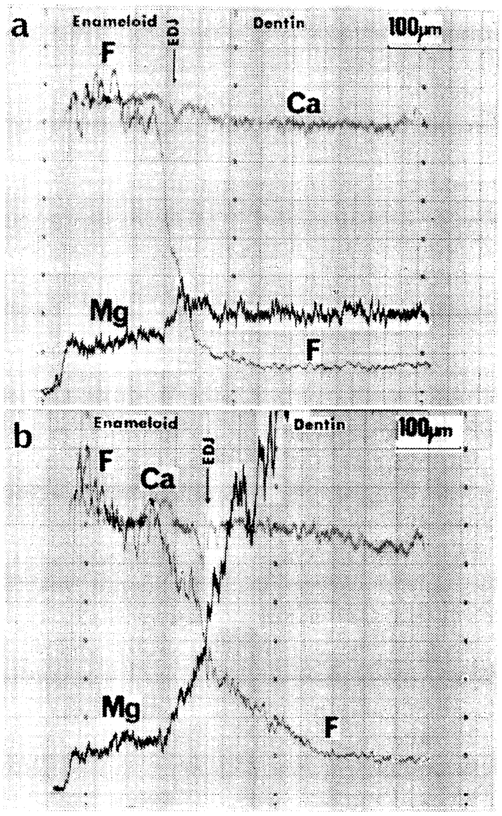

Fig. 7. Distributions of fluoride, magnesium and calcium in the teeth of two freshwater species of the Perciformes revealed by line scan analysis by electron microprobe. Line scan analysis was performed at the cusp of the crown of newly erupted jaw teeth. a: *Channa striata*, b: *Tilapia nilotica*.

The same patterns as observed in the teeth of marine species (Fig. 6) can be seen. ES, enameloid surface; EDJ, enameloid-dentin junction.

Since the fluoride concentration in dentin and bone is very low (lower than 0.75%) in contrast to the high concentration in the enameloid adjacent to them, it has been speculated that there might be a peculiar mechanism to concentrate fluoride to the enameloid in enameloid-forming cells (probably the ameloblasts) (Suga et al., 1980, 1981a). This speculation seems to be supported by the present study, by the fact that, in the narrow dentin layer adjacent to the enameloid-dentin junction, the fluoride concentration tends to increase gradually towards the junction.

The fluoride concentration in sea water is about 1.3 ppm all over the oceans of the world (Greenhalgh and Riley, 1963), whereas that in fresh water is lower than about 0.26 ppm with a few exceptions (Matsuura and Kokubu, 1972). In this context, the above-mentioned findings obtained from the teeth of many teleosteans from various environments are not compatible with the general concept that the fluoride concentration in the enamel of mammals is closely related to that in drinking water and food (Brudevold and Söremark, 1967; Wheatherell and Robinson, 1973).

In order to confirm the speculation on the relationships between fluoride concentration in enameloid and fish phylogeny, the teeth of many perciform species from both marine and fresh waters were carefully examined here. The results indicate that the enameloid of all species examined contains fluoride at more than about 2.00% with few exceptions, regardless of the salinity conditions of their habitats and, in freshwater species, regardless of their position in zoogeographical classification. The value of more than 2.00% corresponds with the fluoride concentrations in the enameloid of sharks (Büttner, 1966; Suga et al., 1978b; Daculsi and Kérebel, 1980) and balistoids (Suga et al., 1981b). In no perciform is the fluoride concentration as low as in the cypriniform *Cyprinus carpio* (ca. 0.17%) (Suga et al., 1978a, 1981a) and in tetraodontoids (<0.17%) (Suga et al., 1981b). Even in the few exceptions the enameloid contains fluoride higher than 1.44%.

All these facts support the previous speculation that the fluoride concentration in the enameloid of fish teeth is related to phylogenetic relationships rather than the fluoride concentration in environmental water (Suga et al., 1980, 1981a, b).

The teeth of fishes show a remarkable range of adaptation in form and size, associated with feeding habits and physical properties of diet. The teeth of perciforms vary in shape and size, and the proportion between the amounts of enameloid and dentin varies greatly. However, no data in this study indicate the existence of a particular correlation between the fluoride concentration in the enameloid and the form and size of the enameloid. Cichlids exhibit a vast diversity in their feeding habits, including sand-plowers, detritivores, herbivores, insectivores, carnivores, fin-biters, scale-eaters, and egg- and larva-thieves (e.g., Bond, 1979). The examination of fluoride concentration in the enameloid for 12 species of African and South American cichlid species in this study indicates that the fluoride concentration is completely independent of the shape and size of teeth, feeding habits and geographical distribution.

The fluoride concentration in the dentin and bone is very low compared with that in the enameloid. The concentration in the perciform dentin and bone is almost equal to that in the same tissues of balistoids, whose enameloid contains high fluoride, and a little higher than that in tetraodontoids and *Cyprinus carpio*, whose enameloid contains low fluoride (Suga et al., 1980, 1981a, b). There is no significant difference in the fluoride concentration in the dentin and bone associated with habitat and zoogeographical conditions of the perciforms examined in this study (Fig. 8). The tendency for the concentration to be slightly higher in the dentin than in the bone is probably due to the deposition of fluoride penetrating from the enameloid side during tooth formation (Suga et al., 1981a, b), as revealed by line scan analysis (Figs. 6, 7).

The significance of high concentration of fluoride in the enameloid of the Perciformes, contrasting with the low values in the Tetraodontoidei and Cyprinidae, is not yet known. Human enamel is composed of hydroxyapatite, which contains fluoride at about 0.17% at the surface layer and lower than 0.05% in other layers (Brudevold and Söremark, 1967; Wheatherell and Robinson, 1973). Crystallographic investigations using X-ray diffraction and infrared spectroscopy performed on the enameloid of some teleostean fishes containing various amounts of fluoride indicated that the

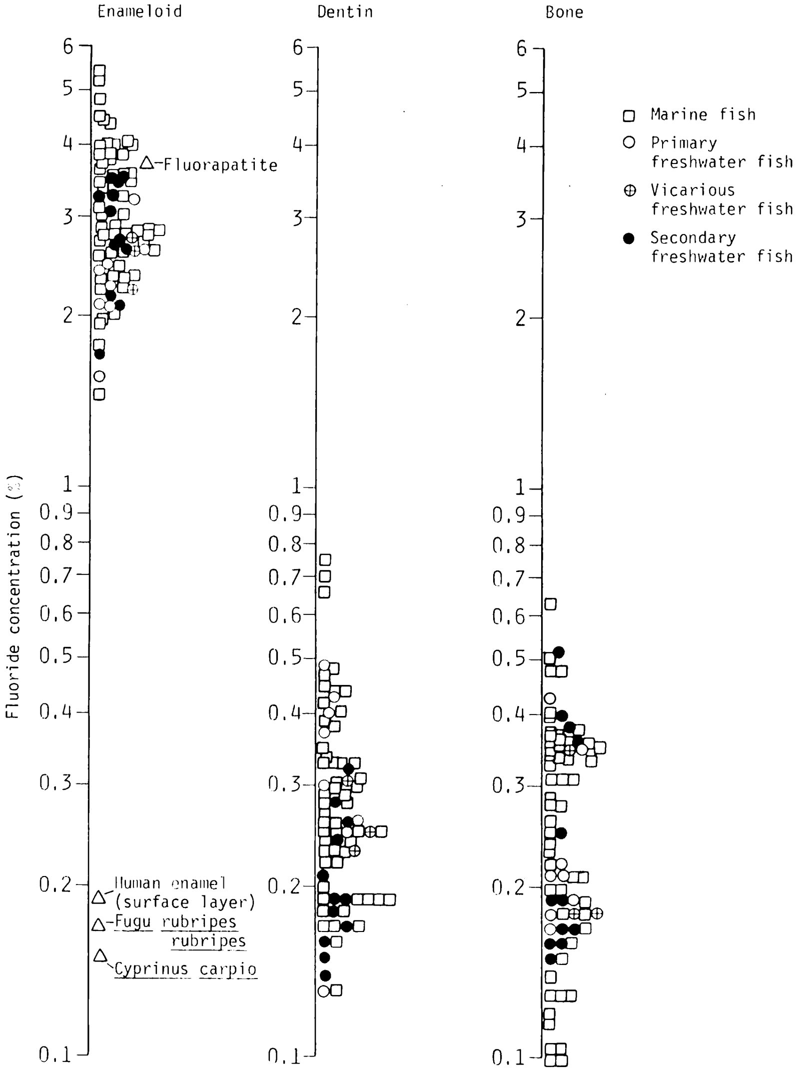

Fig. 8. Distribution of 78 perciform species examined in the present study, plotted according to the fluoride concentration in the enameloid, dentin and bone. The fluoride concentration in human mature enamel (surface layer) (Suga et al., 1980), in the enameloid of *Cyprinus carpio* (Suga et al., 1980) and Takifugu *rubripes rubripes* (*Fugu r. rubripes* in Suga et al., 1981b) and in fluorapatite are also plotted.

fluoride incorporation resulted in increase in crystallite size, reduction in carbonate content, and systematic decrease in the a-axis lattice parameter (Suga et al., 1980; LeGeros and Suga, 1980).

It is presumed that such differences in crystallographic nature reflect on the physical and chemical properties of enameloid. However, the fluoride concentration in the enameloid is, in fact, not related to feeding habits, though the form, size and distribution of teeth show a wide range of adaptation in association with feeding habits. A similar fact has been pointed out on the teeth of the Tetraodontiformes and some other fishes (Suga et al., 1981a, b). The results of this study seem to indicate that the evolution of chemical composition of fish enameolid is completely independent of the morphological adaptation of teeth.

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(SS: Department of Pathology, Nippon Dental University, Tokyo, 1-9-20, Fujimi, Chiyoda-ku, Tokyo 102, Japan; YT: Tokyo University of Fisheries, 5-7, Konan-4, Minato-ku, Tokyo 108, Japan; KW: National Research Institute of Aquaculture, Kashiko-jjima Branch, Kashiko-jima, Ago-cho, Shima-gun, Mie 517-05, Japan)

スズキ目魚類の歯質中のフッ素含量と系統との関係

須賀昭一・多紀保彦・和田浩爾

スズキ目の魚78種（海水魚: 55，第一次淡水魚: 8，第二次淡水魚: 12，代理性淡水魚: 3）の歯質中のフッ素(F)含量をエレクトロンマイクロプルーブの点分析によって測定した．ほとんどすべての魚種でエナメロイド中のフッ素含量は2.0%以上，象牙質や骨では0.6%以下であった．本目の魚のエナメロイド中のフッ素含量はすでに報告したモンガラカワハギ亜目魚類のそれとほぼ同じで，コイやフグ亜目（約0.2%以下）よりはるかに高い．また，海水魚や各種の淡水魚の間で含量に特別な違いはない．本目魚類の歯の形や大きさは食性に応じて多様であるが，エナメロイド中のフッ素含量はそれとは関連しない．

以上の事実はエナメロイド中のフッ素含量は環境水よりもむしろ魚の系統発生と関連していること，また，歯質組成の進化は歯の形の食性や環境への適応とは無関係であることを示唆している．

（須賀: 102 東京都千代田区富士見 1-9-20 日本歯科大学病理学教室; 多紀: 108 東京都港区港南 4-5-7 東京水産大学; 和田: 517-05 三重県志摩郡阿児町賢島 養殖研究所賢島支所）