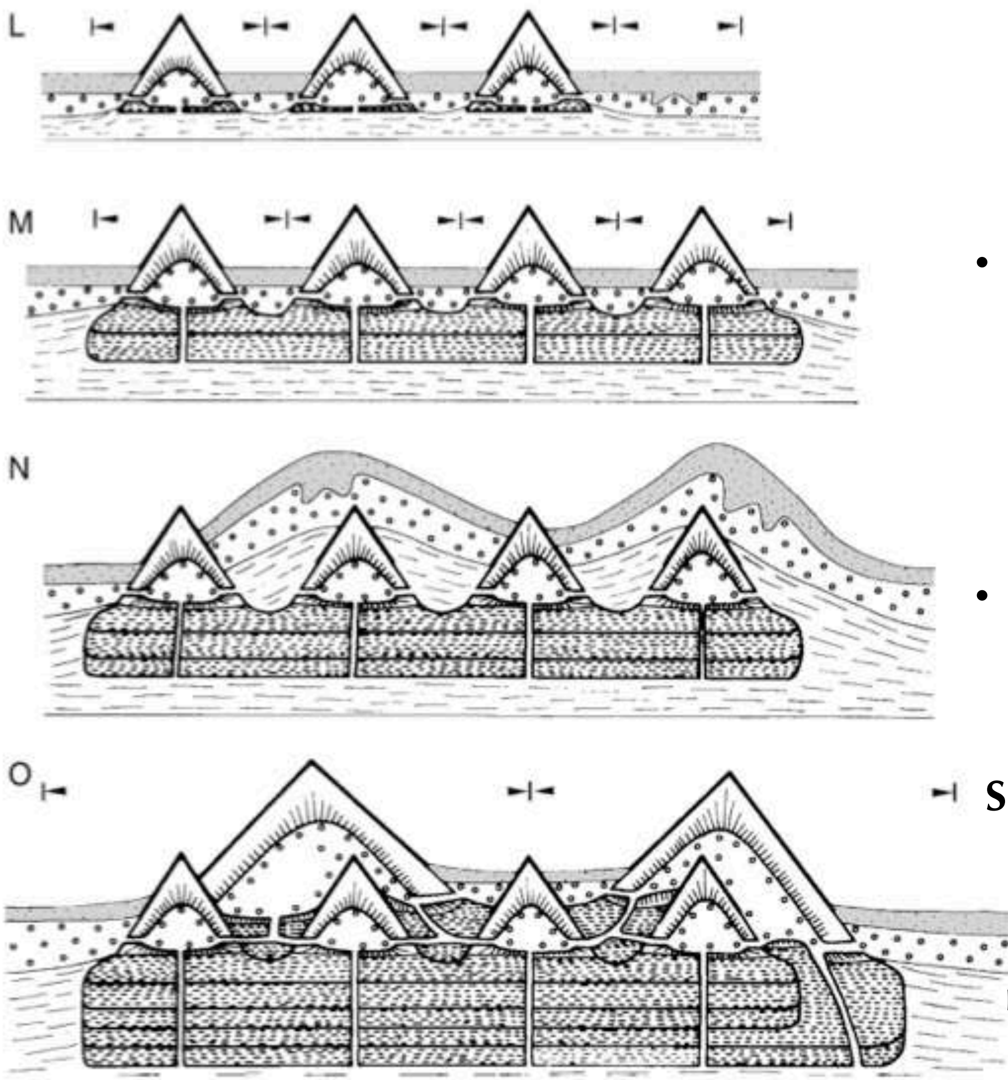
Obecná a srovnávací odontologie

And now something completely different

Vývojové souvislosti 5

odontoda; zuby 1. a 2. typu; systematická část

Odontoda

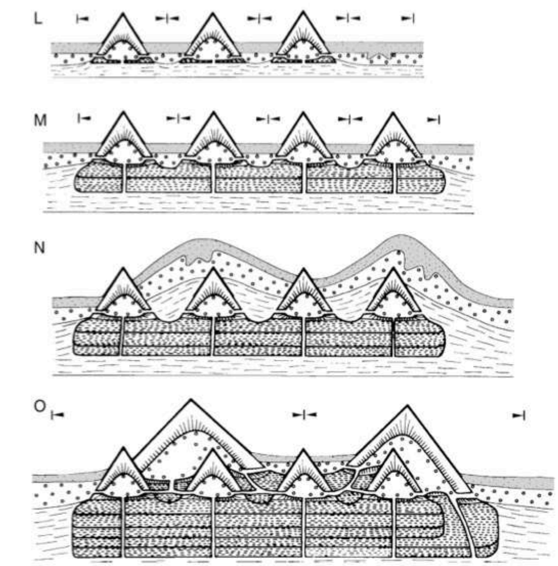


Tor Ôrwig 1967: termín odontoda

- vyvíjí se z mesenchymu a plakody (EP-MES-interakce)
- skládá se z dentinu či dent. tkání a většinou obsahuje superficiální vrstvu enamelu/enameloidu
- dle klasic. definice nenáleží k dentici, nemá funkci zubů *sensu stricto*
- vždy supeficiální pozice, není nahrazována jako zub

Skeletální (a dentální?) modul, mající mnoho společného se zubem.
Operační koncept umožňující rozeznání morfologické jednotky v rámci dermálního skeletu

Odontodová regulační teorie



WE Reif, 1982: odontodová regulační teorie

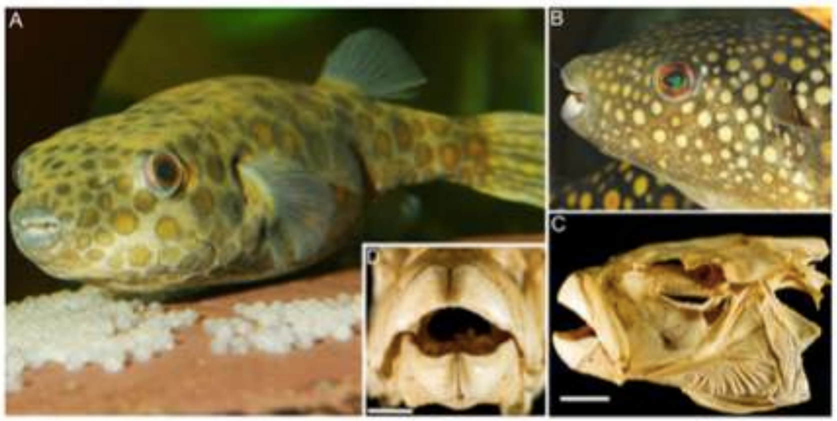
- navazuje na Orviga
- odontodou zde může být i zub!
- přiznaným archetypem je plakoidní šupina jako základní dermální jednotka

- Zub/dentice povstává díky diferenciaci či transformaci "odontody" jakožto modulární či archetypální jednotky.
- Větší a složitější zuby vznikají díky změnám ve vývoji či morfogenezi jediné odontody, ne splynutím několika odontod (*sensu* lepidomoriová teorie).
- Veškerá diverzita dentálních a dermoskeletálních tkání vzniká díky změnám v morfogenezi a diferenciaci této jednotky!

Replacing the first-generation dentition in pufferfish with a unique beak

Gareth J. Fraser[a,1], Ralf Britz[b], Andie Hall[b], Zerina Johanson[c], and Moya M. Smith[d]

[a]Department of Animal and Plant Sciences, University of Sheffield, Sheffield S10 2TN, United Kingdom; [b]Zoology Department and [c]Palaeontology Department, The Natural History Museum, London SW7 5BD, United Kingdom; and [d]Department of Craniofacial Development and Stem Cell Biology, Dental Institute, King's College London, London SE1 9RT, United Kingdom



viz též:

...veškerá diverzita dentálních a dermoskeletálních tkání vzniká díky změnám v morfogenezi a diferenciaci odontody

Teleost fishes comprise approximately half of all living vertebrates. The extreme range of diversity in teleosts is remarkable, especially, extensive morphological variation in their jaws and dentition. Some of the most unusual dentitions are found among members of the highly derived teleost order Tetraodontiformes, which includes triggerfishes, boxfishes, ocean sunfishes, and pufferfishes. Adult pufferfishes (Tetraodontidae) exhibit a distinctive parrot-like beaked jaw, forming a cutting edge, unlike in any other group of teleosts. Here we show that despite novelty in the structure and development of this "beak," it is initiated by formation of separate first-generation teeth that line the embryonic pufferfish jaw, with timing of development and gene expression patterns conserved from the last common ancestor of osteichthyans. Most of these first-generation larval teeth are lost in development. Continuous tooth replacement proceeds in only four parasymphyseal teeth, as sequentially stacked, multigenerational, jaw-length dentine bands, before development of the functional beak. These data suggest that dental novelties, such as the pufferfish beak, can develop later in ontogeny through modified continuous tooth addition and replacement. We conclude that even highly derived morphological structures like the pufferfish beak form via a conserved developmental bauplan capable of modification during ontogeny by subtle respecification of the developmental module.

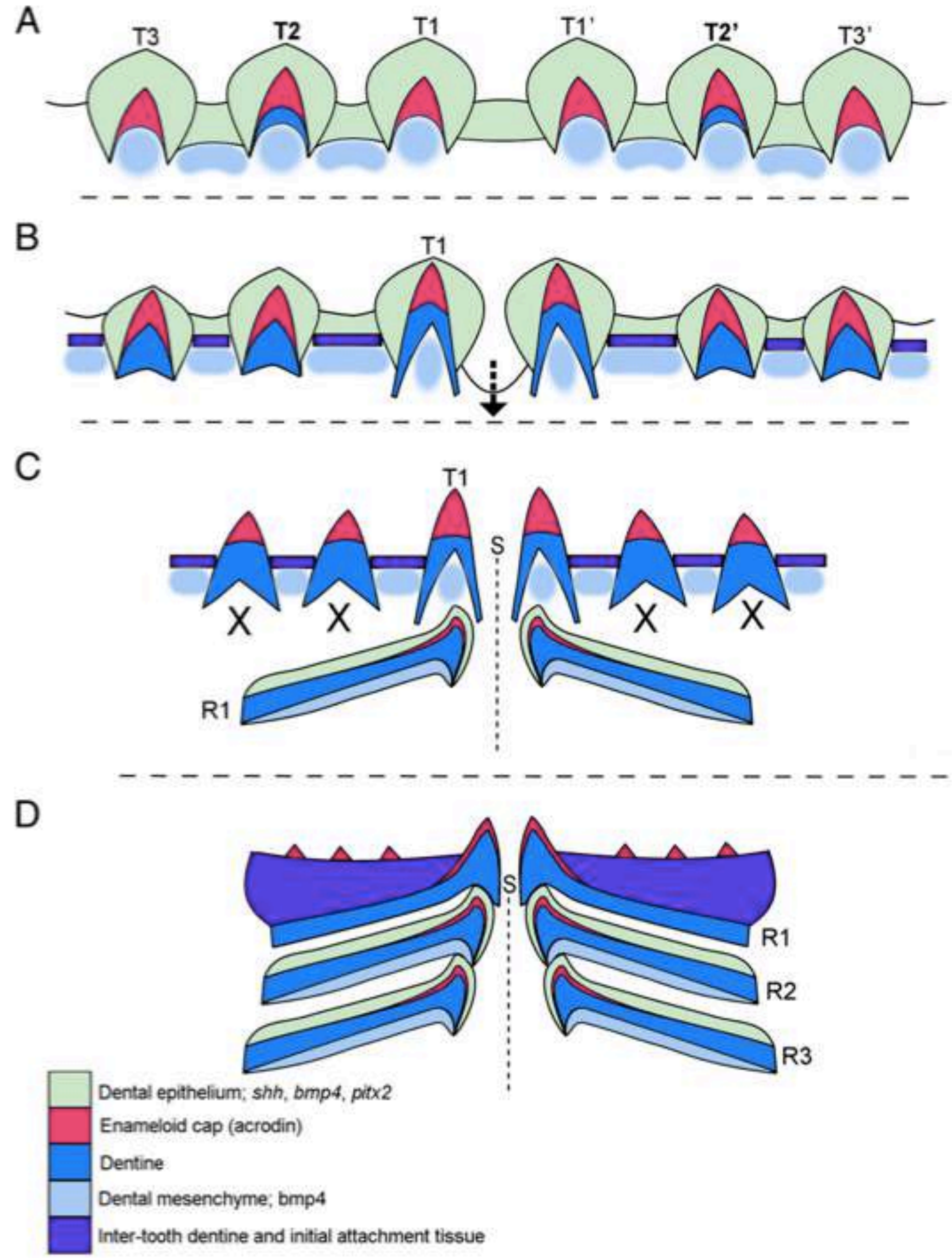
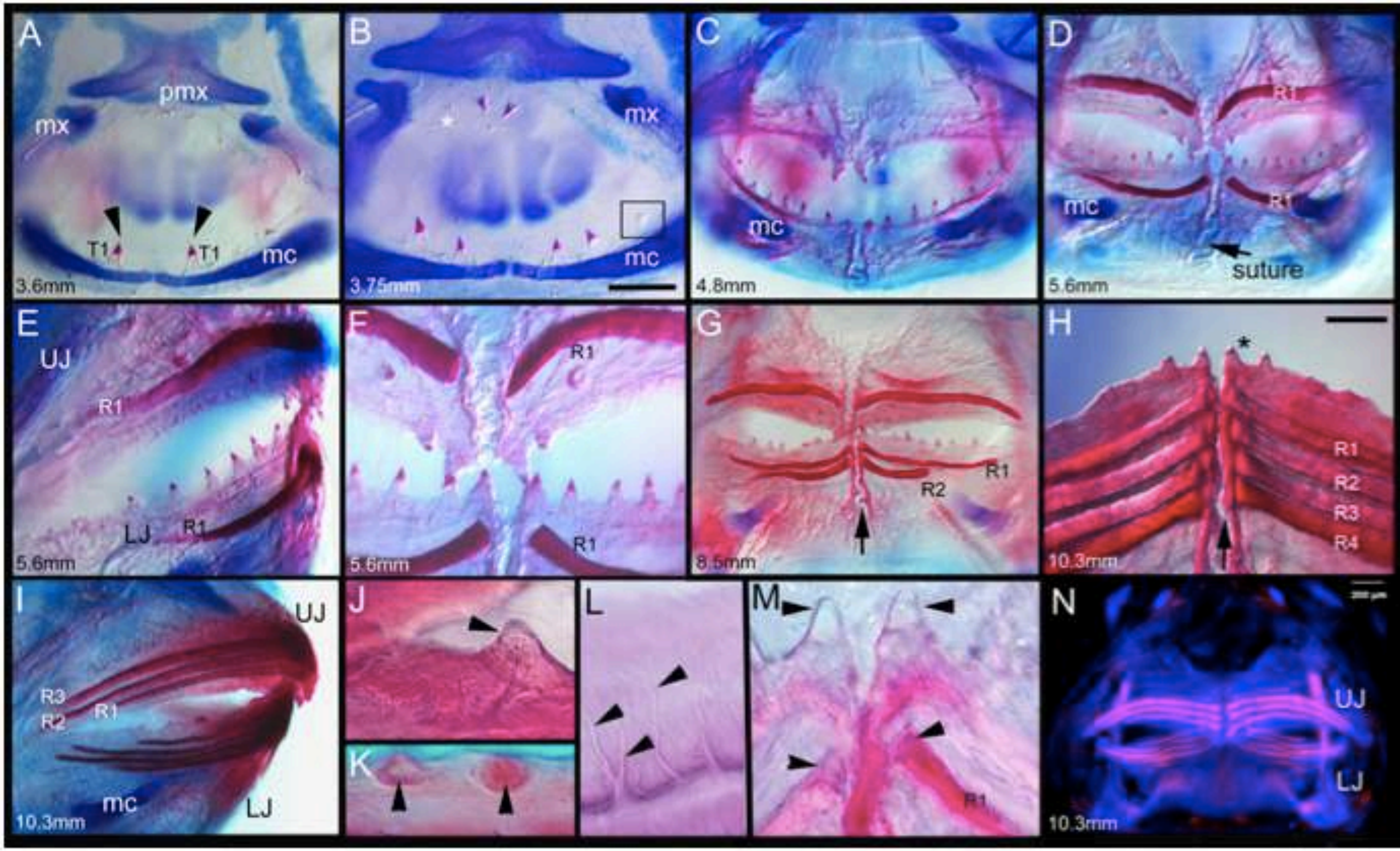


Fig. 5. Conserved developmental origins in pufferfish with teeth in order before appearance of the unique beak represented by schematic drawings of the transitional stages forming the beak constructed via tooth replacement (representing only the lower jaw dentition). (*A*) In stage A, first-generation superficial tooth development exemplifies the osteichthyan pattern. The order of initiation is different from the order along the jaw in a conserved pattern: T2, T3, and T1, with the number referring to position along the jaw from most proximal (parasymphyseal), T1. In addition, expression of key "tooth" genes (*bmp4*, *shh*, and *pitx2*) is conserved during this phase of development. All teeth form a cap of acrodin (red), but parasymphyseal teeth (T1) are larger. (*B*) In stage B, development of the parasymphyseal (medial, T1) teeth progresses to provide a deep extension (arrow) of dental epithelium from the tooth germ for initiation of beak morphogenesis. At this time, new intertooth dentine (purple) develops to surround first-generation teeth and join bases together for a functional surface, the "first bite." (*C*) In stage C, restricted replacement teeth form (R1) only for the parasymphyseal teeth. Proximal tooth positions (e.g., T2, T3) are lost (X) and never replaced. Replacement teeth (R1) are structurally very different from the first- generation teeth, as growth extends to the length of the jaw and each dentine band forms in the cavity within the bone of the jaws. First and future generations of replacement teeth are formed of single bands of dentine for each replacement round, as successive events within the bone. Expression of *pitx2*, *shh*, and *bmp4* continues to be redeployed for further morphogenesis of the replacement teeth into the characteristic bands of dentine (dark blue) to form the beak structure. The medial tips of each replacement band (stage D, R1–R3) contain an acrodin cap (red). (*D*) In stage D, further rounds of replacement (R1–R3) continue before the stacked dentine bands become a fully functional and novel structure as the beak. Each quadrant of the beak is separated by a complex sutured symphysis (S, dashed line). Dental epithelium (green) expresses *bmp4*, *pitx2*, and *shh* during both tooth initiation and continued replacement and initiation of dentine bands. Dental mesenchyme (light blue) expresses *bmp4* at all stages of tooth initiation and replacement band initiation and development.


A
pmx
mx
T1
T1
mc
3.6mm
B
mx
mc
3.75mm
C
mc
4.8mm
D
R1
R1
mc
suture
5.6mm
E
UJ
R1
LJ
R1
5.6mm
F
R1
R1
5.6mm
G
R1
R2
8.5mm
H
R1
R2
R3
R4
10.3mm
I
UJ
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N
UJ
LJ
10.3mm

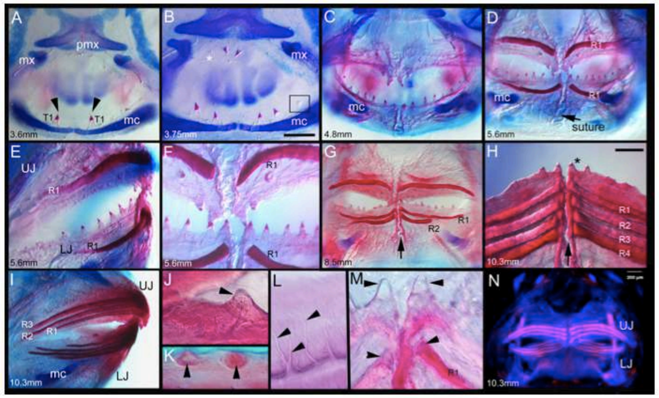

Fig. 2. Developmental sequence from a conserved pattern of initial teeth to replacement dentine bands during the formation of the unique pufferfish beak. (*A–D*, *F–H*, *M*, and *N*) Frontal views (into the mouth) of the developing dentition (3.6 mm NL to 10.3 mm SL) of a pufferfish (*Monotrete suvattii*). (*E*, *I*, and *L*) Lateral views. (*K*) Medial view. *A–M* show specimens cleared and double- stained with alizarin red (staining calcium-rich tissues, e.g., bone and dentine) and alcian blue (staining mucopolysaccharides in cartilage). The first-generation dentition in pufferfish is composed of individual teeth with acrodin (enameloid) caps identical to those of other actinopterygians (*A–H*). From the youngest stage with 2 teeth in the lower jaw (LJ) (*A*, black arrowheads, T1), separate teeth are added along the jaws [*B*, 4 teeth plus a developing tooth (black box) in the LJ, 2 teeth plus a developing tooth in the upper jaw (UJ), denoted by an asterisk] with up to 14 (*C*) to 16 teeth (*D*) in the LJ and up to 6 teeth in the UJ (*C* and *D*). First-generation teeth and superficial intertooth dentine are retained until worn (*H*, asterisk). Strongly mineralized jaw length bands of dentine form from individual replacement teeth, stacked below the first-generation teeth in the UJ and LJ, increasing in number with size from one band in *D* to up to four bands in *H* and *N*, the largest stage that we studied (10.3 mm SL). These stacks of dentine bands (R1–R4) form as multigeneration replacement teeth of only the four most medial teeth (*D–H*). *H* shows a frontal view of the lower jaw beak, showing the four generations of replacement bands (R1–R4) of stacked dentine that will form the adult beak. The asterisk denotes the retained first-generation teeth at the beak surface; black arrows denote the symphysis between the left and right halves of the LJ (*D*, *G*, and *H*). Dentine tubules from living cells are present in first-generation teeth (*J*) and in replacement dentine bands (*L*, black arrowheads). (*N*) Optical projection tomography image of the juvenile *M. suvattii* beak in frontal view, showing the pink fluorescent bands of stacks of replacement dentine bands forming the beak. (Scale bar: 200 μm.) mc, Meckel's cartilage; mx, maxillary; pmx, premaxillary. Lengths are provided as either NL or standard length SL in mm of embryonic and juvenile *M. suvattii* (*A*, 3.6 mm NL; *B*, 3.75 mm NL; *C*, 4.8 mm SL; *D–F*, 5.6 mm SL; *G*, 8.5 mm SL; *H*, *I*, and *N*, 10.3 mm SL; *J–M*, 5.6 mm SL).

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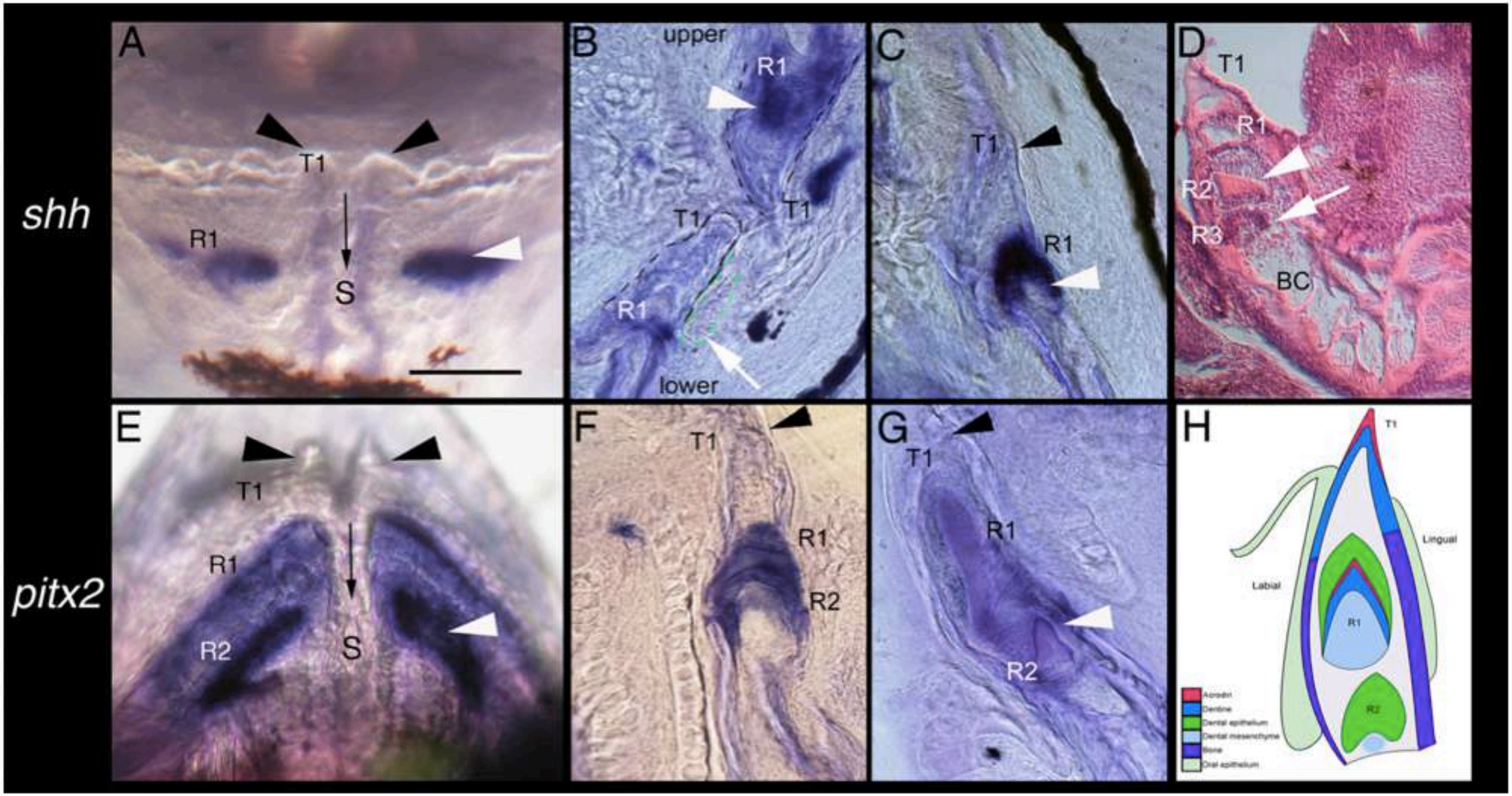

nové zuby se tvoří uvnitř kosti; zobák vzniká díky specifické zubní výměně 4 paraphyseálních zubů; novinkou je "jen" modifikace pozdní ontogeneze, geny stejné

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Formation of dermal skeletal and dental tissues in fish: a comparative and evolutionary approach

JEAN-YVES SIRE[1] and ANN HUYSSEUNE[2]

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[2] *Biology Department, Ghent University, Ledeganckstraat* 35, *B*-9000 *Ghent, Belgium* (e-mail: Ann.Huysseune@rug.ac.be)

viz též:

odontodou může být i zub!

...veškeré dentální i dermální tkáně jako modifikace archetypální odontody, ale pozor, ne vše je odontoda

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"šupina" - odontoda (žralok) vs.
"šupina" - scute na dermální kosti (ryba)

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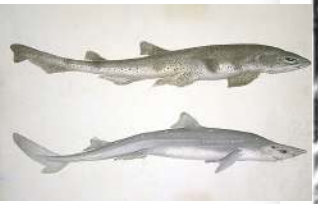


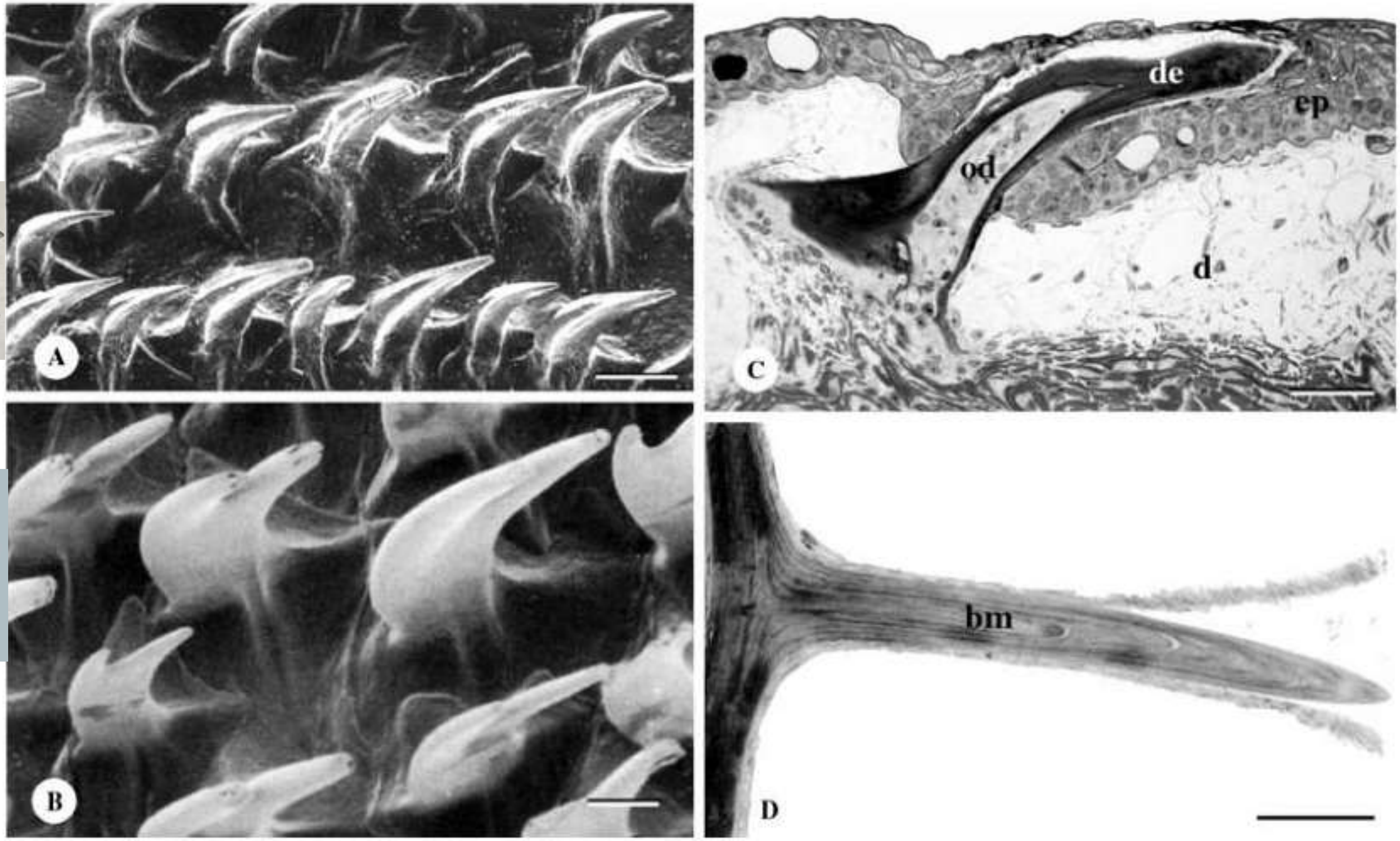
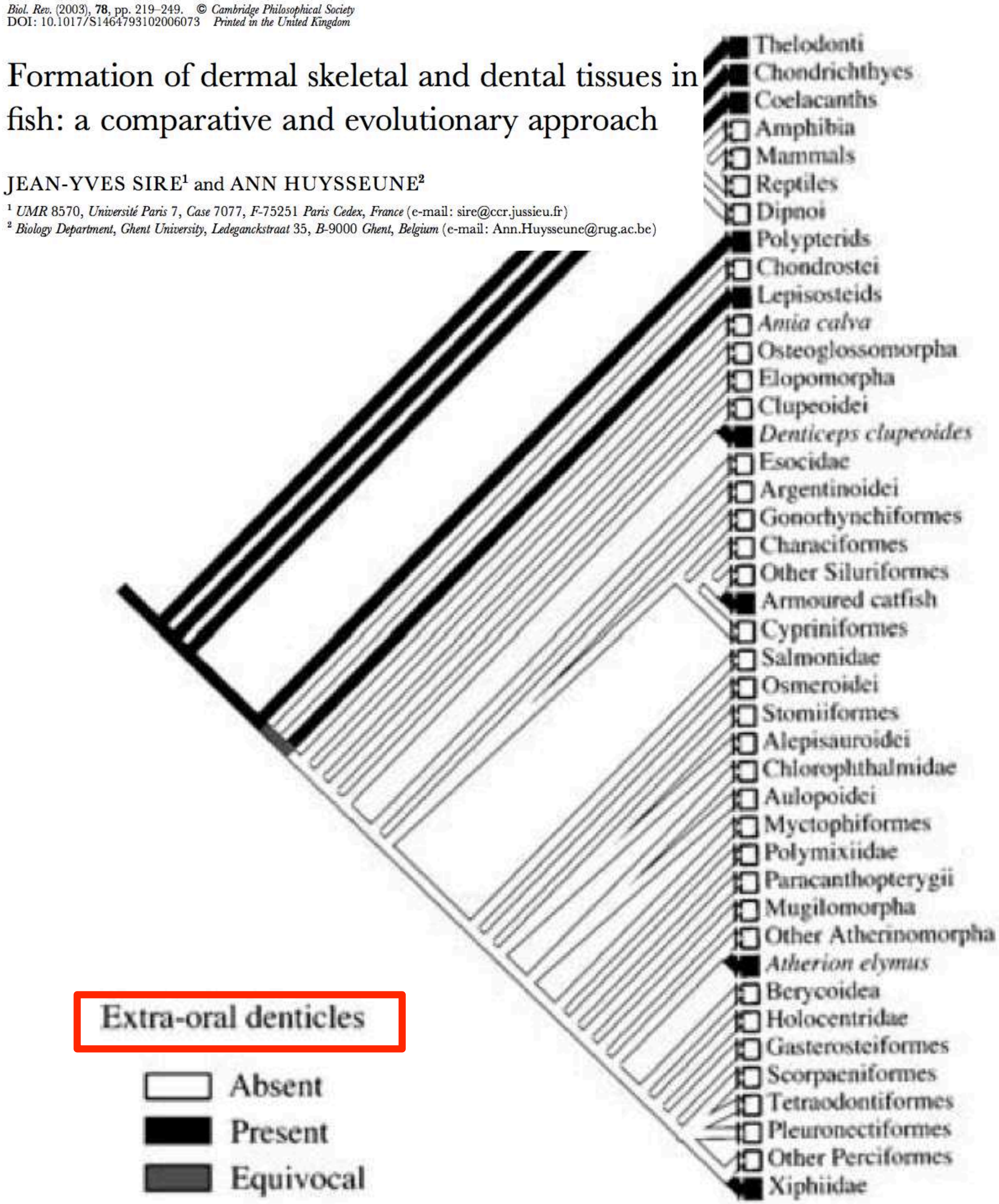


Fig. 1. Examples of homoplasy in the dermal skeleton: similarity in shape but difference in structure. (A, B) Scanning electron micrographs of (A) odontodes ornamenting the body surface of the catshark, *Scyliorhinus canicula*, and (B) postcranial dermal plates ornamenting the body surface of the gasterosteiform, *Notopogon xenosoma*. Note the similar shape and orientation. (C, D) 1-μm-thick sections of (C) an odontode of a 6-month-old embryo of *S. canicula*, and (D) a postcranial dermal plate in *N. xenosoma*. The odontode shows a dental structure whereas the scute is composed of bone matrix only. bm, bone matrix; d, dermis; de, dentine; ep, epidermis; od, odontoblast. Scale bars: A, B, D = 50 μm; C = 10 μm.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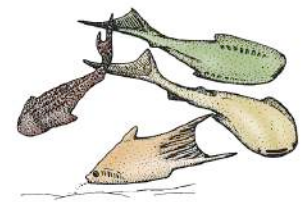
Odontody

(zde jako extra-oral denticles):

přítomny od nejstarších bezčelistnatých (Thelodonti),



zachovány u žraloků, lalokoploutvých, bichirů, kostlínů;

superficiální **"dentik(u)ly"** pak byly znovuzískány nezávisle u 4 linií teleostei.

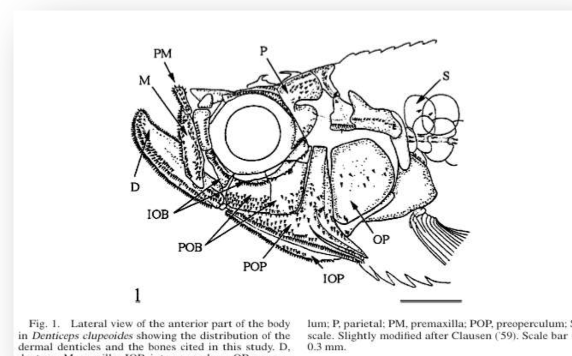
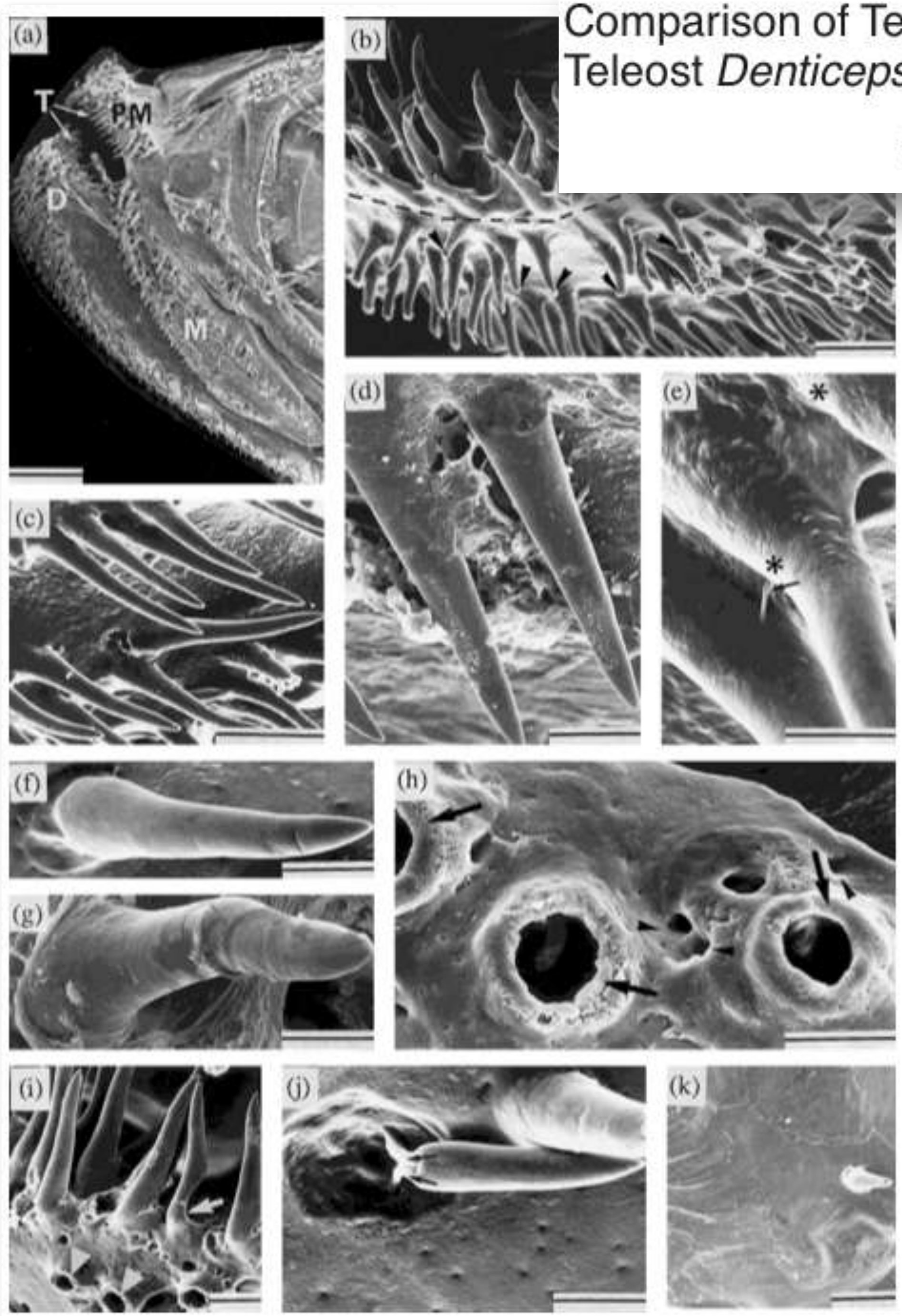
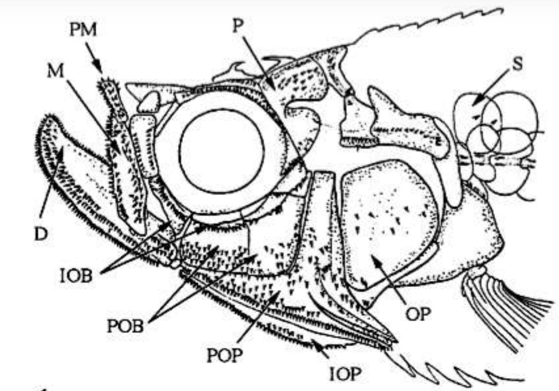


Fig. 1. Lateral view of the anterior part of the body in *Denticeps clupeoides* showing the distribution of the dermal denticles and the bones cited in this study. D, dentary; M, maxilla; IOP, interoperculum; OP, operculum; P, parietal; PM, premaxilla; POP, preoperculum; S, scale. Slightly modified after Clausen ('59). Scale bar = 0.3 mm.

Comparison of Teeth and Dermal Denticles (Odontodes) in the Teleost *Denticeps clupeoides* (Clupeomorpha)

JEAN-YVES SIRE,* STANISLAS MARIN, AND FRANÇOISE ALLIZARD
Université Paris 7-Denis Diderot and CNRS, URA 1137, Paris, France





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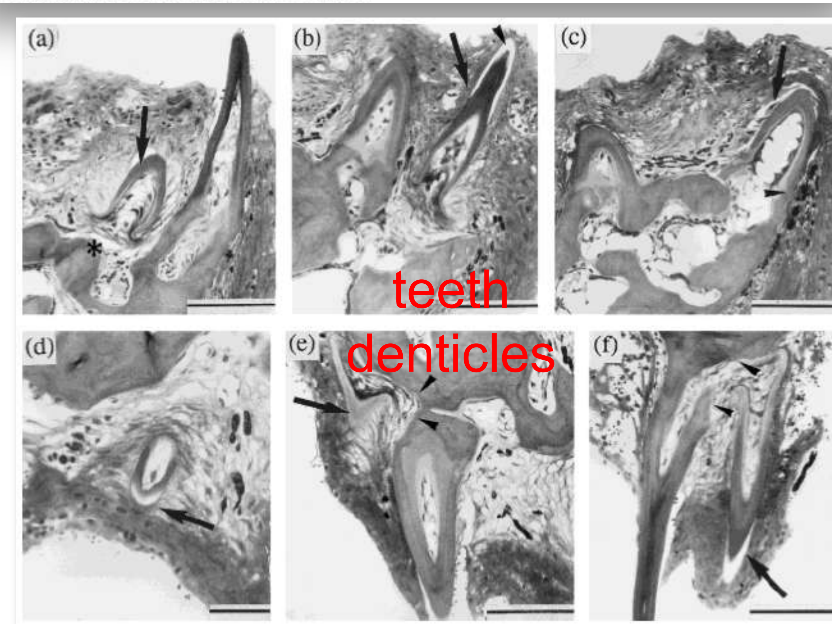

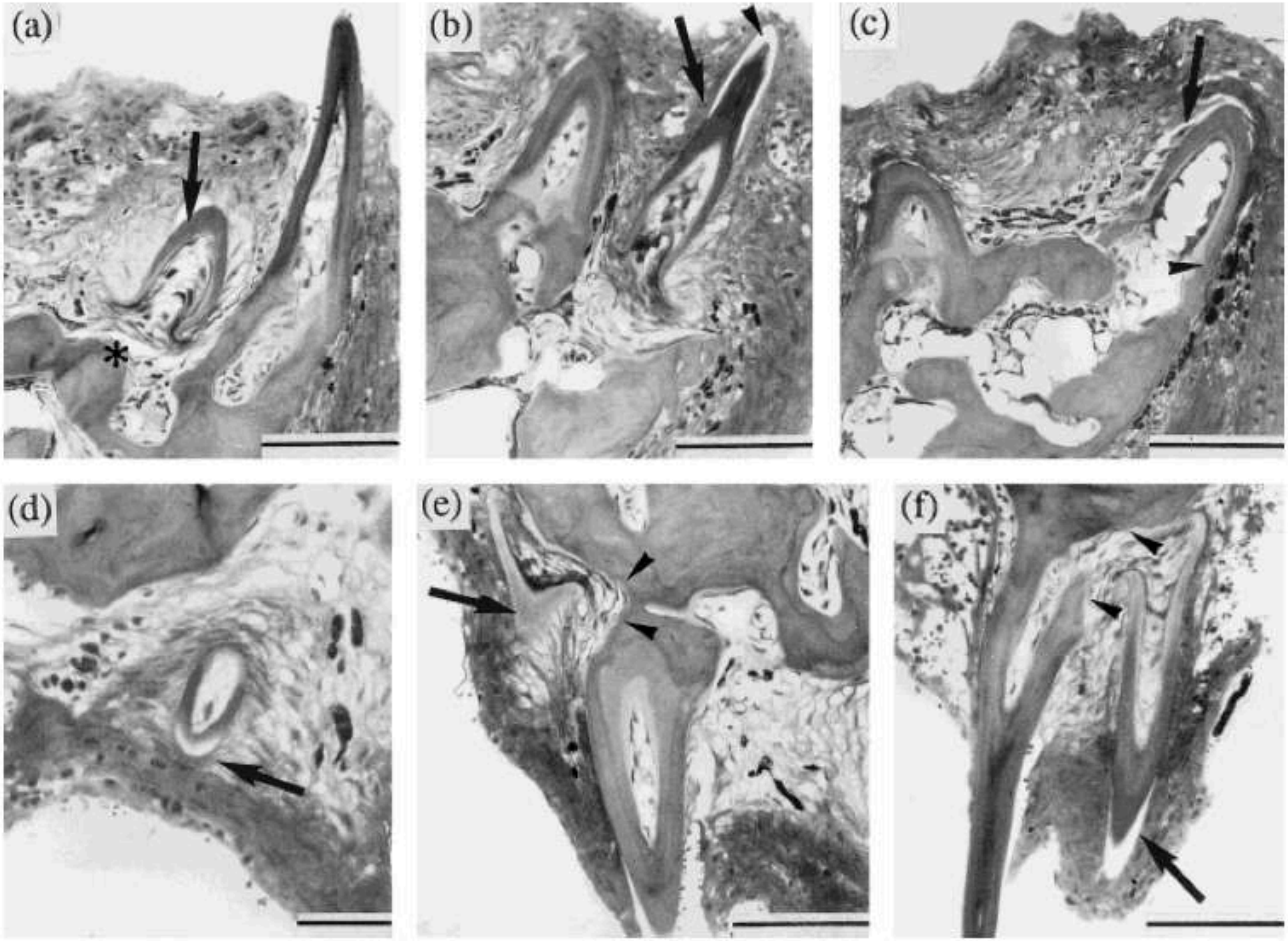

Fig. 4. *Denticeps clupeoides*. One-micron-thick transverse sections through the dentary as in Figure 3a illustrating three developmental stages of replacement teeth a–c and replacement denticles d–f. **a**: The dentine cone of this young tooth (arrow) is well formed. Its base is not mineralized and lies close to the dentary surface

ized. The limit between the attachment bone and the mineralized dentine is clear (arrowhead). Note the large network of cavities in the bone of this region. **d**: Young denticle developing its dentine cone. The cap matrix has been demineralized (arrow). **e**: Base of the dentine cone of a young denticle (arrow). The denticle has elongated

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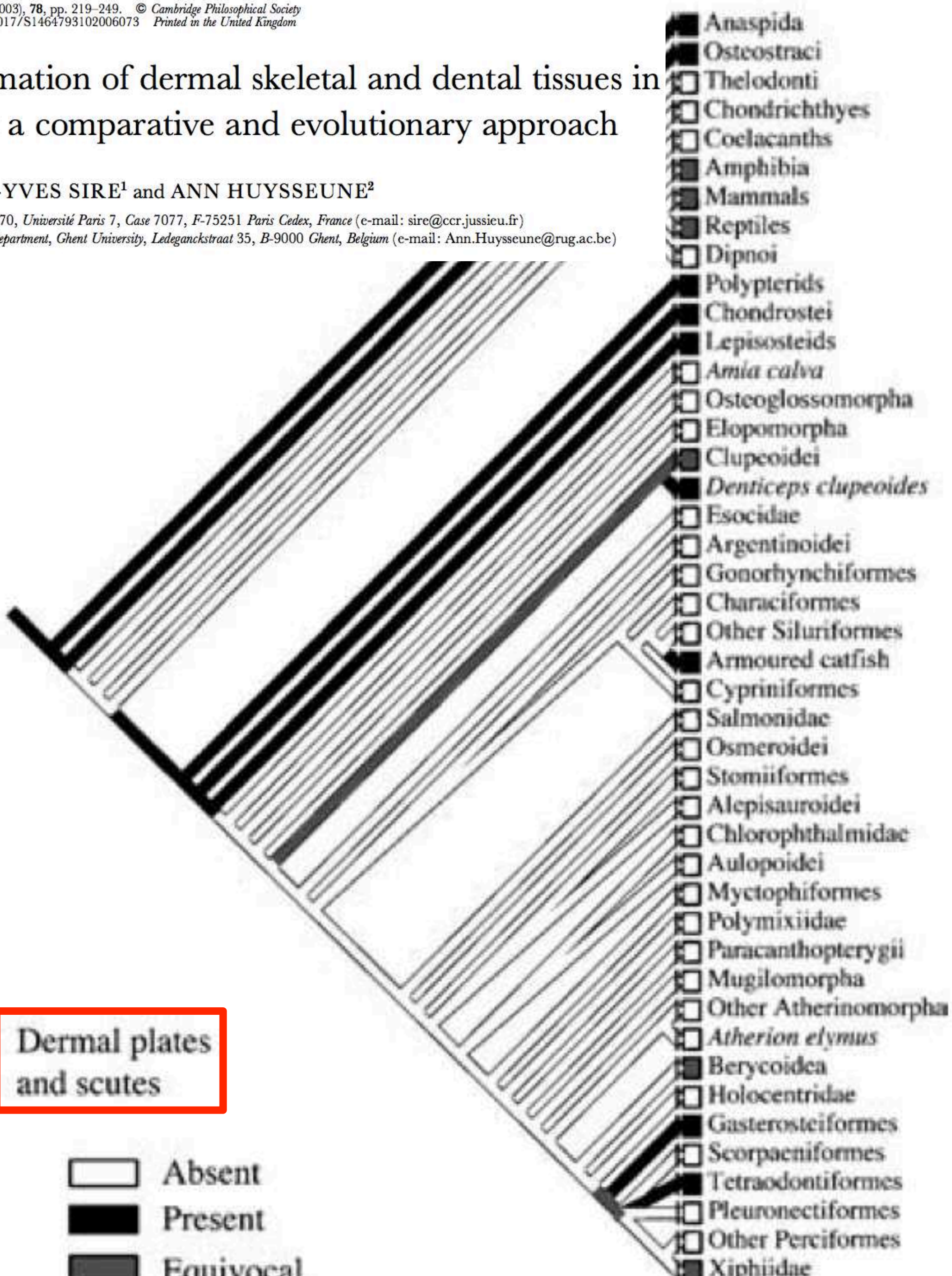
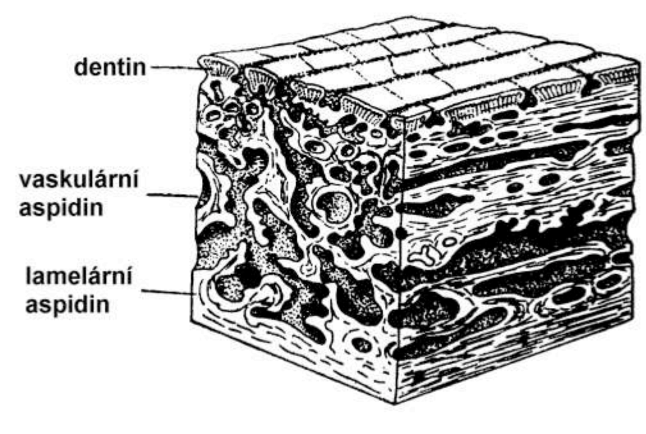


Dermální (hlavně trupové) krunýře: přítomny od nejstarších bezčelistnatých (Anaspida, Osteostraci), uchovány u bazálních ryb a zřejmě i u tetrapod;

šupiny (*scutes*) a podobné trupové štíty u teleostei jsou považovány za fylogeneticky nepříbuzné původním dermálním plátům.



Obr. 110 Schema stavby acelulárního dermálního štítu primitivních obratlovců (Cyclostomata, Placodermi). Podle Ørviga a Kiaera, z Jarvika (1980).

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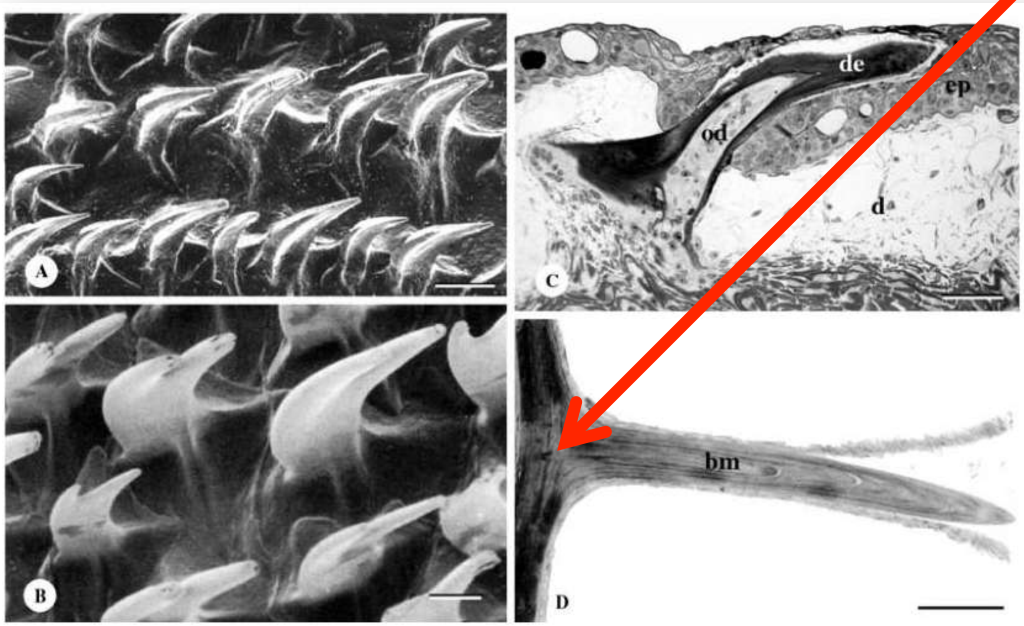

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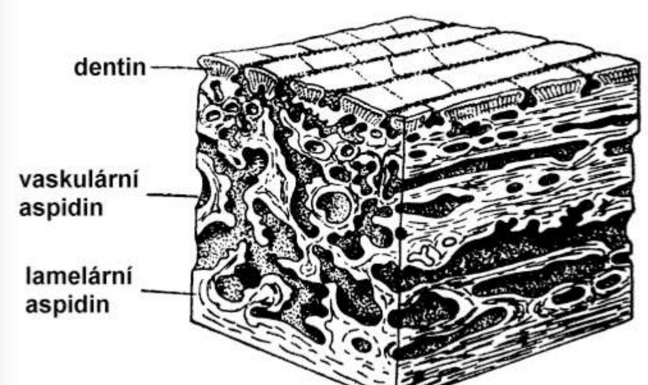

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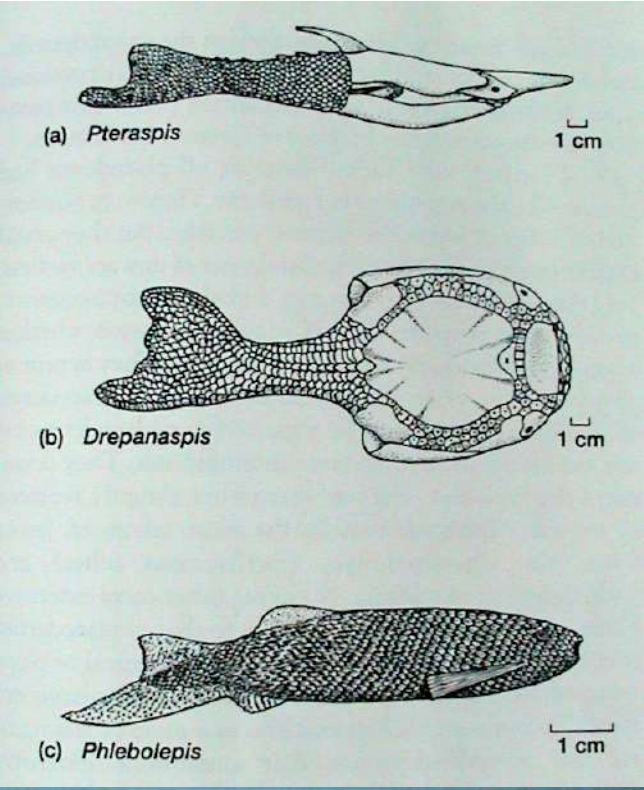
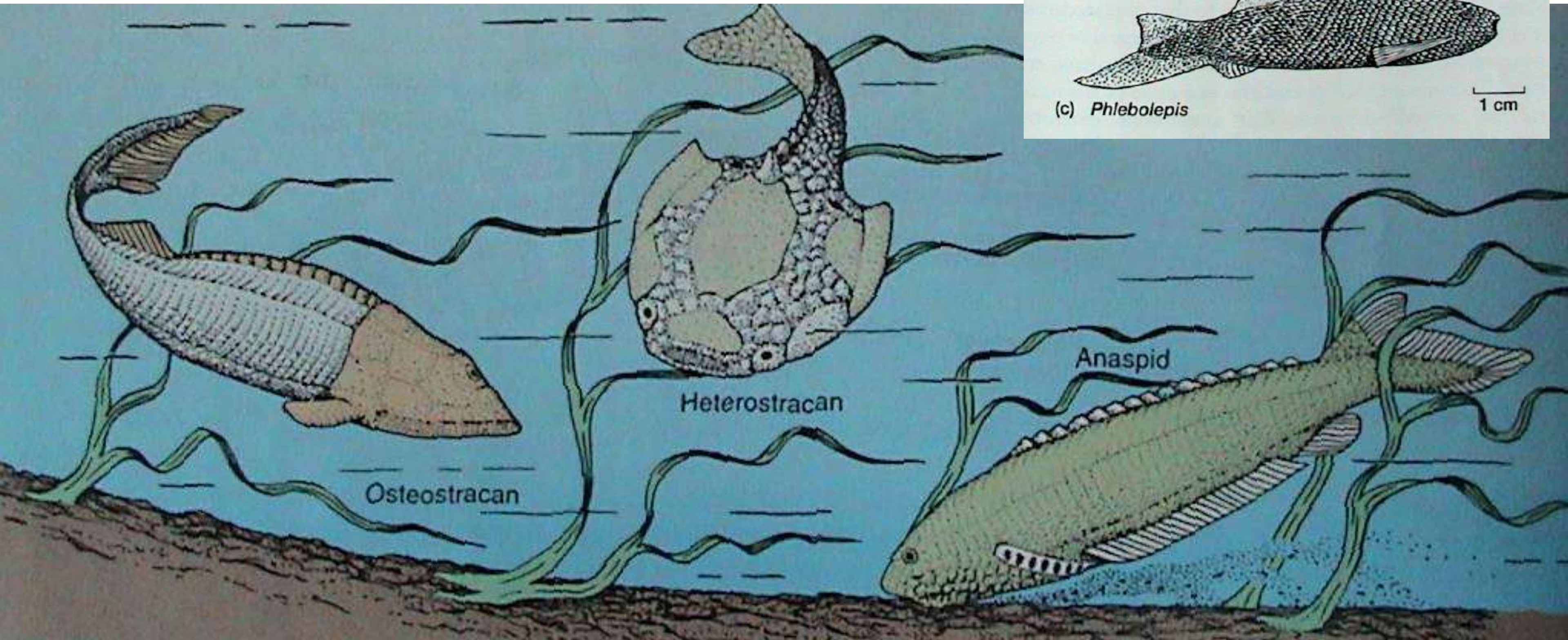
Nejstarší obratlovci (Agnatha)

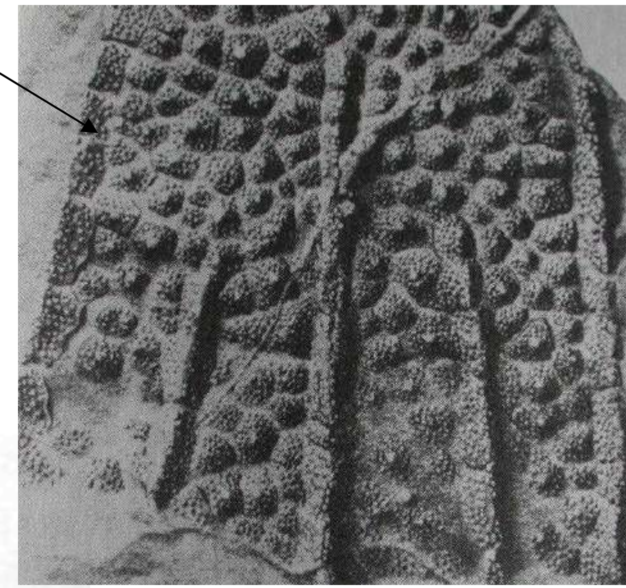
Ostracodermi - štítnatci (Ca-De):
sběrná skupina - několik linií (Pteraspida, Anaspida, “Thelodonta”)

kostní krunýř: bentičntí ? mikrofágové

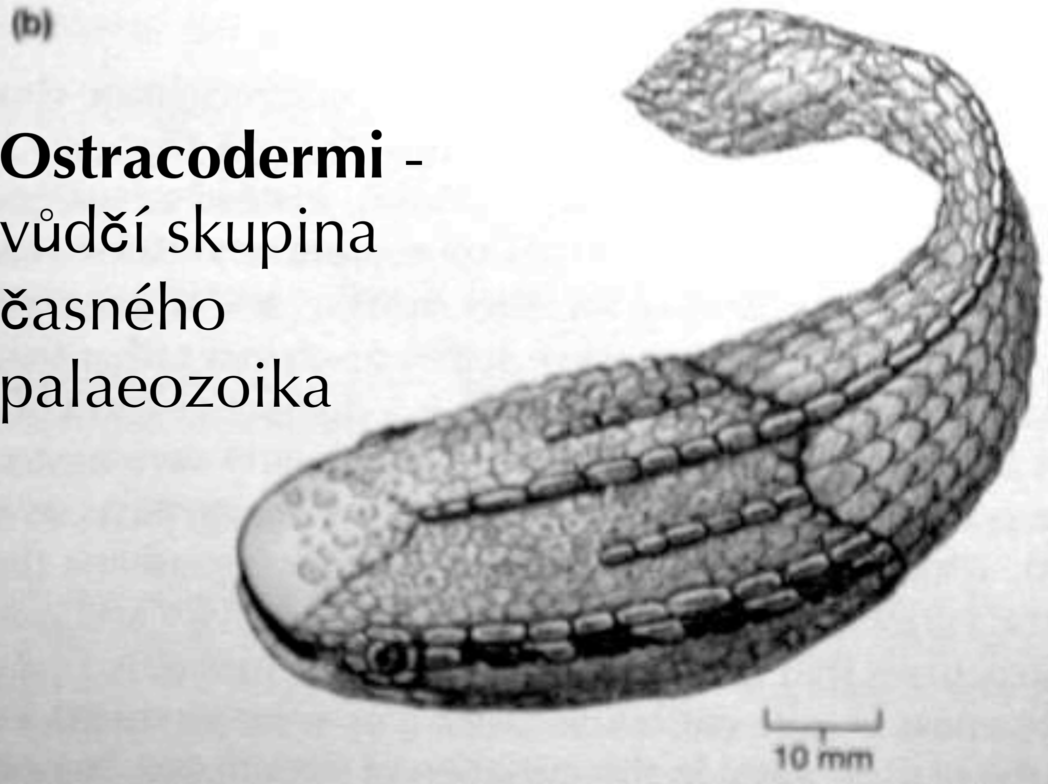




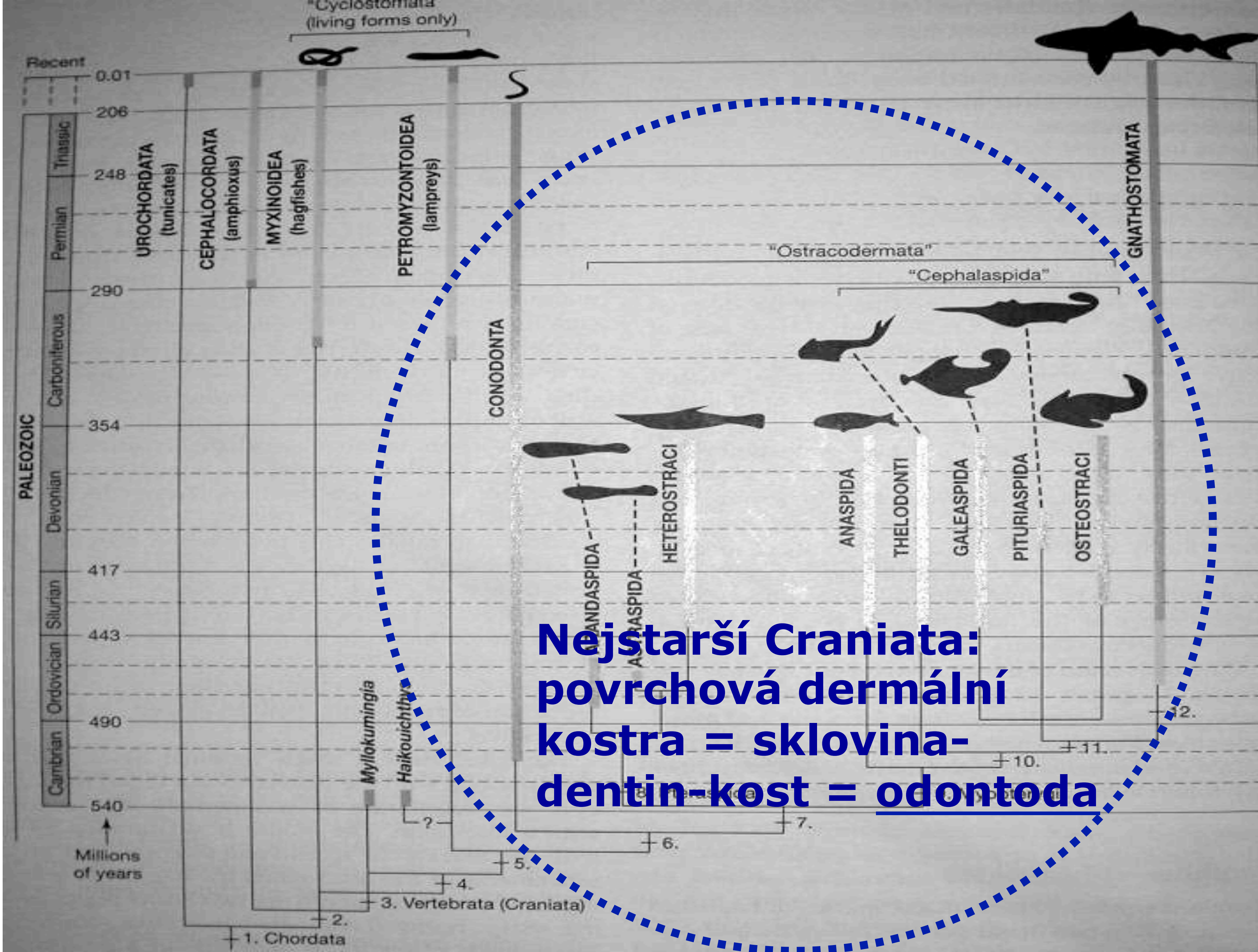
Dermální skelet - odontody:
„sklovina“- dentin - kost:



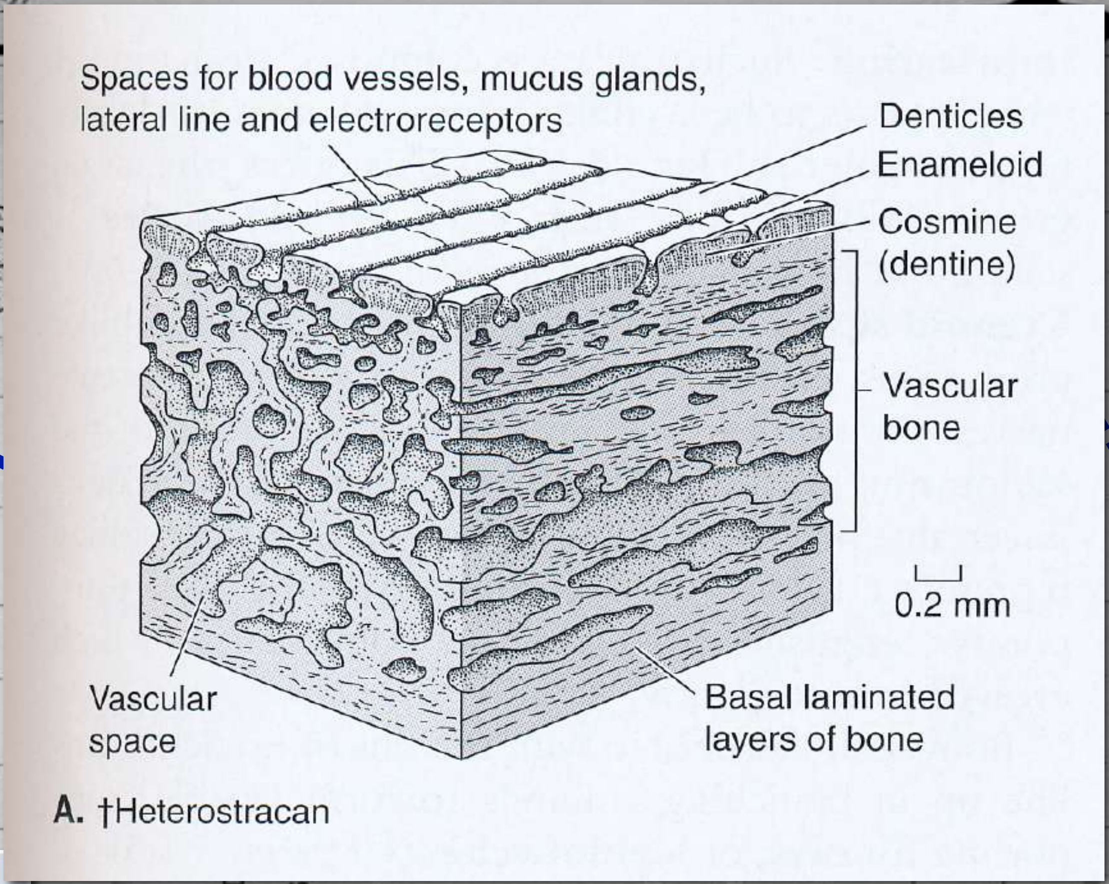
Ostracodermi -
vůdčí skupina
časného
palaeozoika

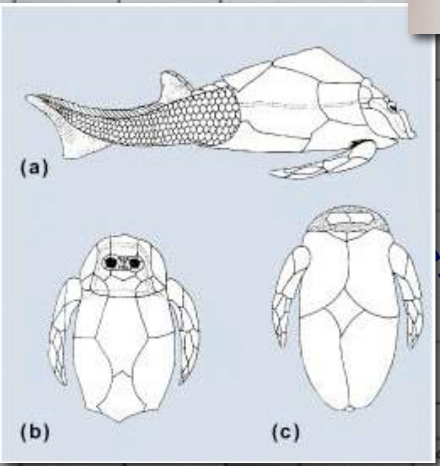


Astaraspis sp.
(Pteraspidomorpha),
N. Am - Ordovik



Nejstarší Craniata: povrchová dermální kostra = sklovina-dentin-kost = odontoda





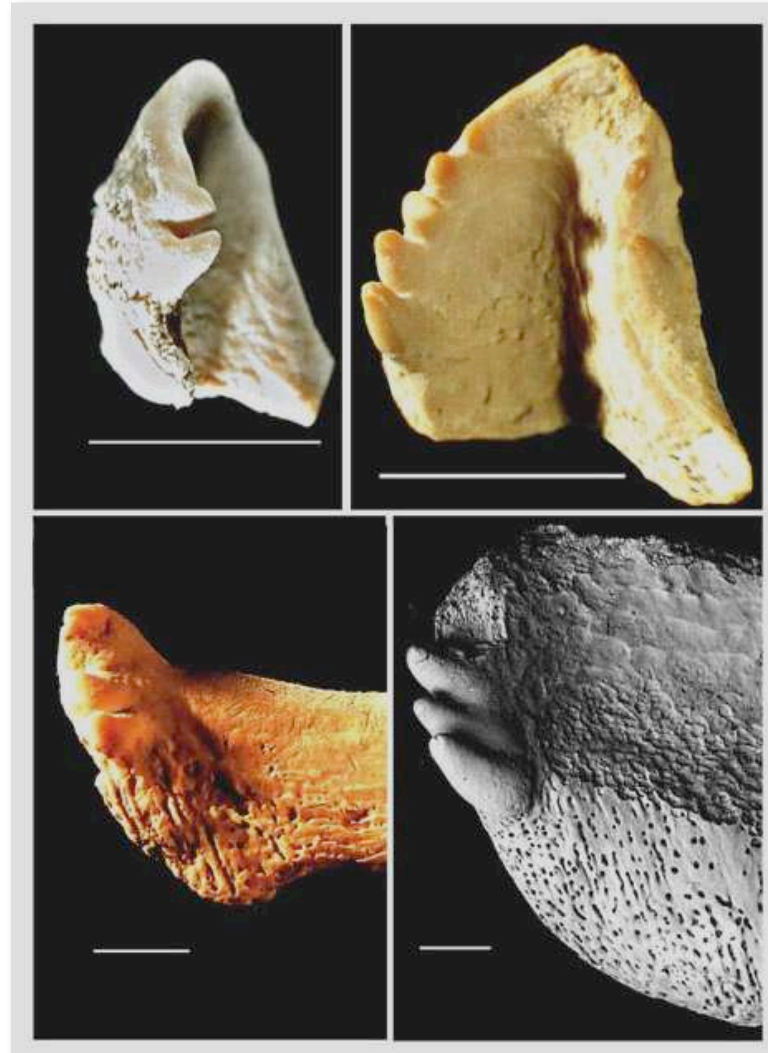
Nejstarší Craniata: povrchová dermální kostra = sklovina-dentin-kost

Placodermi - pancířnatí

acelulární kost, mohutné štíty, <u>**pravé zuby**</u>?!?

Tooth evolution:

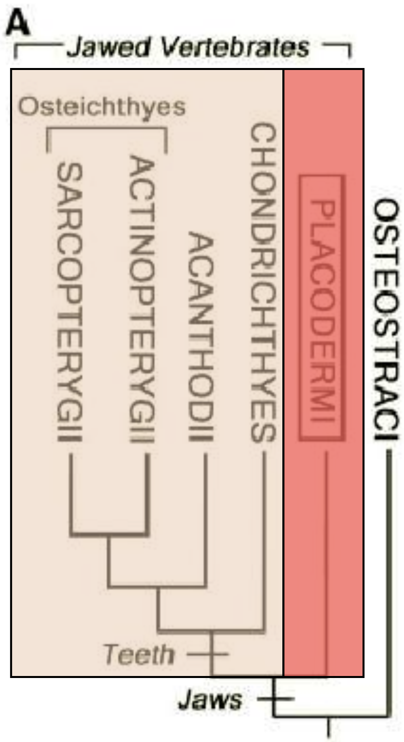
. . . several times & independently?

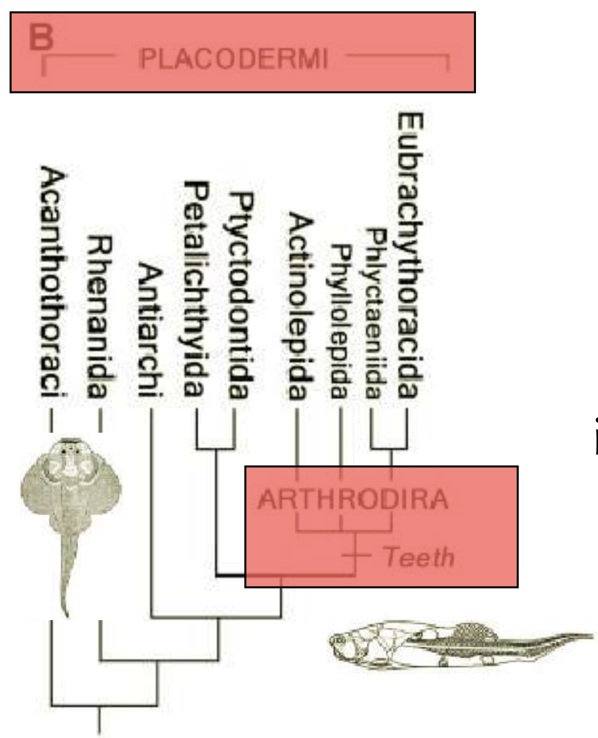


SCIENCE VOL 299 21 FEBRUARY 2003

Separate Evolutionary Origins of Teeth from Evidence in Fossil Jawed Vertebrates

Moya Meredith Smith[1]* and Zerina Johanson[2]



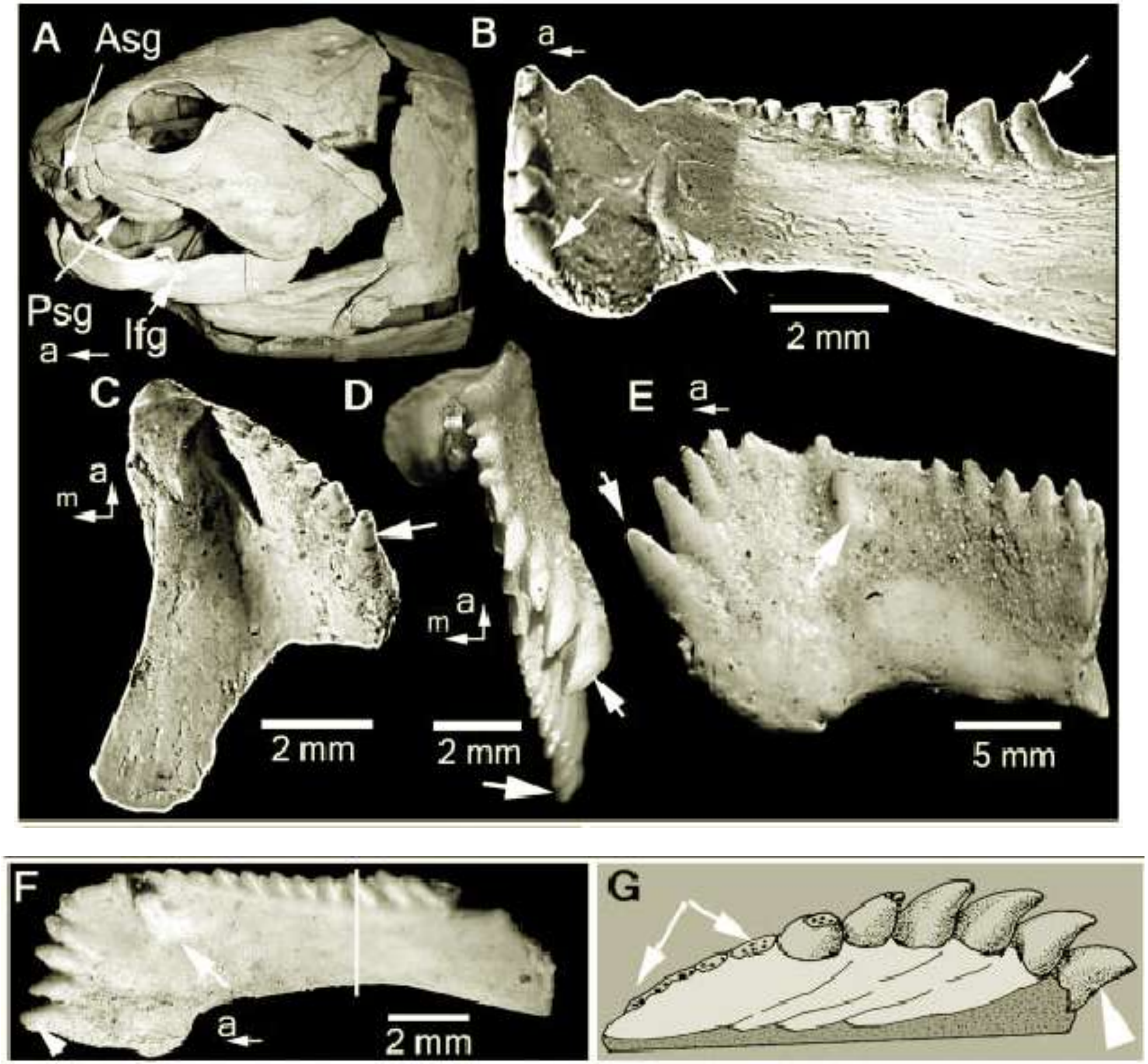


Dual origin of teeth ?!?

In Arthrodira, derived placoderms, teeth are suggested to develop independently and are not homologous to other "real teeth" of jawed vertebrates... WTF?

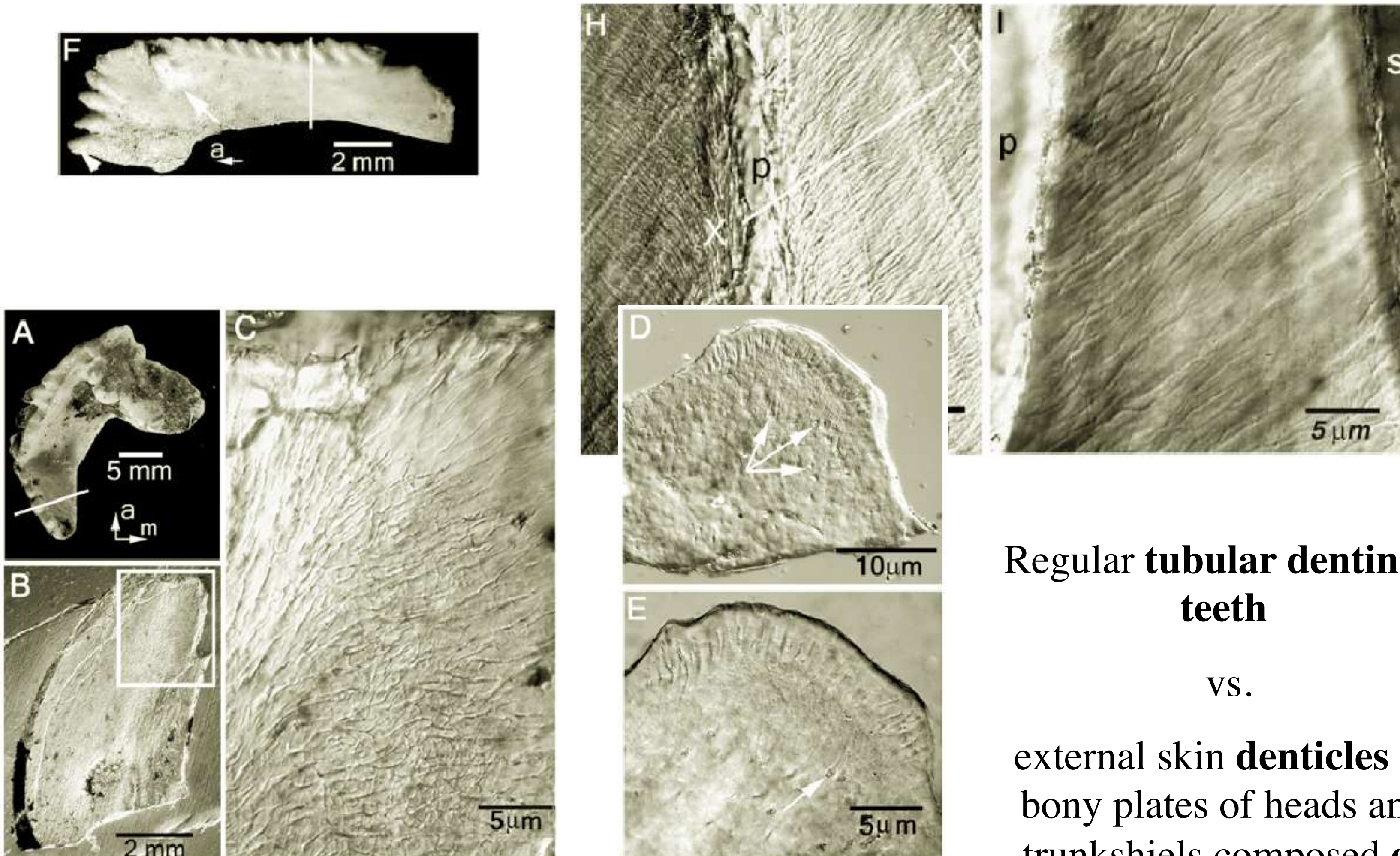
Some placoderms have upper and lower dental plates with "teeth"

Placodermi: Eubrachythoracida (*Eastmanosteus* sp., *Gogopiscis* sp., *Compagopiscis* sp.)



- New teeth are described to be organized and being added to recognizable rows on each dental plate!
- thus, tooth development was patterned and regulated!
- therefore, teeth should develop from teeth-primordia, being regulated in space and time by tooth-specific tisuues!
- dental lamina?!?

These teeth are composed of **regular** (=gnathostome type) **dentine,** formed from cells within a pulp cavity (*contrary to accepted opinions*)

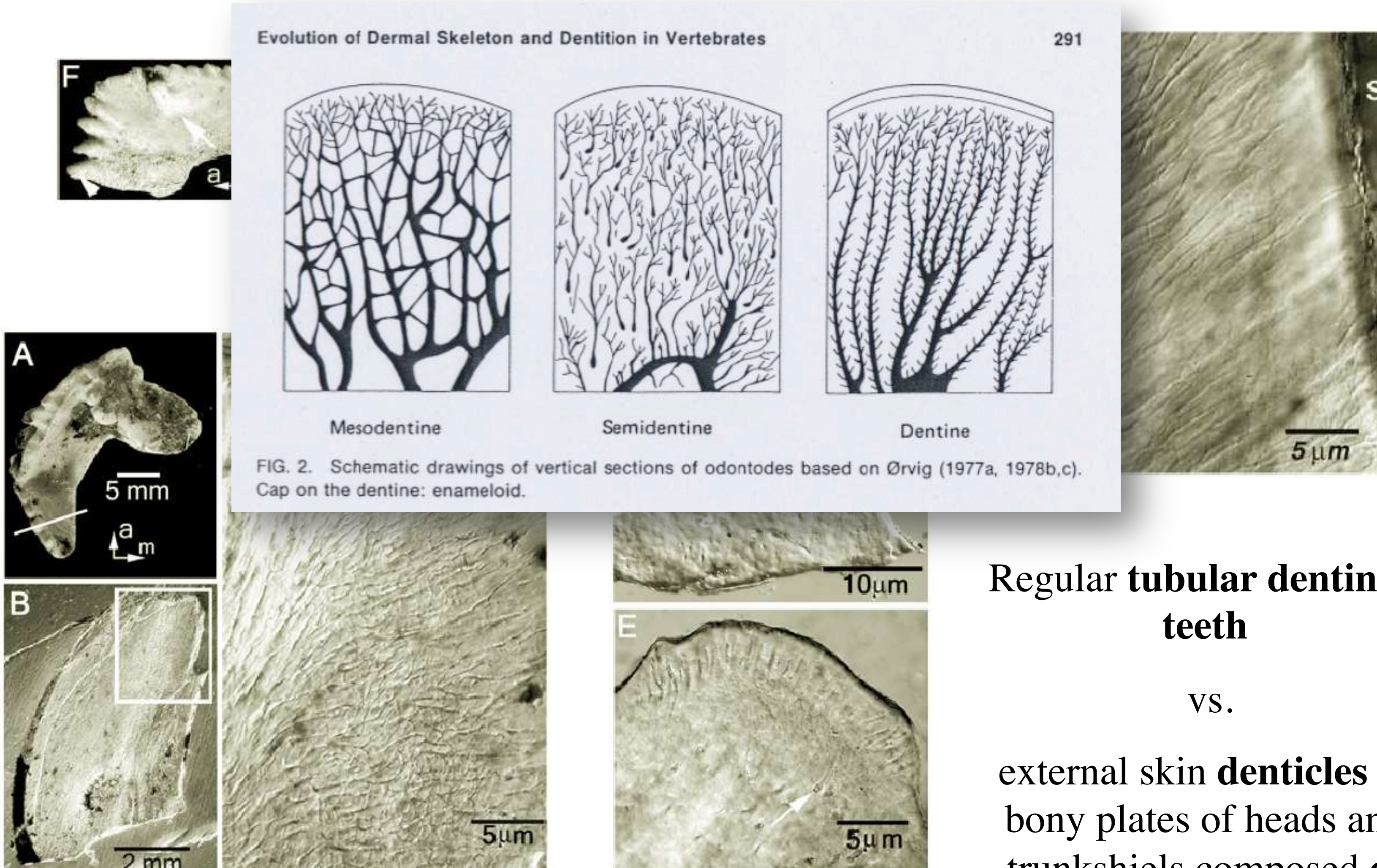


Regular **tubular dentin of teeth**

vs.

external skin **denticles** or bony plates of heads and trunkshiels composed **of semidentine/mesodentine**

These teeth are composed of **regular** (=gnathostome type) **dentine** formed from cells within a pulp cavity (contrary to accepted opinions)



Regular **tubular dentin of teeth**

vs.

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SCIENCE VOL 299 21 FEBRUARY 2003

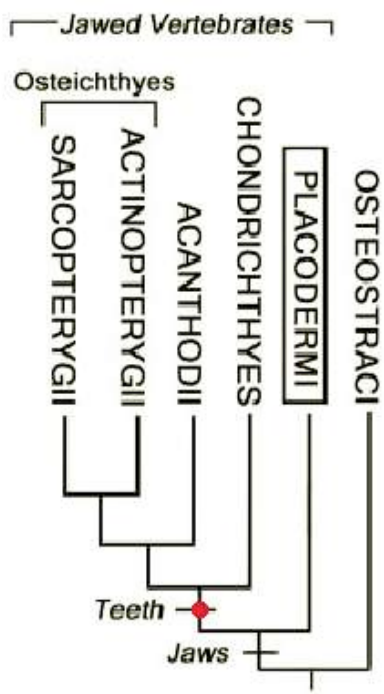
Separate Evolutionary Origins of Teeth from Evidence in Fossil Jawed Vertebrates

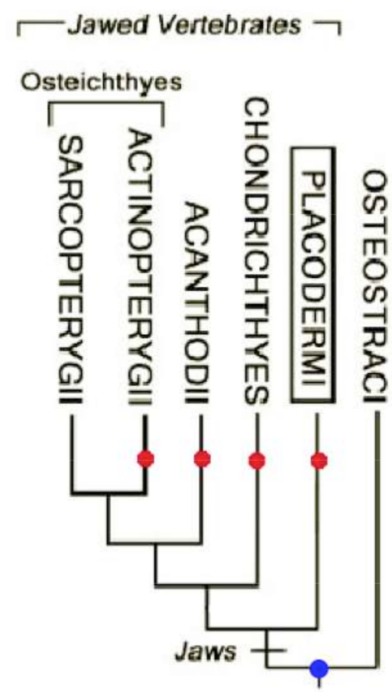
Moya Meredith Smith[1]* and Zerina Johanson[2]

Arthrodira teeth develop and are regulated as in other jawed vertebrates,

because Arthrodira are among derived placoderms, teeth evolved at least twice (as it was argued in this paper!)

kolikrát vznikly či mohly vzniknout zuby ?!?





LETTER

doi:10.1038/nature11555

Development of teeth and jaws in the earliest jawed vertebrates

Martin Rücklin[1], Philip C. J. Donoghue[1], Zerina Johanson[2], Kate Trinajstic[3,4], Federica Marone[5] & Marco Stampanoni[5,6]

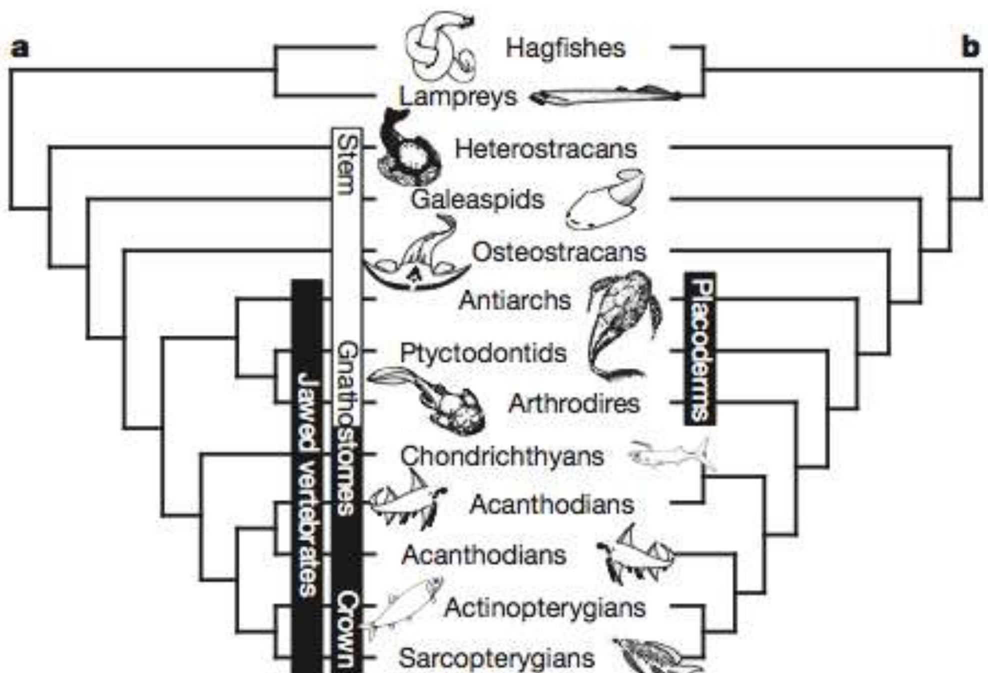


Figure 1 | Evolutionary relationships of principal groups of vertebrates. **a, b**, Phylogenetic relationships among the principal groups of stem and crown gnathostomes. The traditional view of placoderm monophyly[27,28] (**a**) versus the more recent hypothesis of placoderm paraphyly[4] (**b**).

LETTER

doi:10.1038/nature11555

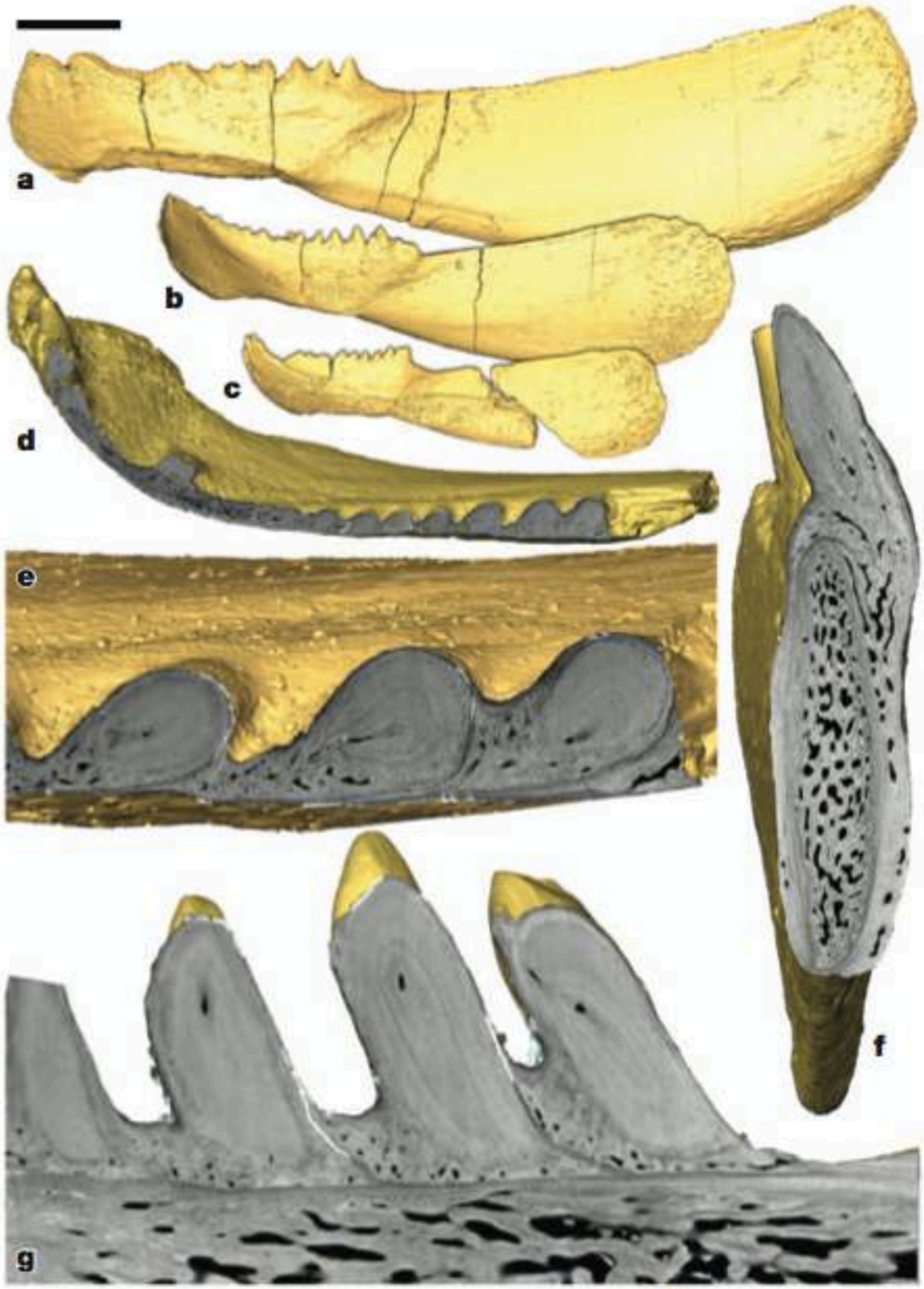
Development
vertebrates

Martin Rücklin[1], Philip C. J. Donog

a

tooth-like structures[9–11] or that they possess true teeth[12]. Here we use synchrotron radiation X-ray tomographic microscopy (SRXTM)[13] of a developmental series of *Compagopiscis croucheri* (Arthrodira) to show that placoderm jaws are composed of distinct cartilages and gnathal ossifications in both jaws, and a dermal element in the lower jaw. The gnathal ossification is a composite of distinct teeth that developed in succession, polarized along three distinct vectors, comparable to tooth families. The teeth are composed of dentine and bone, and show a distinct pulp cavity that is infilled centripetally as development proceeds. This pattern is repeated in other placoderms, but differs from the structure and development of tooth-like structures in the postbranchial lamina and dermal skeleton of *Compagopiscis* and other placoderms. We interpret this evidence to indicate that *Compagopiscis* and other arthrodires possessed teeth, but that tooth and jaw development was not developmentally or structurally integrated in placoderms. Teeth did not evolve convergently among the extant and extinct classes of early jawed vertebrates but, rather, successional teeth evolved within the gnathostome stem-lineage soon after the origin of jaws. The chimaeric developmental origin of this model of modularity reflects the distinct evolutionary origins of teeth and of component elements of the jaws.

Figu
a, b,
gnatl
more



LETTER

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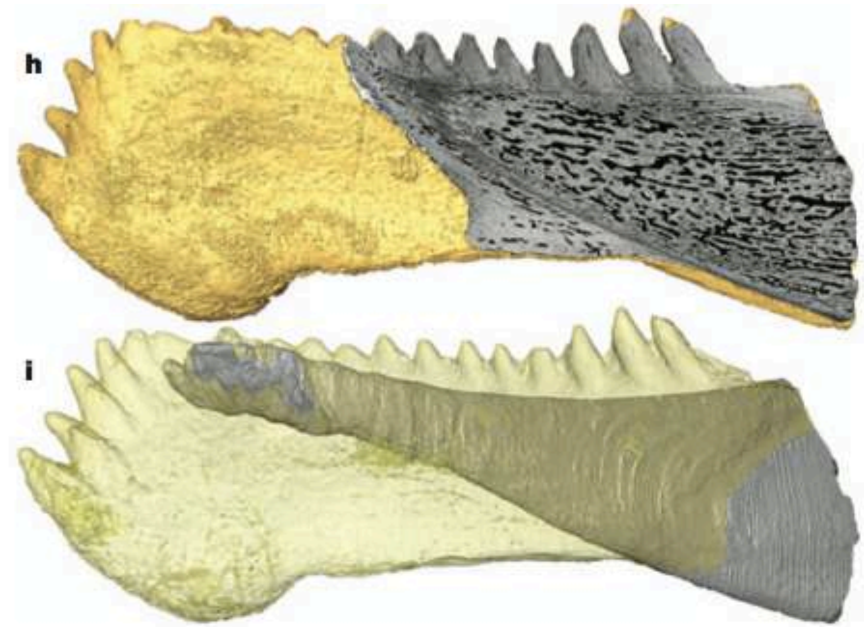
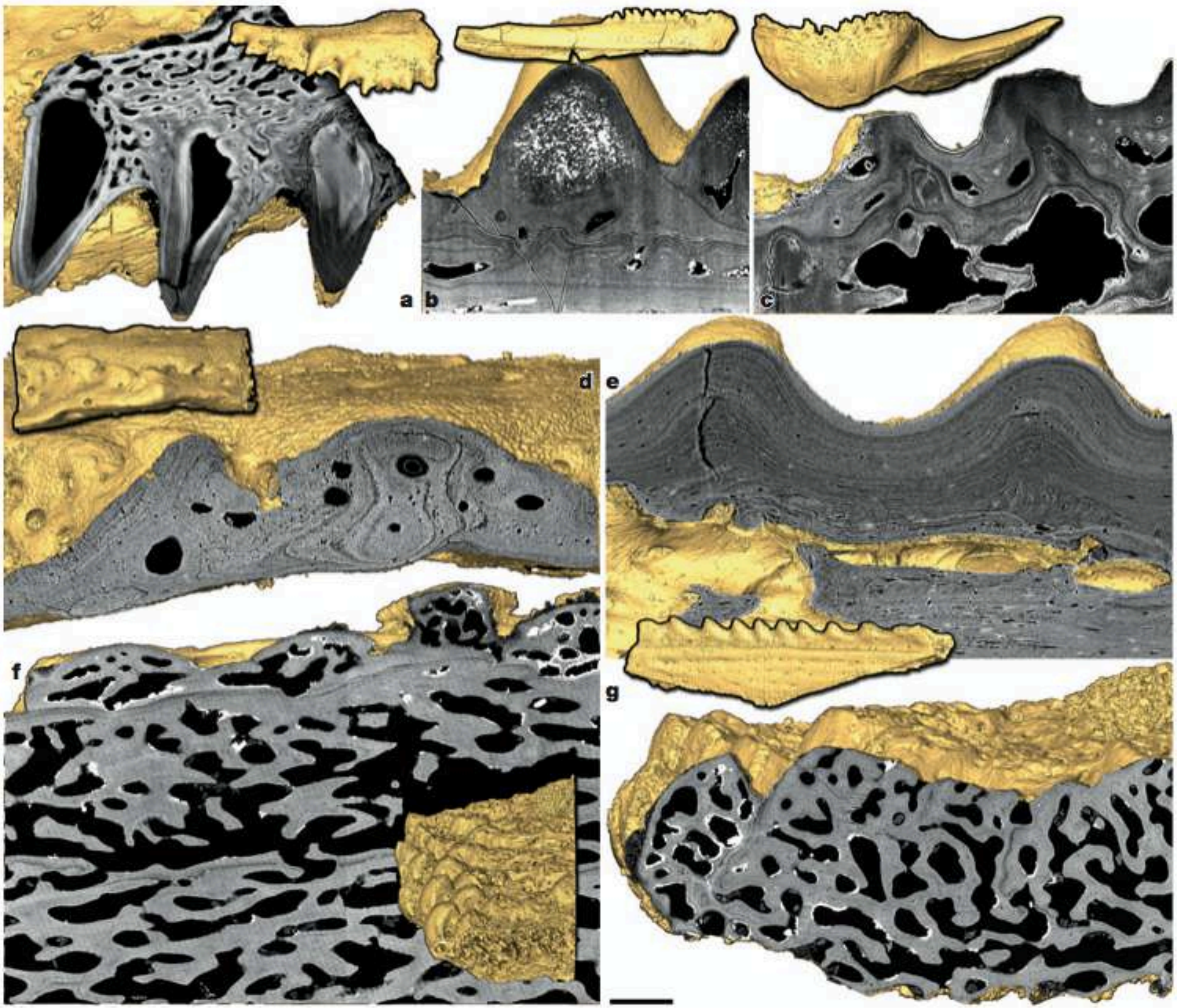


Figure 2 | Lower-jaw element of *Compagopiscis croucheri*, Late Devonian period, Australia. **a–c**, microCT data; **d–i**, SRXTM data. Volume rendering of jaws and teeth (**a–c**, **i**) and surface cut (**d–h**). Ontogenetic sequence in lateral view (**a**) NHMUK PV P.50948, (**b**) NHMUK PV P.50943 and WAM 91.4.3 (**c**). Teeth and jaw ossifications WAM 91.4.3: horizontal section (**d**, **e**), vertical section (**f**), longitudinal section (**g**, **h**) and labelled sclerochronology as virtual dental ossification (transparent) and bony shaft (shaded, **i**). Scale bar in **a** represents 2 mm (**a–c**), 1 mm (**d**, **h**, **i**), 240 μm (**f**), 400 μm (**e**, **g**).

svrchní čelist (*C. croucheri*) 2x spodní čelist



D: "tubercles", marginální dermální deska (*C. croucheri*)

E: "marginal cusps", hřeben prsní ploutve

F,G: "tooth-like cusps", postbranchiální lamina

Journal of Vertebrate Paleontology 23(4):987–990, December 2003

RAPID COMMUNICATION

DID PLACODERM FISH HAVE TEETH?

GAVIN C. YOUNG
Geology Dept., Australian National University, Canberra, ACT, Australia

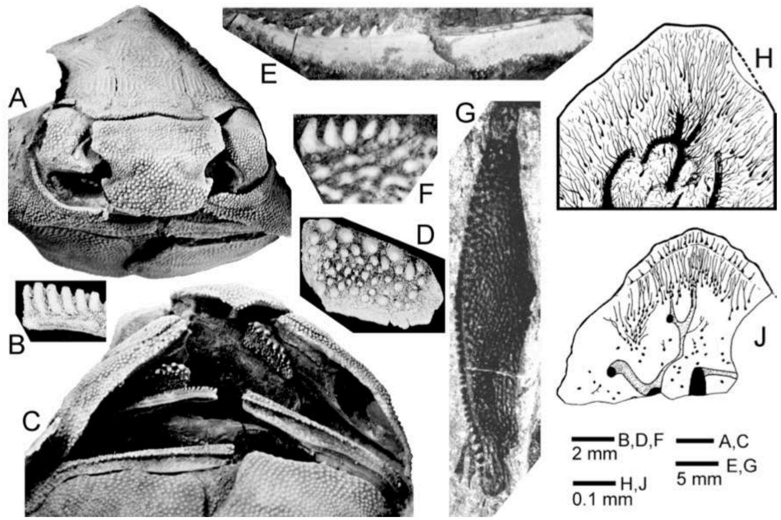
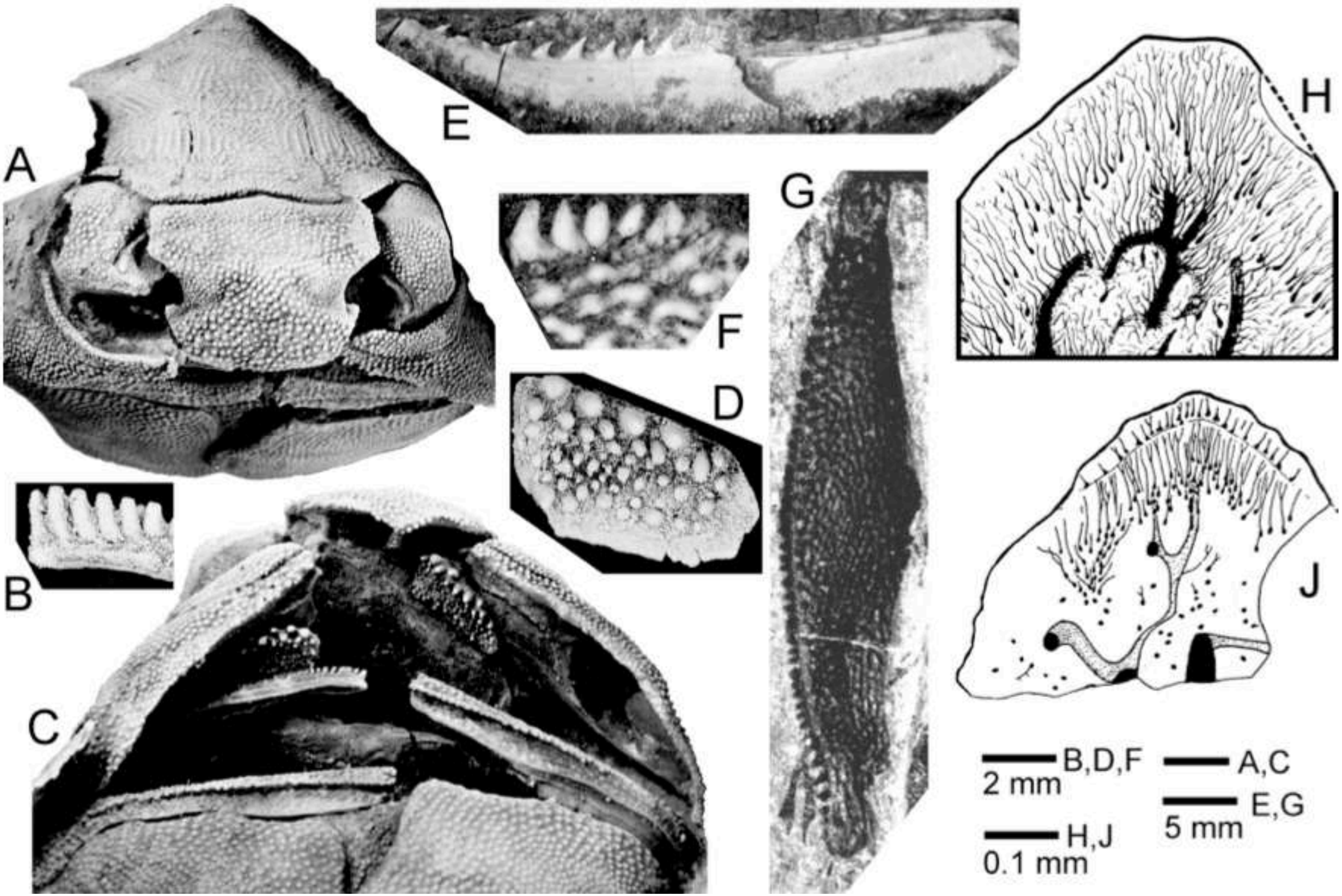


FIGURE 1. **A–D**, articulated 'buchanosteid' arthrodire, ANU V244, at a more advanced stage of acid preparation than previously figured (Young et al., 2001:figs. 2, 3C, 4D). Head and anterior trunk armor in anterior (**A**) and ventral (**C**) views. **B**, labial view of first six denticles on the left lower jawbone (infragnathal; removed from preserved position). **D**, occlusal view of upper jawbone (left anterior supragnathal; removed from preserved position). **E**, spinal plate, phlyctaeniid arthrodire from the Lashly Mountains, South Victoria Land, Antarctica (ANU V890). **F**, denticles on the armored pectoral fin of *Bothriolepis* sp., southern Boomerang Range, South Victoria Land, Antarctica (ANU V2255). **G**, lateral denticles on a complete lateral marginal plate from the pectoral fin of *Bothriolepis perija* Young and Moody, 2002 (Upper Devonian, Sierra de Perijá, western Venezuela). **H**, special placoderm hard tissue semidentine (pear-shaped cell spaces) in an oral denticle ('tooth') of *Phlyctaenius* [modified from Denison (1978; after Ørvig, 1967)]. **J**, semidentine in a dermal tubercle of *Phlyctaenius* [modified from Burrow and Turner (1999; after Gross, 1957)].

Journal of Vertebrate Paleontology 23(4):987–990, December 2003



Journal of Vertebrate Paleontology 23(4):987–990, December 2003

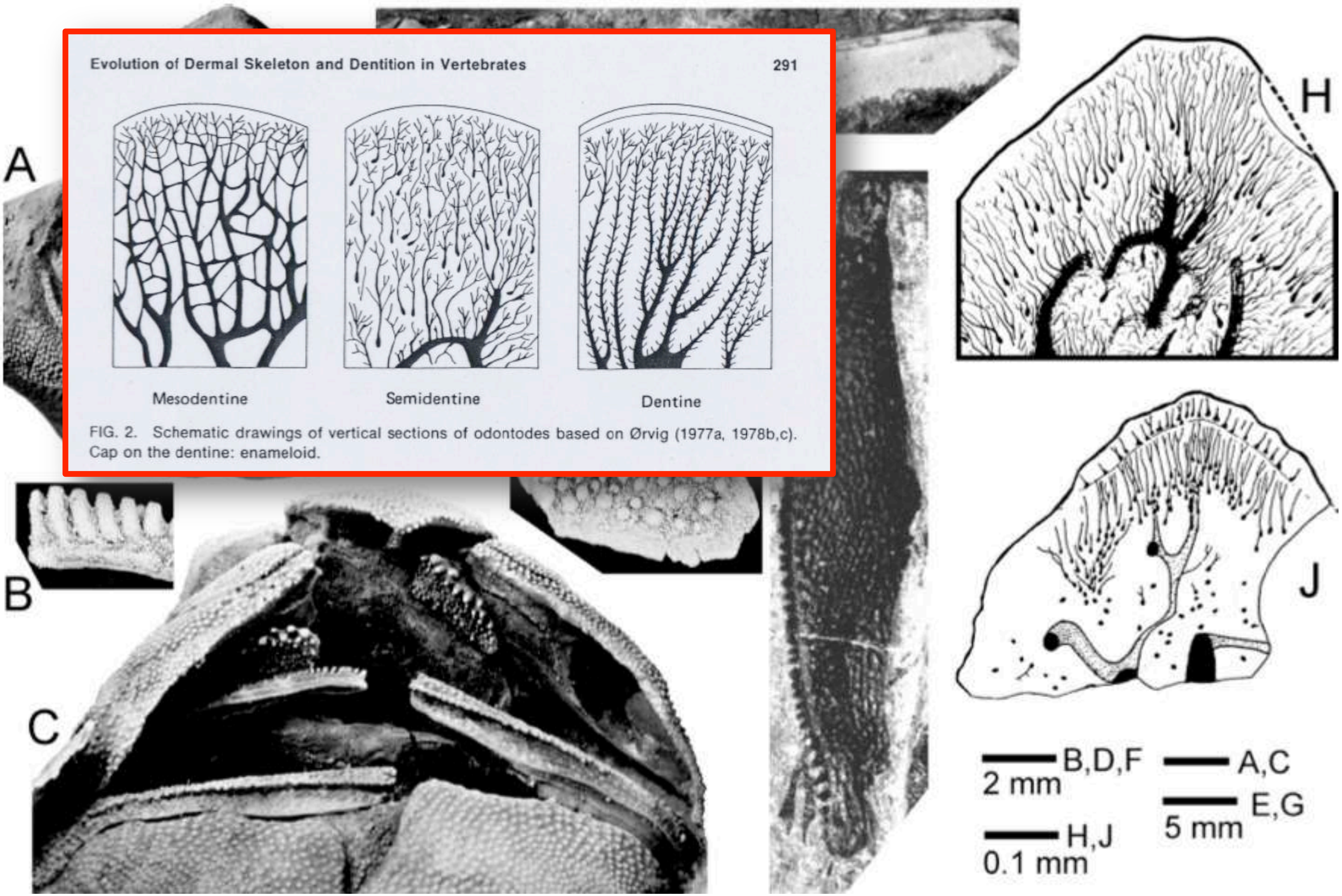


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FIG. 2. Schematic drawings of vertical sections of odontodes based on Ørvig (1977a, 1978b,c). Cap on the dentine: enameloid.

The ins and outs of the evolutionary origin of teeth

Philip C. J. Donoghue,[a,*] and Martin Rücklin[a,b]

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SUMMARY The role of teeth and jaws, as innovations that underpinned the evolutionary success of living jawed vertebrates, is well understood, but their evolutionary origins are less clear. The origin of teeth, in particular, is mired in controversy with competing hypotheses advocating their origin in external dermal denticles ("outside-in") versus a de novo independent origin ("inside-out"). No evidence has ever been presented demonstrating materially the traditional "outside-in" theory of teeth evolving from dermal denticles, besides circumstantial evidence of a commonality of structure and organogenesis, and phylogenetic evidence that dermal denticles appear earlier in vertebrate phylogeny that do teeth. Meanwhile, evidence has mounted in support of "inside-out" theory, through developmental studies that have indicated that endoderm is required for tooth development, and fossil studies that have shown that tooth-like structures evolved before dermal denticles (conodont dental elements), that tooth replacement evolving before teeth (thelodont pharyngeal denticles), and that teeth evolved many times independently through co-option of such structures. However, the foundations of "inside-out" theory have been undermined fatally by critical reanalysis of the evidence on which it was based. Specifically, it has been shown that teeth develop from dermal, endodermal or mixed epithelia and, therefore, developmental distinctions between teeth and dermal denticles are diminished. Furthermore the odontode-like structure of conodont elements has been shown to have evolved independently of dermal and internal odontodes. The tooth-like replacement encountered in thelodont pharyngeal odontodes has been shown to have evolved independently of teeth and tooth replacement and teeth have been shown to have evolved late within the gnathostome stem lineage indicating that it is probable, if not definitive, that teeth evolved just once in gnathostome evolution. Thus, the "inside-out" hypothesis must be rejected. The phylogenetic distribution of teeth and dermal denticles shows that these odontodes were expressed first in the dermal skeleton, but their topological distribution extended internally in association with oral, nasal and pharyngeal orifices, in a number of distinct evolutionary lineages. This suggests that teeth and oral and pharyngeal denticles emerged phylogenetically through extension of odontogenic competence from the external dermis to internal epithelia. Ultimately, internal and external odontodes appear to be distinct developmental modules in living jawed vertebrates, however, the evidence suggests that this distinction was not established until the evolution of jawed vertebrates, not merely gnathostomes.

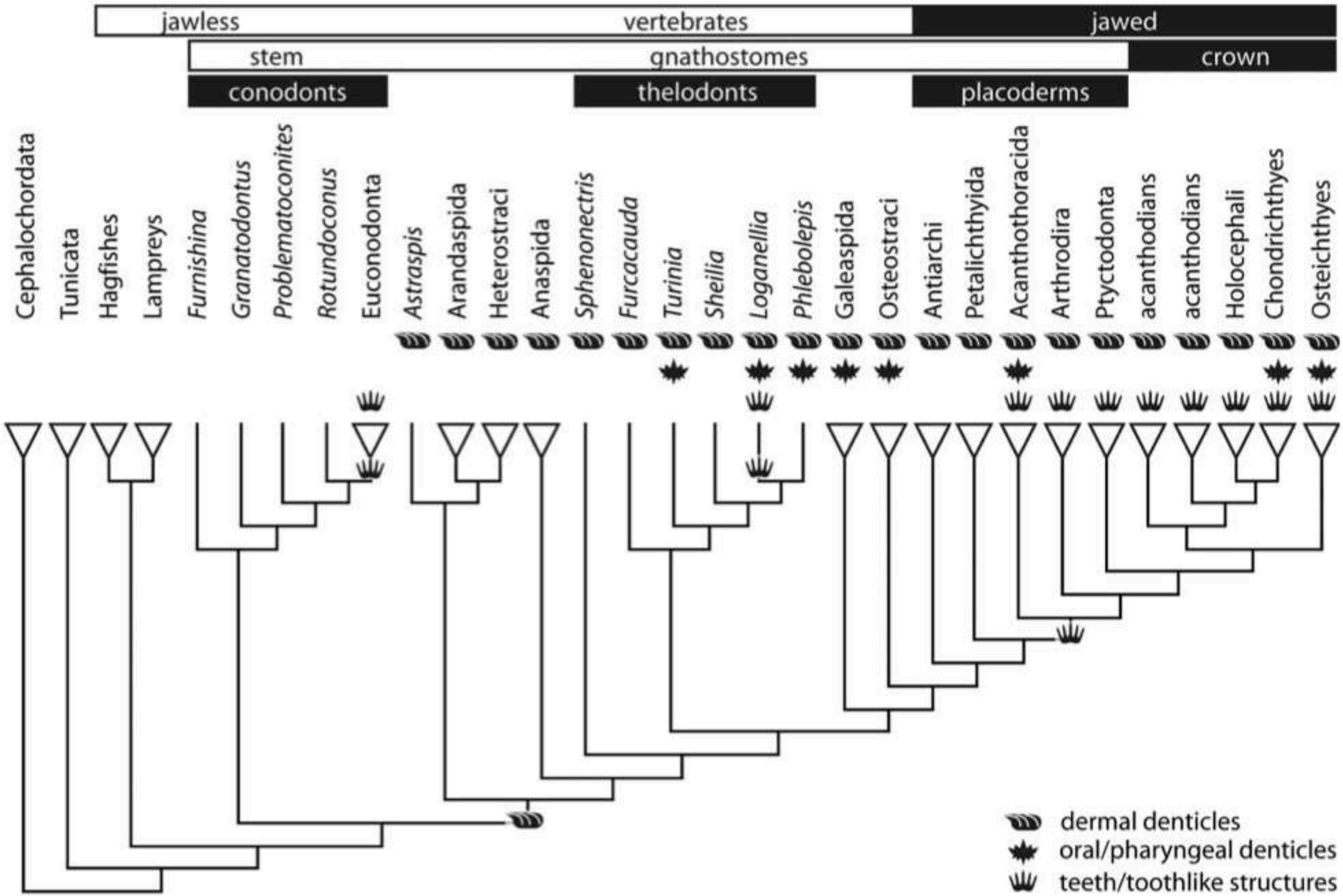


Fig. 1. Distribution of dermal denticles, oral/pharyngeal denticles and teeth/tooth-like structures, plotted on a phylogenetic tree of vertebrates. Phylogeny after Donoghue et al. (2000, 2008), Donoghue and Smith (2001), Brazeau (2009), Davis et al. (2012), Zhu et al. (2013), Murdock et al. (2013), Dupret et al. (2014).

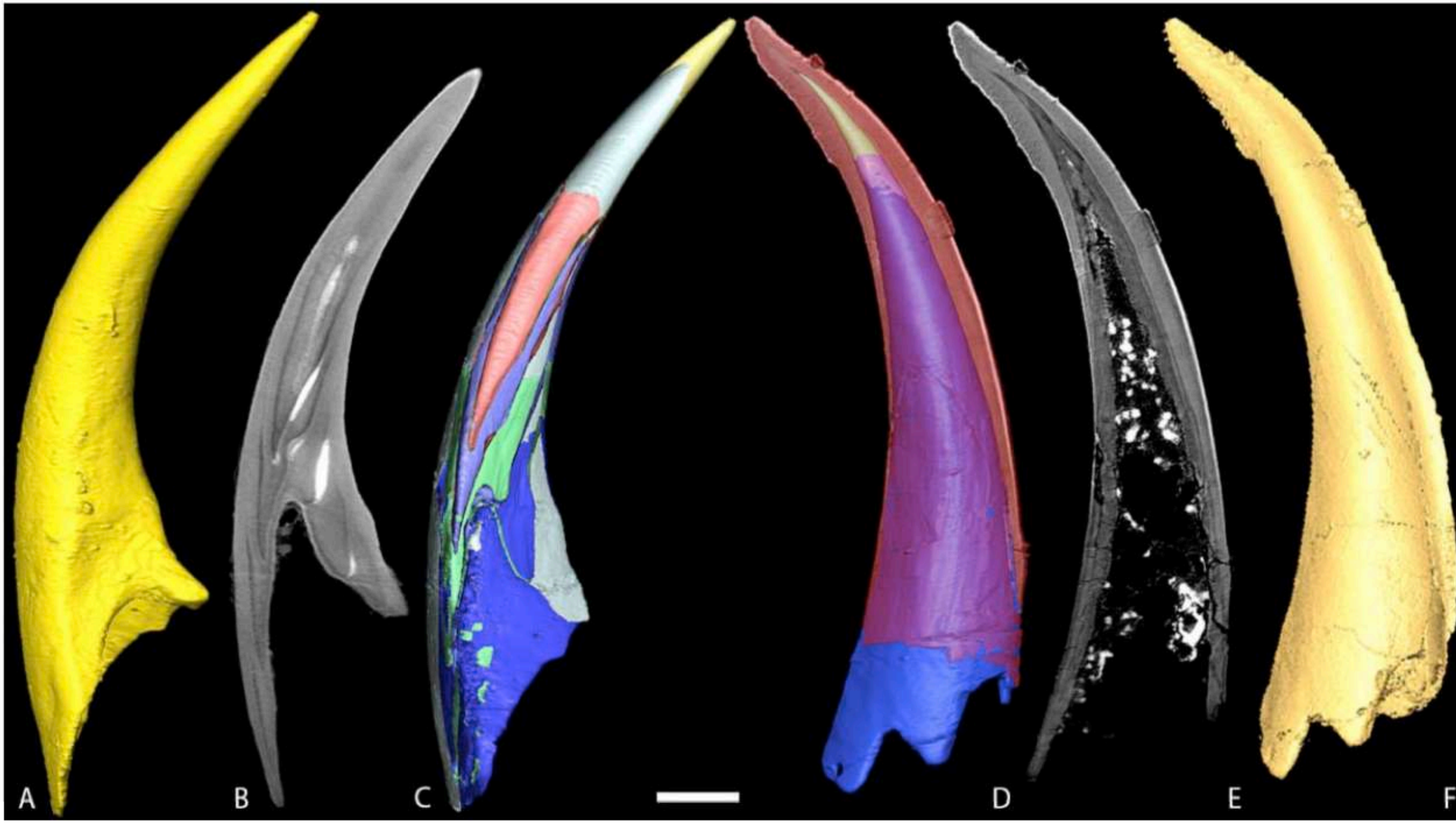
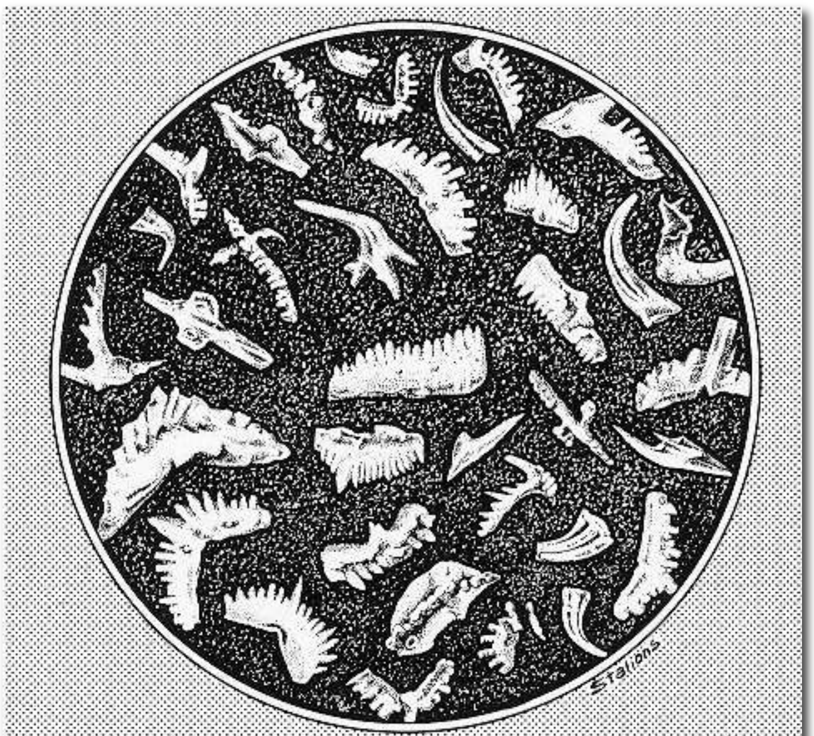
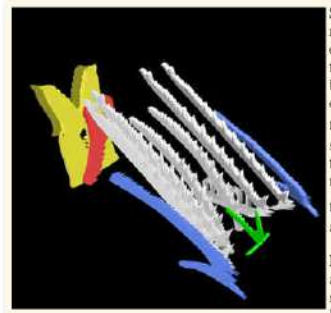


Fig. 2. Growth and microstructure of paraconodont and euconodont elements. (A–C) Paraconodont *Furnishina* sp., Threadgill Creek section, Wilberns Formation, 1,115 feet above base of Cambrian strata, central Texas, USA. (A) Surface model derived from SRXTM data. (B) Tomographic orthoslice of the same specimen showing the growth arrest lines. (C) Segmentation of the component growth stages with the oldest in yellow at the tip and the youngest in gray at the base (D–F) Euconodont *Proconodontus posterocostatus*, Gros Ventre Formation, Late Cambrian, Bighorn Mountains, Wyoming, USA. (D) Segmentation of the component growth stages of the basal body with the oldest in yellow at the tip and the youngest in blue at the base. (E) Tomographic orthoslice of the same specimen showing the growth arrest lines. (F) Surface model derived from SRXTM data. Relative scale bar represents 36 μm (A–C) and 53 μm (D–F).

Zubní elementy: Konodonta

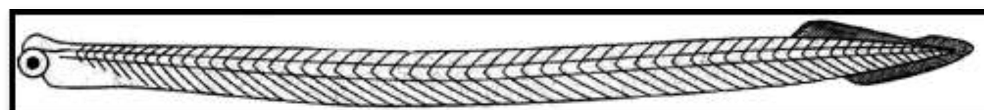




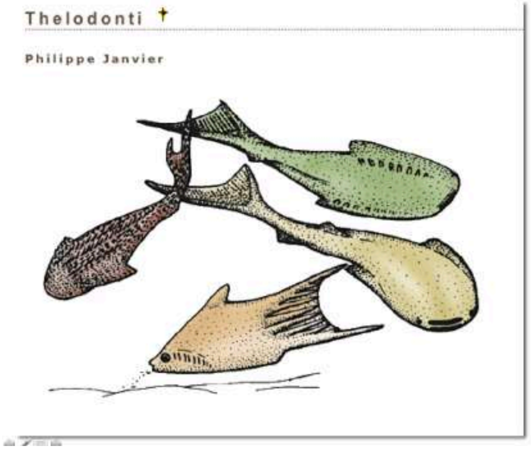
S-Elements: In the image of an *Idiognathodus* natural assemblage at right, the S-elements are the long, rod-like bones with straight, transverse pectinate teeth and a sort of pick-axe at the anterior or rostral end. More generally, S-elements are frequently curved, as in the *Manticolepis* model below. However, they are all relatively simple in shape, relatively gracile, and with strong longitudinal asymmetry, the base being located much closer to one end than the other. Each conodont has 4 or 5 mirror-image pairs of S-elements, numbered S_1 to S_4 or S_5 In addition, each conodont possesses a symmetrical, unpaired, median S_0 element, shown as green on the figure on the left. The S_0 is an unpaired, bilaterally symmetrical, medial element which is effectively at least *triramous*. Two of its branches create a stout, transverse, *rastrate* bar across the bottom of the mouth, denticles facing upward. The S-element numbering system is symmetrically arranged around this S_0 element, with the first element to the left of the S_0 designated S_1^s, the first to the right S_1^d, and so on (with the superscript designations for *sinister* and *dexter*).

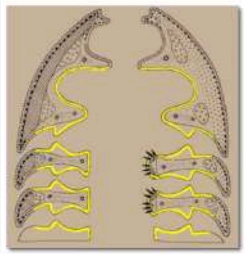
M-Elements: Conodonts have a single pair of M-elements. These are only loosely connected to the S-assemblage and appear to have been attached in the mouth cavity on its dorsal or lateral surface. Their shapes are frequently complex, vaguely reminiscent of anything from a nunchuck to a dart. While the M-elements are structurally obscure, their functional role is clear. They are the fork which held the food item in place as it was sliced or scooped by the S-elements, which acted as a combination knife and spoon.

P-Elements: The P-elements are the stout bones at the right of the right image, the left of the left image, and the bottom of the bottom (*Manticolepis*) image. Contrary to everyone's expectations, they appear to have been oriented vertically, with the two sets of denticles facing and, in fact, interdigitating as shown in the *Idiognathodus* natural assemblage. Purnell has produced convincing SEM images showing regular wear facets. The clear implication is that, at least in *Idiognathodus*, the teeth occluded in a regular and precise way. High resolution images of these facets may be found at Wear on conodont elements.



Thelodont (agnathan)
pharyngeal denticles





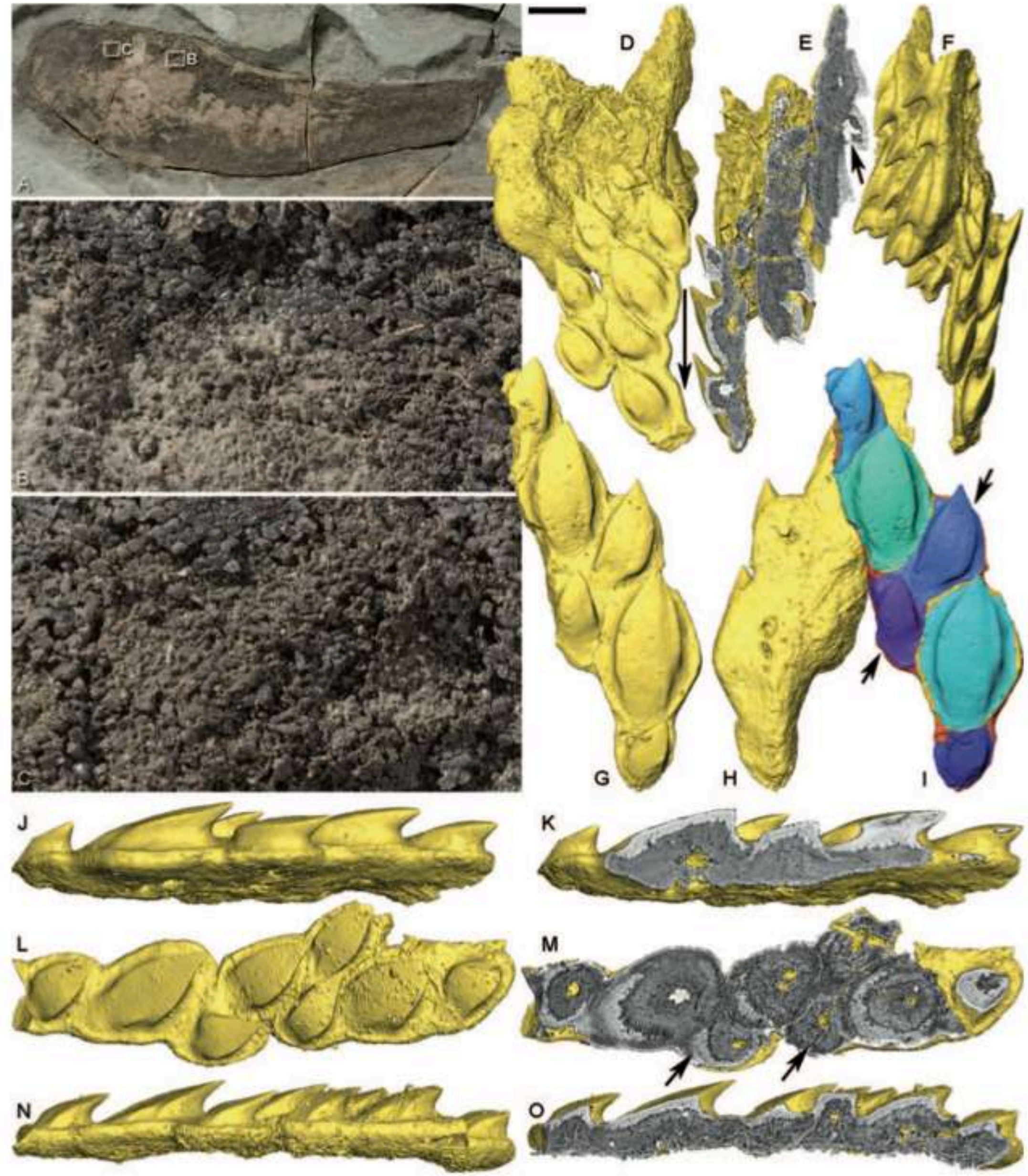
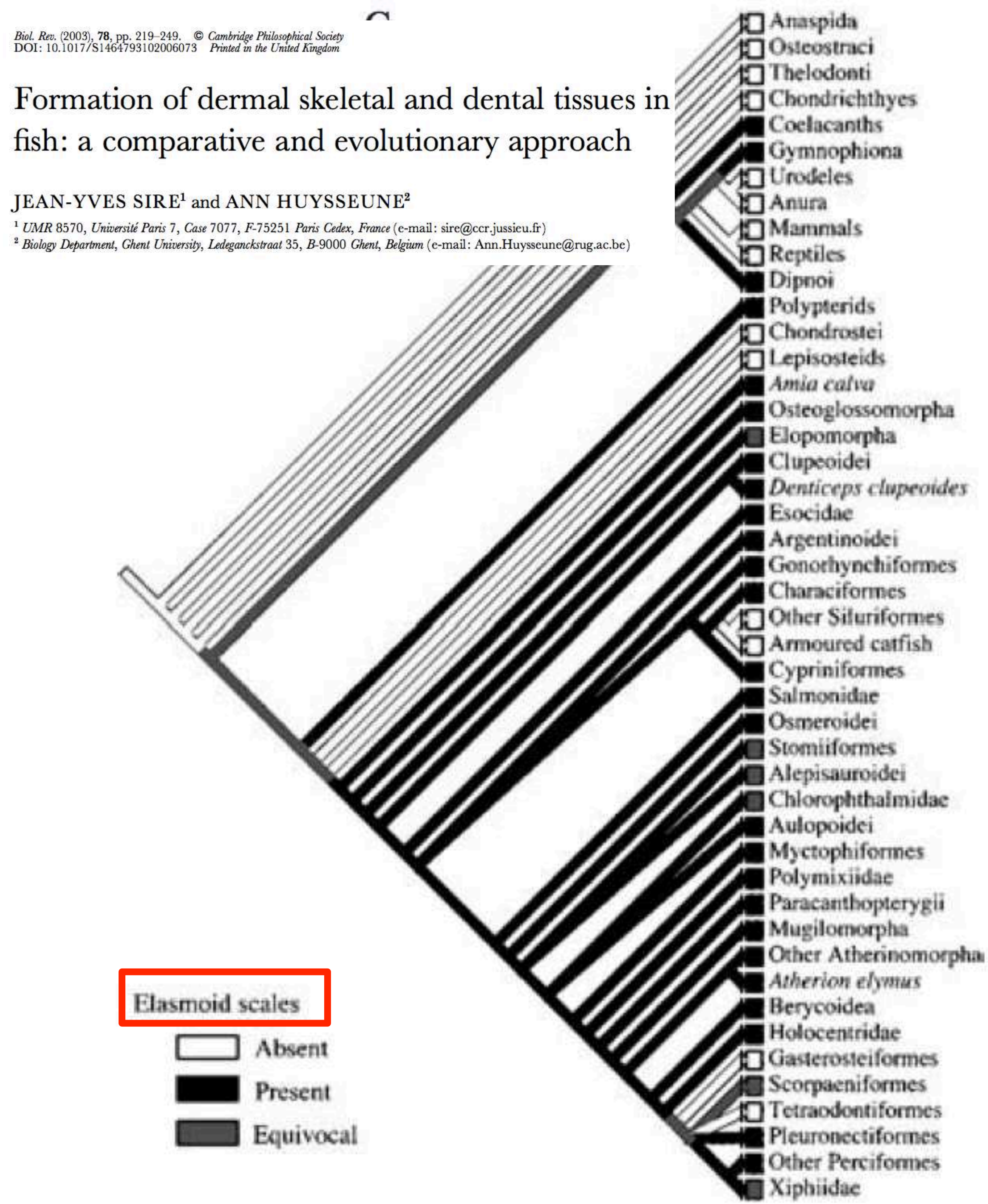


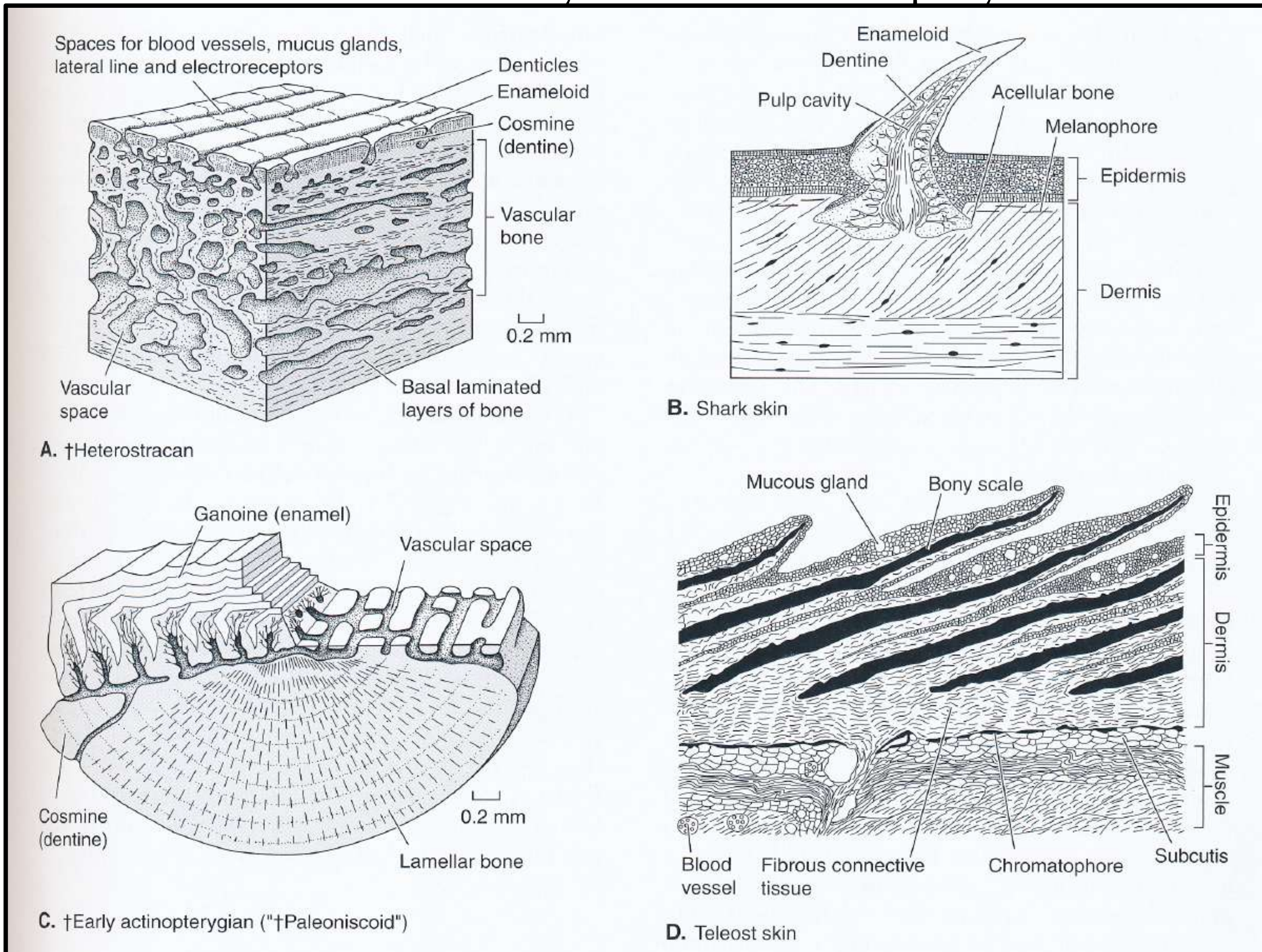
Fig. 3. *Loganellia scotica* from the Silurian of Scotland (MB.f.4013), morphologically complete specimen with internal scales in situ and detailed SRXTM images of internal scales. Overview (A), posterior pharyngeal area (B) and anterior pharyngeal area (C). Pharyngeal scale aggregate of polarized, sequentially added denticles and others with marginally added denticles (D–F). Unpolarized pharyngeal scale aggregate with denticles that differ in size (G–I). Elongated pharyngeal scale aggregate with sequentially added denticles and randomly added denticles (J–O). Long arrow indicates direction of polarized growth (D) and short arrows randomly added denticles (E, I, M). Relative scale bar represents 25 mm (A), 2.5 mm (B), 1.7 mm (C), 81 μm (D–F), 54 μm (G–I), and 57 μm (J–O).



Elasmoidní šupiny

původně chyběly, objevily se až u basálních paprskoploutvých ryb a byly sekundárně ztraceny či postupně modifikovány v kůži tetrapod

Kůže vodních rybovitých obratlovců a redukce odontody: trend od tvrdého krytí k elastičnosti a pohybu

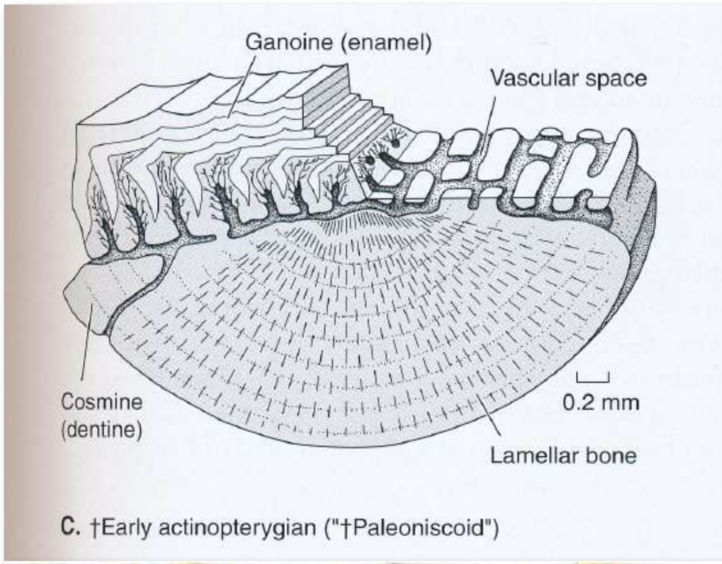


kosmoidní: hodně dentinu=cosmine; **plakoidní**: *a la* zub; **ganoidní**: hodně ganoinu (enamel);
rybí (ktenoidní, cykloidní): (Teleostei) » tenké šupiny z acelulární kosti

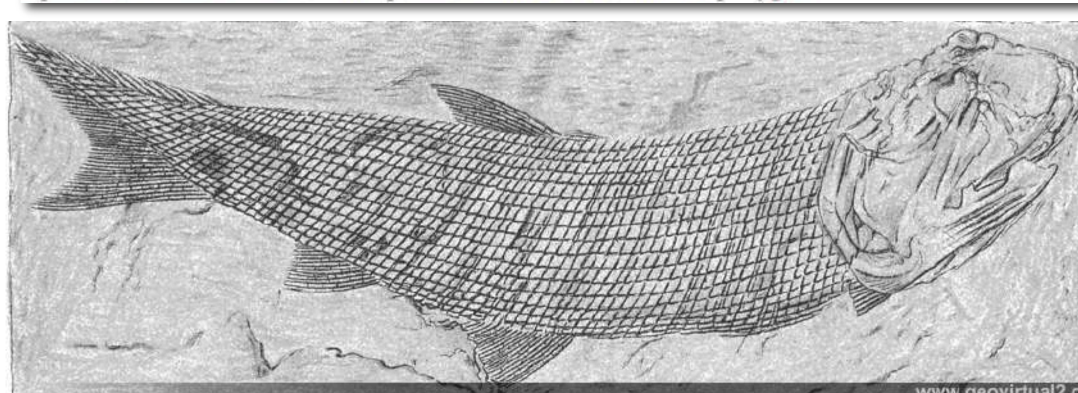
Ganoidní šupina paleonisků:

Ganoin ~ lamelární enamel;

málo dentinu

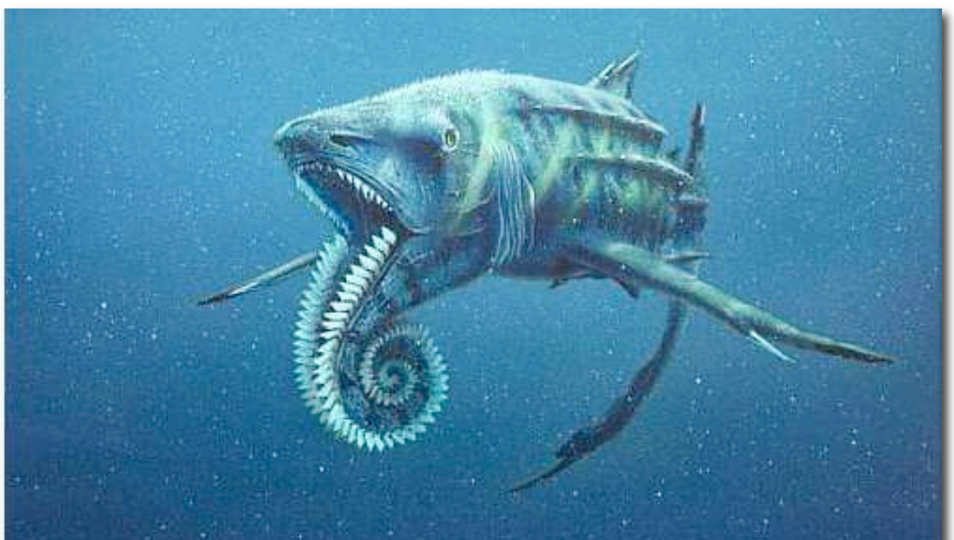


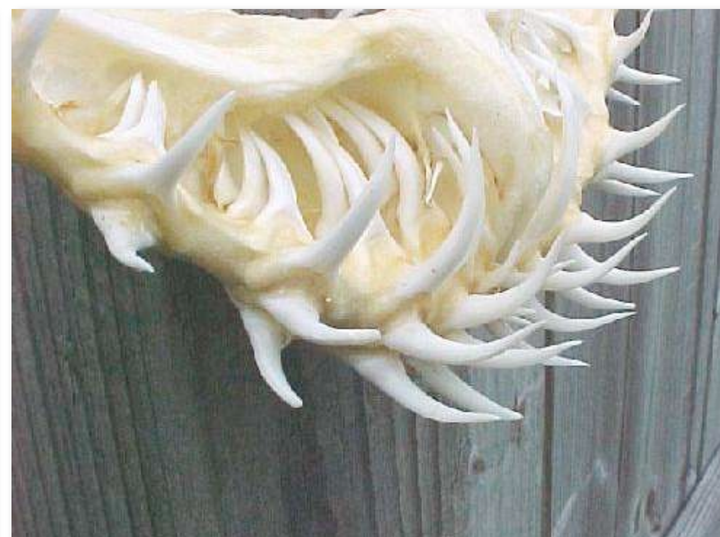
ganoid scale = a non-overlapping or partially-overlapping scale, often rhomboidal in shape, with thick outer ganoine layer (enamel-like substance), a middle layer of dentine and an inner dermal, cosmine bony layer. Grows by addition of material above and below, e.g. in Lepisosteidae, Amiidae and Polypteridae. Lepisosteidae have lost the dentine layer. The scales of Lepisosteidae are called lepisosteoid scales as distinct from paleaoniscoid scales of Brachiopterygii.



Paleoniskové (primitivní vymřelí osteichthyes);
bichiři, kostlíní, kaprouni

Kůže paryb:
plakoidní šupiny homologické zubům






Myliobatis noctula.

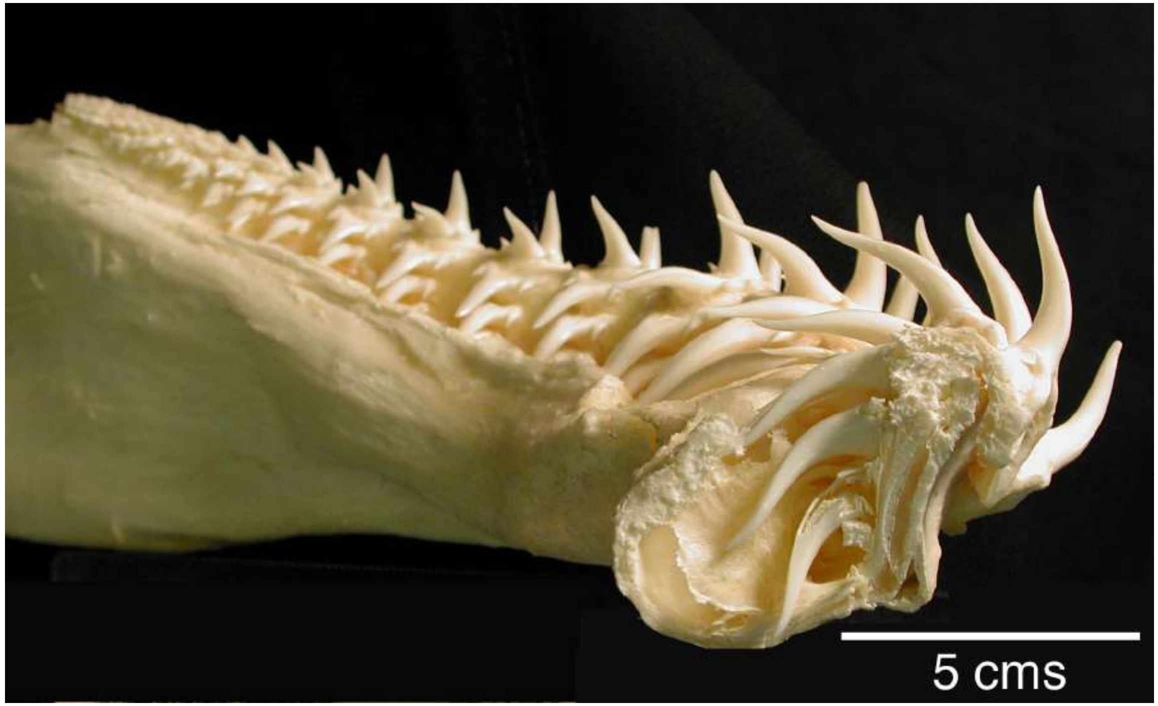
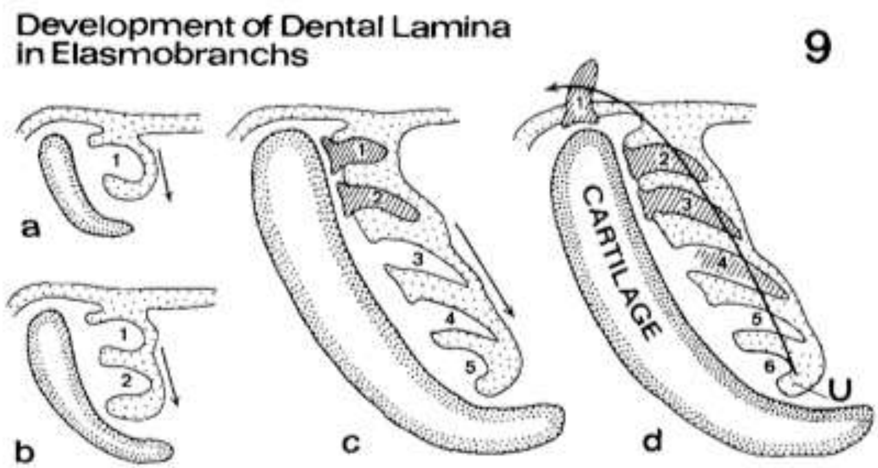
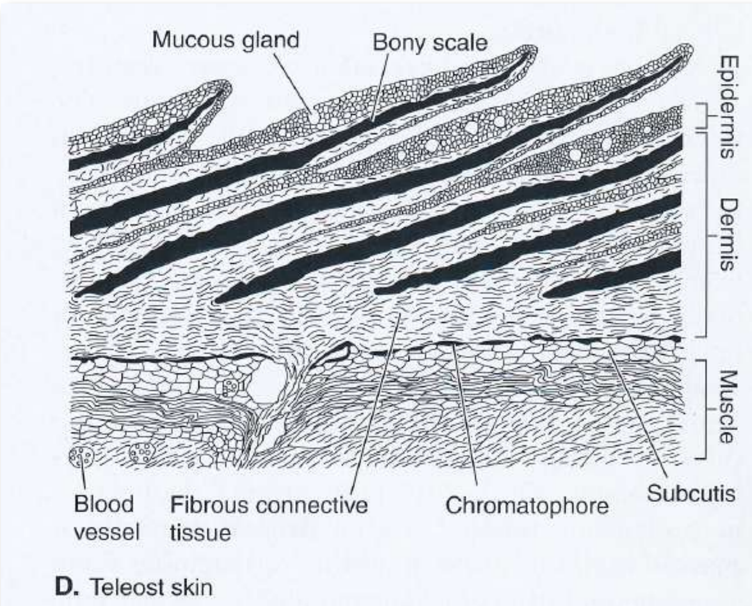


Fig. 9 a–d
General scheme for embryogenesis of the dental lamina in elasmobranchs. Dotted areas-ectoderm (surrounded by mesenchyme). Tooth germs are formed in the course of the infolding of the ectoderm (a–c). At the end of embyogensis the tooth exchange mechanism begins to work (d), moving tooth no. 1 into functional position. At the same time the germ of tooth no. 6 is formed at the lower end of the dental lamina (see p. 14 and Fig. 31)



další redukce u ryb kostnatých » tenké šupiny z acelulární kosti (flexibilita!), apoziční, koncentrický růst kolem centra



D. Teleost skin

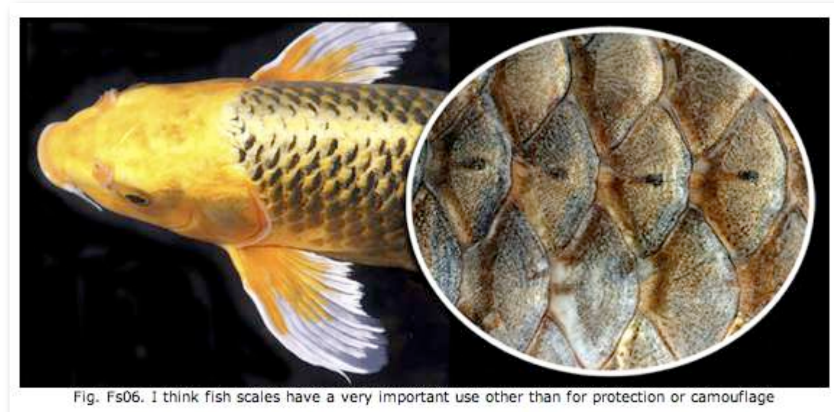
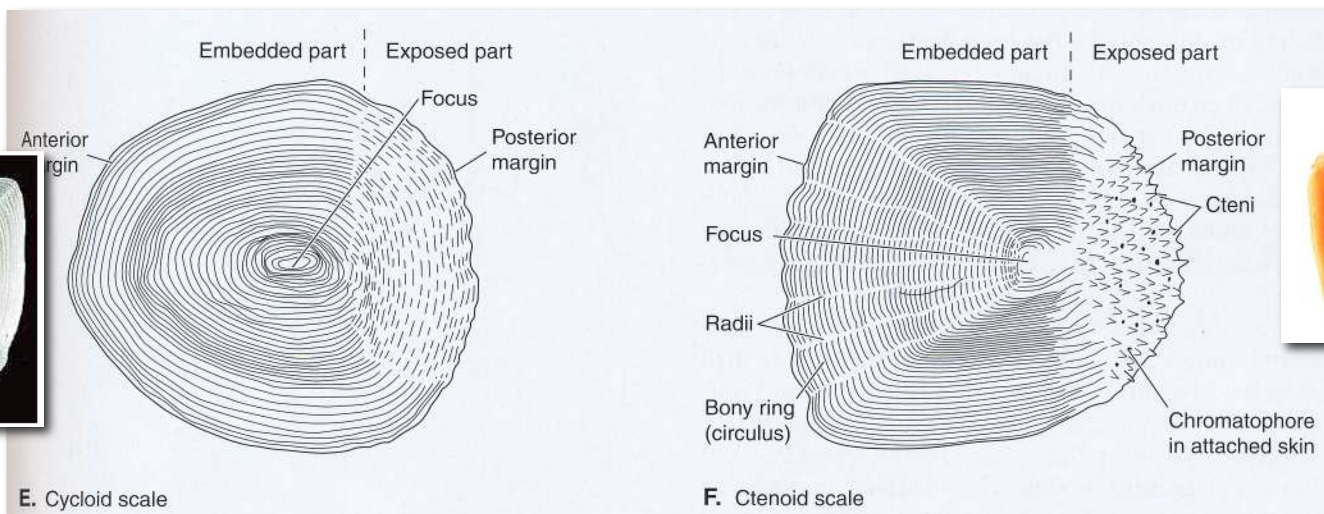


Fig. Fs06. I think fish scales have a very important use other than for protection or camouflage



E. Cycloid scale

F. Ctenoid scale

MICROSCOPY RESEARCH AND TECHNIQUE 59:408–434 (2002)

First-Generation Teeth in Nonmammalian Lineages: Evidence for a Conserved Ancestral Character?

JEAN-YVES SIRE,[1]* TIPHAINE DAVIT-BEAL,[1] SIDNEY DELGADO,[1] CHRISTINE VAN DER HEYDEN,[2] AND ANN HUYSSEUNE[2]
[1]*CNRS UMR 8570, Université Paris, France*
[2]*Biology Department, Ghent University, B-9000 Gent, Belgium*

Zuby první generace u nesavčích skupin: zub tzv. 1. a 2. typu

Generalizovaný typ 1 - Actinopterygii, Dipnoi, Urodela:

- malá velikost, jednoduchý konický tvar, atubulární dentin, aprizmatický enamel, malá zubní kavita bez kapilár a krevního zásobení - **krátké období embryogeneze**
- tedy plesiomorfní typ?, ekonomicky výhodné, častější polyfyodoncie

Generalizovaný typ 2 - Chodrichthyes, Lepidosauria, Archosauria, Mammalia:

- spíše větší velikost, komplexní tvar, tubulární dentin, prizmatický enamel, velká zubní kavita s kapilárami
- **v zásadě miniaturní kopie zubu dospělého – nutné prodloužené období embryogeneze**.

MICROSCOPY RESEARCH AND TECHNIQUE 59:408–434 (2002)

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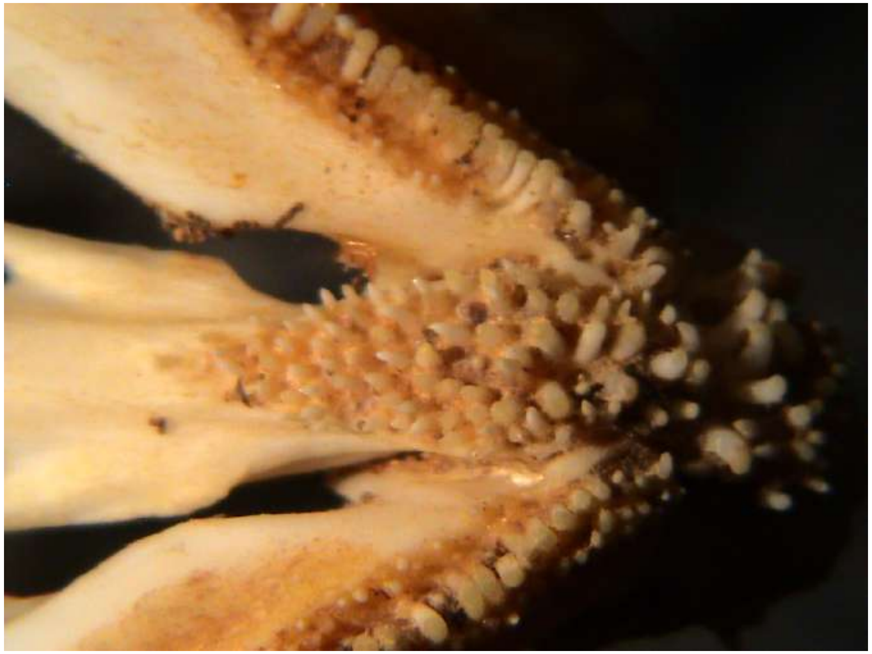
Zuby první generace u nesavčích skupin: zub tzv. 1. a 2. typu



Typ 1 je tedy asi ancestrální; pro přeměnu k typu 2 je nezbytná prodloužená doba embryogeneze umožňující delší vývin zubu!

MICROSCOPY RESEARCH AND TECHNIQUE 59:408–434 (2002)

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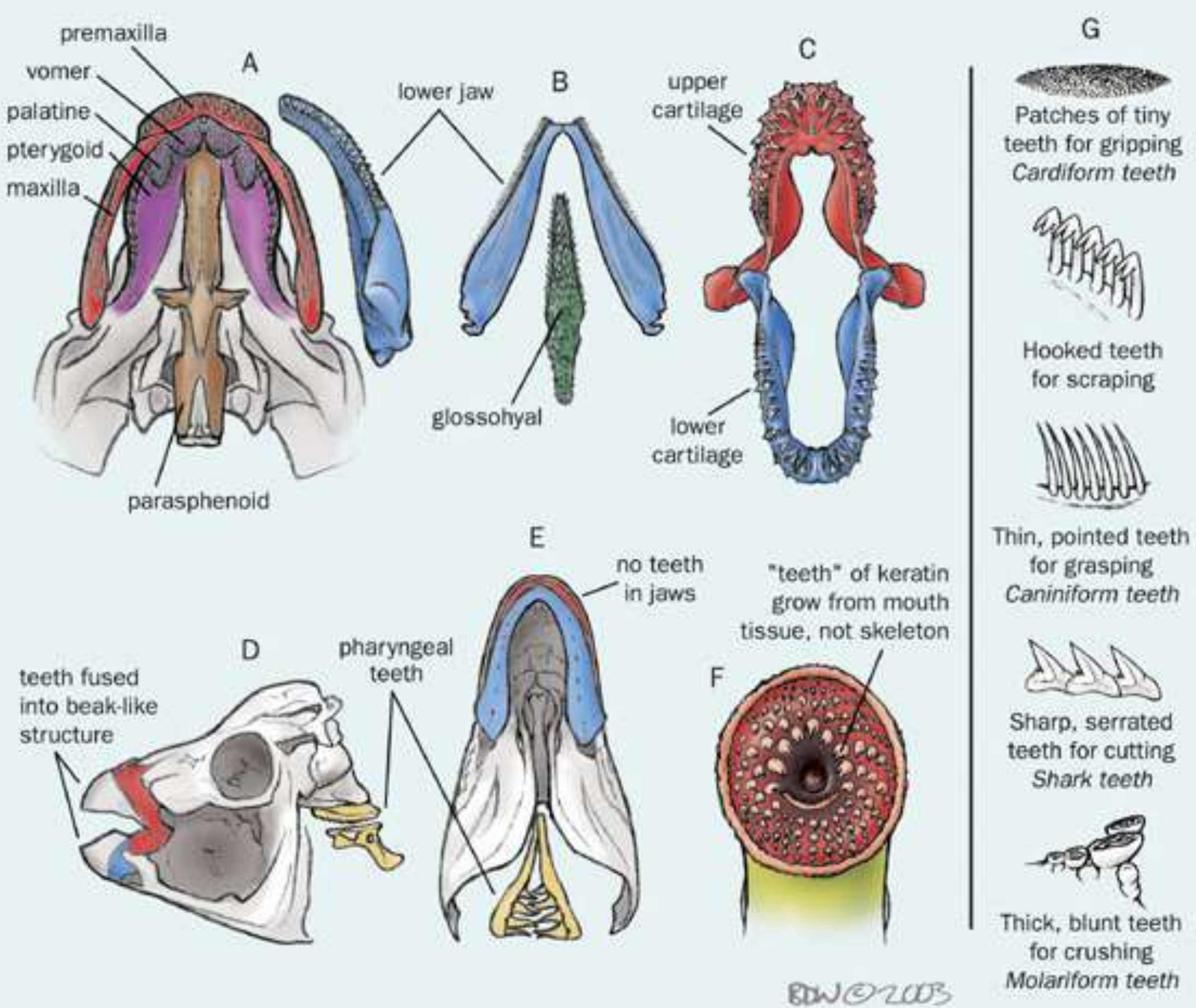
[2]Biology Department, Ghent University, B-9000 Gent, Belgium

ABSTRACT The present study focuses on the main characteristics of first-generation teeth (i.e., the first teeth of the dentition to develop in a given position and to become functional) in representatives of the major lineages of nonmammalian vertebrates (chondrichthyans, actinopterygians, and sarcopterygians: dipnoans, urodeles, squamates, and crocodiles). Comparative investigations on the LM and TEM level reveal the existence of two major types of first-generation teeth. One type (generalized Type 1) is characterized by its small size, conical shape, atubular dentine, and small pulp cavity without capillaries and blood vessels. This type is found in actinopterygians, dipnoans, and urodeles and coincides with the occurrence of short embryonic periods in these species. The other type assembles a variety of first-generation teeth, which have in common that they represent miniature versions of adult teeth. They are generally larger than the first type, have more complex shapes, tubular dentine, and a large pulp cavity containing blood vessels. These teeth are found in chondrichtyans, squamates, and crocodiles, taxa which all share an extended embryonic period. The presence in certain taxa of a particular type of first-generation teeth is neither linked to their phylogenetic relationships nor to adult body size or tooth structure, but relates to the duration of embryonic development. Given that the plesiomorphic state in vertebrates is a short embryonic development, we consider the generalized Type 1 first-generation tooth to represent an ancestral character for gnathostomes. We hypothesize that an extended embryonic development leads to the suppression of tooth generations in the development of dentition. These may still be present in the form of rudimentary germs in the embryonic period. In our view, this generalized Type 1 first-generation teeth has been conserved through evolution because it represents a very economic and efficient way of building small and simple teeth adapted to larval life. The highly adapted adult dentition characteristic for each lineage has been possible only through polyphyodonty. *Microsc. Res. Tech. 59:408–434, 2002.*


A
premaxilla
vomer
palatine
pterygoid
maxilla
parasphenoid
lower jaw
B
glossohyal
C
upper cartilage
lower cartilage
G
Patches of tiny teeth for gripping
Cardiform teeth
Hooked teeth for scraping
Thin, pointed teeth for grasping
Caniniform teeth
Sharp, serrated teeth for cutting
Shark teeth
Thick, blunt teeth for crushing
Molariform teeth
D
teeth fused into beak-like structure
pharyngeal teeth
E
no teeth in jaws
F
"teeth" of keratin grow from mouth tissue, not skeleton
RDW © 2003

moderní obojživelnící (Lissamphibia) a vymřelí labyrinthodonta: **pedicelátní zuby**

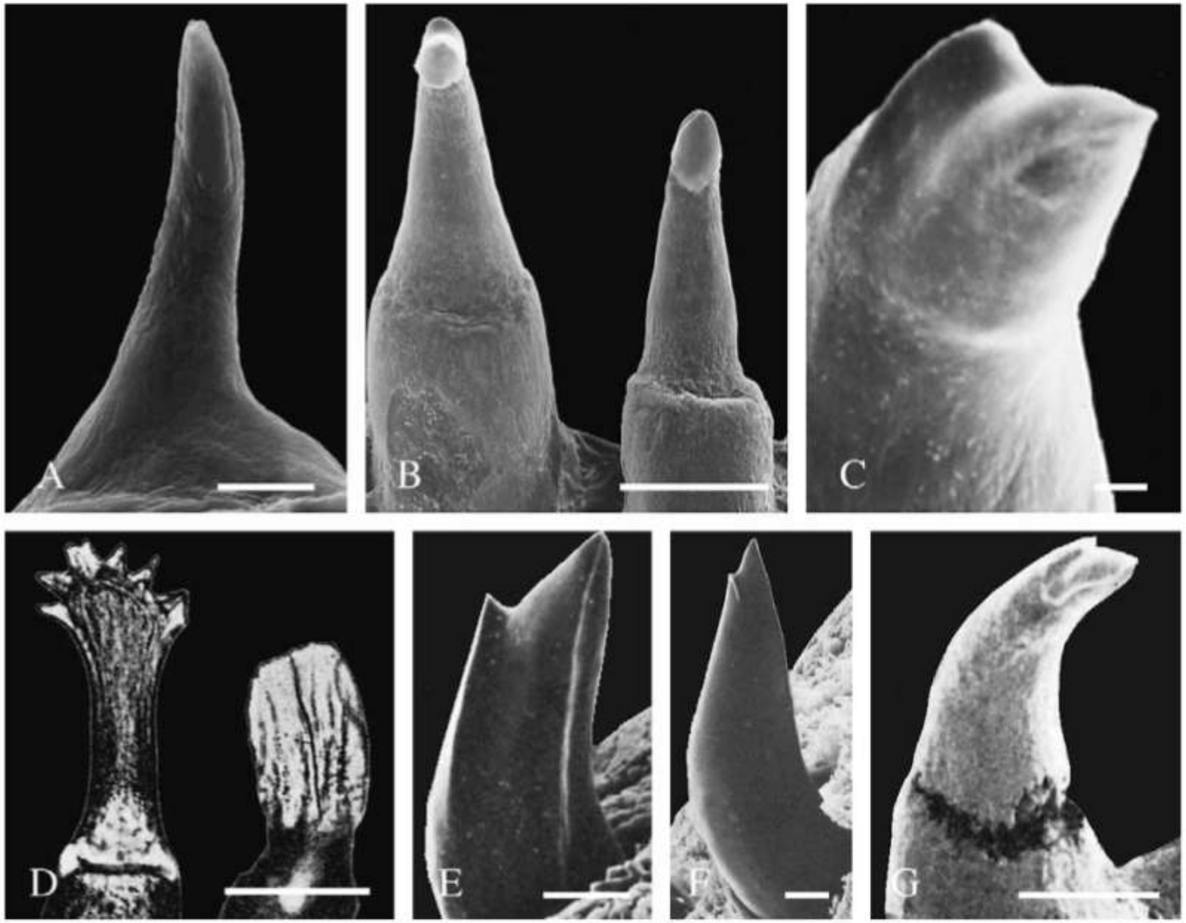


Fig. 3. Examples of tooth morphology in lissamphibians. (A, B, C) Tooth shape throughout ontogeny in the caudate, *Pleurodeles waltl.* (A) First-generation tooth in a larva, stage 44. The tooth is monocuspid and the dividing zone is lacking. (B) Third- (left) and fourth- (right) generation tooth in a five-month-old, postmetamorphosed specimen. The teeth are bicuspid and the dividing zone is visible. (C) Detail of the tooth tip in an adult showing the two cusps. The main cusp is lingually oriented. (D, E, F) Teeth in Gymniophona. (D) Typical tooth morphology in an embryo of *Geotrypetes seraphini* (left) and in a foetus of *Nectocaecilia petersi* (right). (E) Adult tooth in *Hypogeophis rostratus*. (F) Adult tooth in *Geotrypetes seraphini*. (G) Adult tooth in the anuran *Bombina bombina* (Linnaeus, 1761). D modified from Parker & Dunn (1964); E, F from Wake & Wurst (1979): G from Clemen & Greven (1980). Scale bars: A, B, D-G = 100 μm; C = 10 μm.

zubní morfologie: lissamphibia

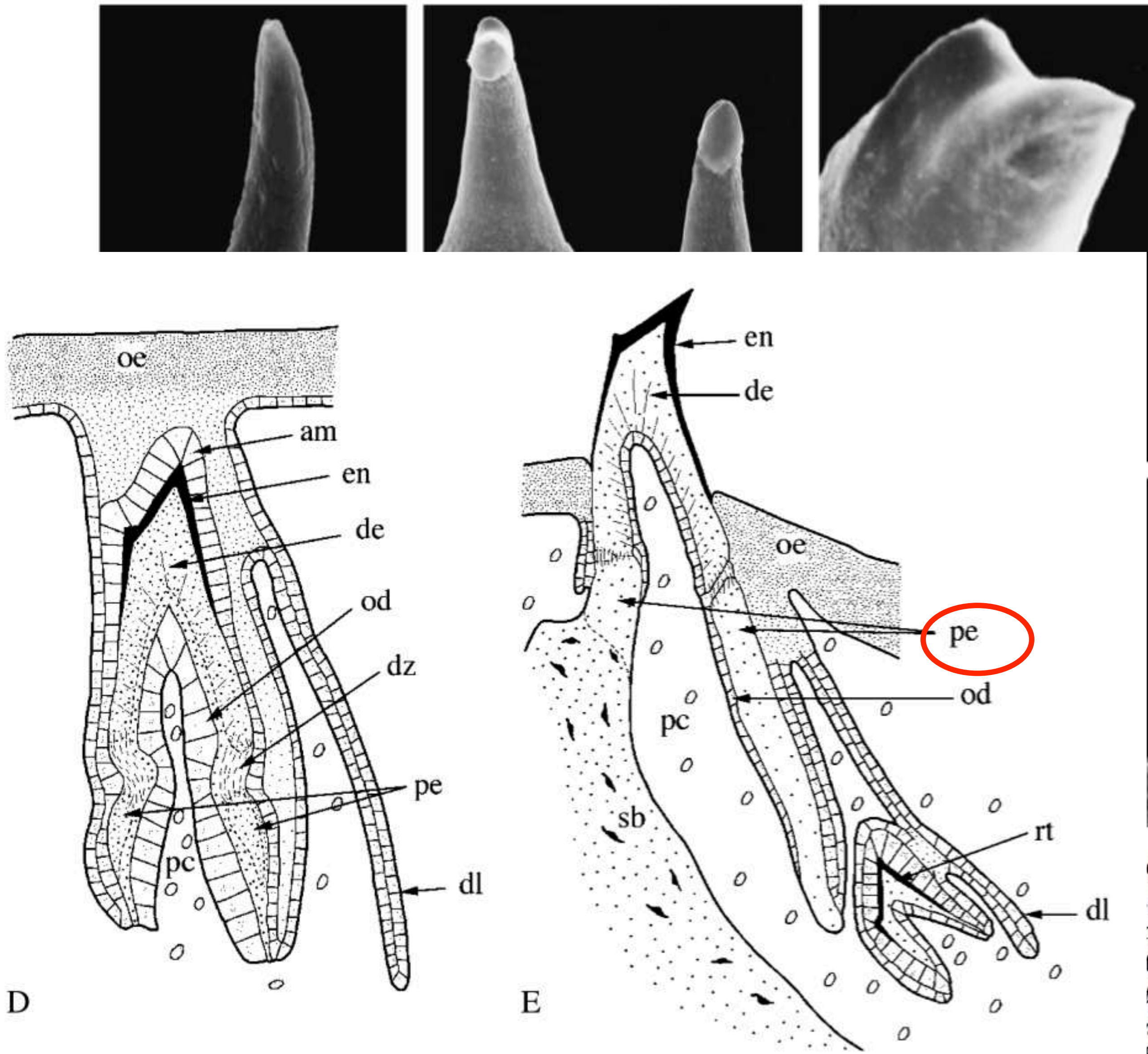
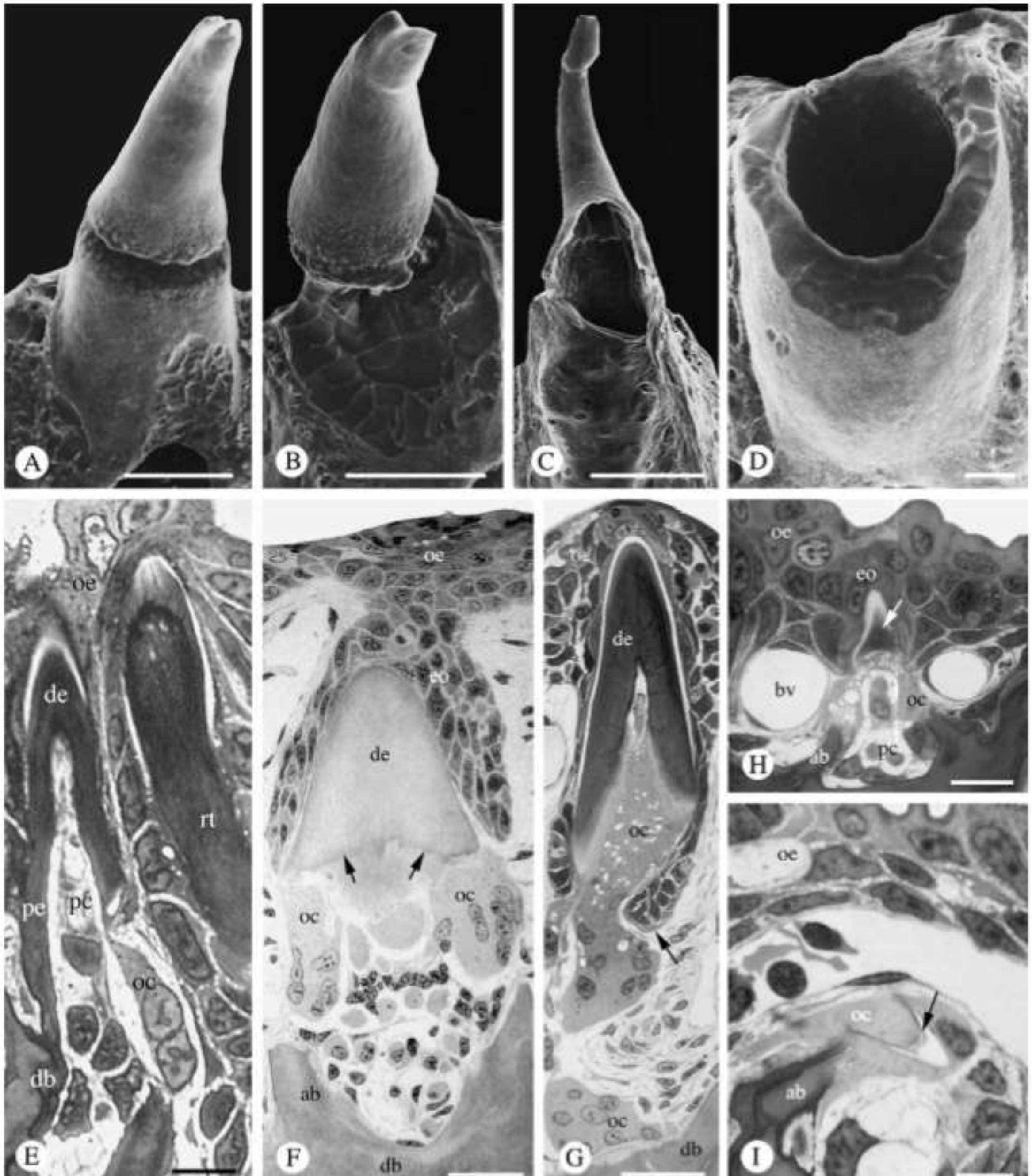
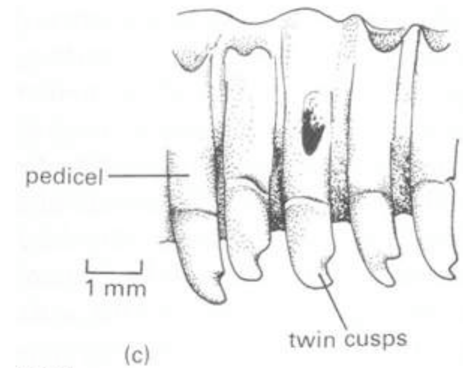
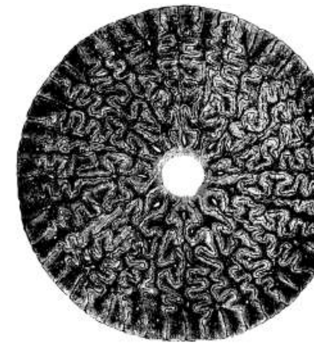


Fig. 3. ... e caudate, *Pleurodeles waltl.* (... (B) Third- (left) and fourth ... nd the dividing zone is visit ... ted. (D, E, F) Teeth in Gyr ... *tocaecilia petersi* (right). (E) Ad ... *na bombina* (Linnaeus, 1761). ... 80). Scale bars: A, B, D-G = 100 µm; C = 10 µm.



pedicel: nezvápněný dentin, nezbytný k zubní výměně (?similarity to bone of attachment?)





labyrintodontní obojživelnící: parafyletická skupina (grade), dle stavby zubu

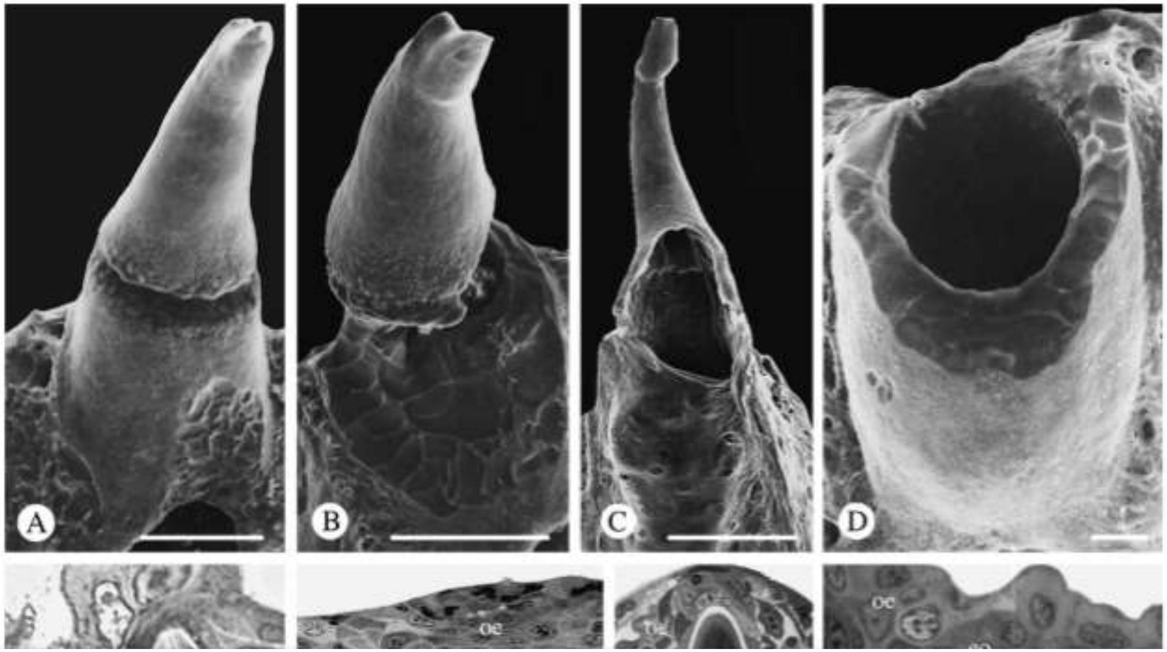
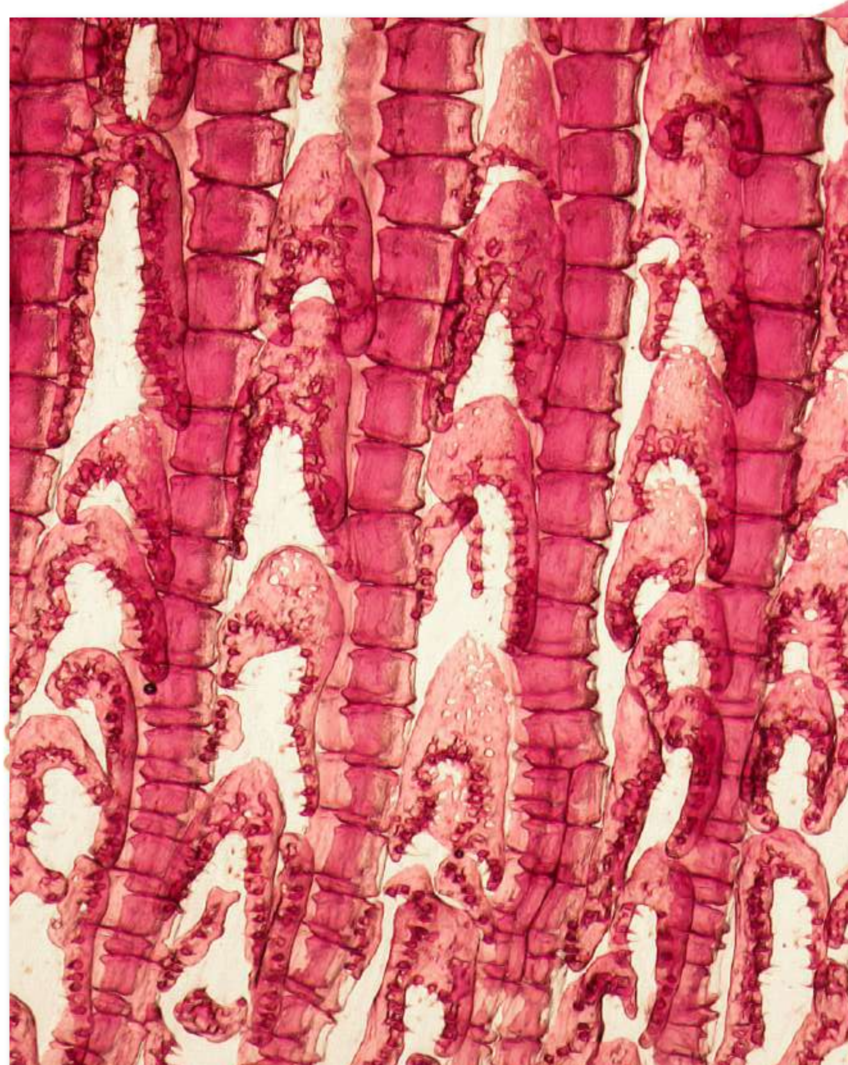


Fig. 13. Tooth resorption in *Pleurodeles waltl*. (A-D) Scanning electron micrographs of teeth subjected to resorption, viewed from the lingual side. Note the numerous, well-delimited lacunae at the resorption sites, revealing the location of the osteoclasts. (A) Adult. Resorption has started at the level of the pedicel. (B) Adult. Resorption has extended to the whole surface of the pedicel. (C) Ten-month-old specimen. The pedicel surface is highly resorbed as well as the base of the crown, where the pulp cavity has been opened. (D) Adult. The tooth has been entirely resorbed, but most of the pedicel remains. (E-I) One µm-thick, vertical sections of teeth subjected to resorption. (E) Larva, stage 51. The surface of the pedicel located close to the enamel organ of the replacement tooth is subjected to resorption. (F) 12-month-old specimen. Most of the pedicel has been resorbed and two large, multinucleated osteoclasts are attacking the base of the dentine crown (arrows). (G) Eight-month-old specimen. An osteoclast has penetrated the pulp cavity and a large part of the dentine crown is resorbed. Note the decalcification of the dentine matrix prior to resorption. Another osteoclast is apposed onto the surface of the dentary bone. The cells of the enamel organ of the resorbed tooth have not retracted (arrow), while the dentine crown they were covering has been resorbed. (H) Larva, stage 48. The resorption of this first-generation tooth is well advanced. Note that a single osteoclast is involved in the resorption of the dentine cone and of the attachment bone, simultaneously. (I) Larva, stage 52. This first-generation tooth has been resorbed, but its tooth tip is still visible (arrow), entirely surrounded by an osteoclast. Scale bars: A, B, C = 100 µm; D, H = 20 µm; E, I = 10 µm; F, G = 50 µm. ab: attachment bone; bv: blood vessel; db: dentary bone; de: dentine; eo: enamel organ; oc: osteoclast; oe: oral epithelium; pc: pulp cavity; pe: pedicel; rt: replacement tooth.

bichir *Polypterus senegalus:*
skeletální preparát, palatální pohled

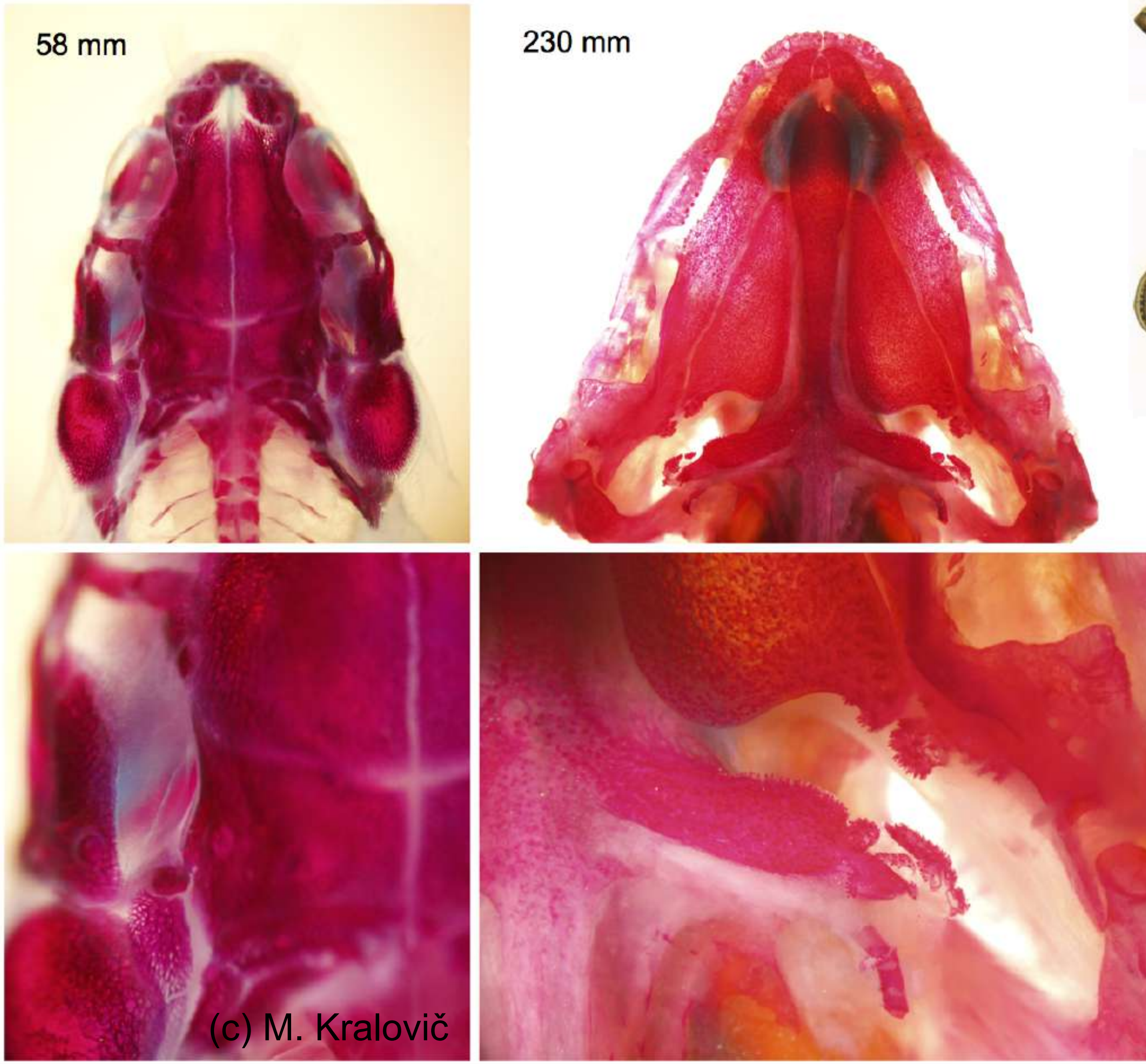
bichir *Polypterus senegalus:*
skeletální preparát barven alizarinem red

bichir *Polypterus senegalus:*
skeletální preparát barven alizarinem red



"zubní elementy" [odontody] v ploutevních paprscích

bichir *Polypterus senegalus*: zuby ve spirakulu



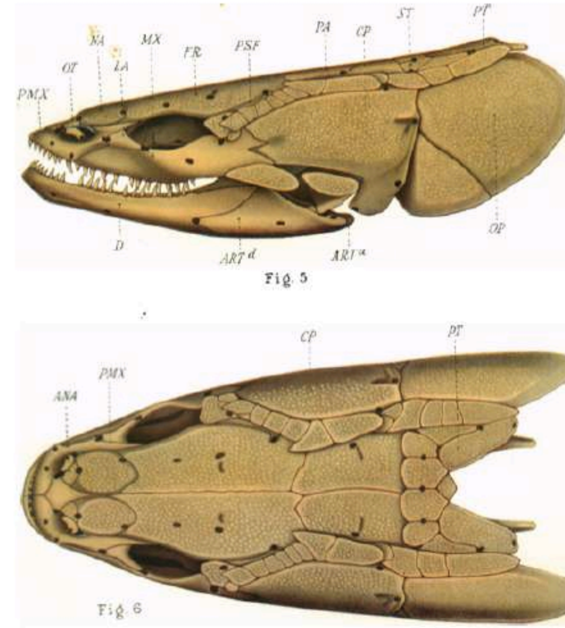
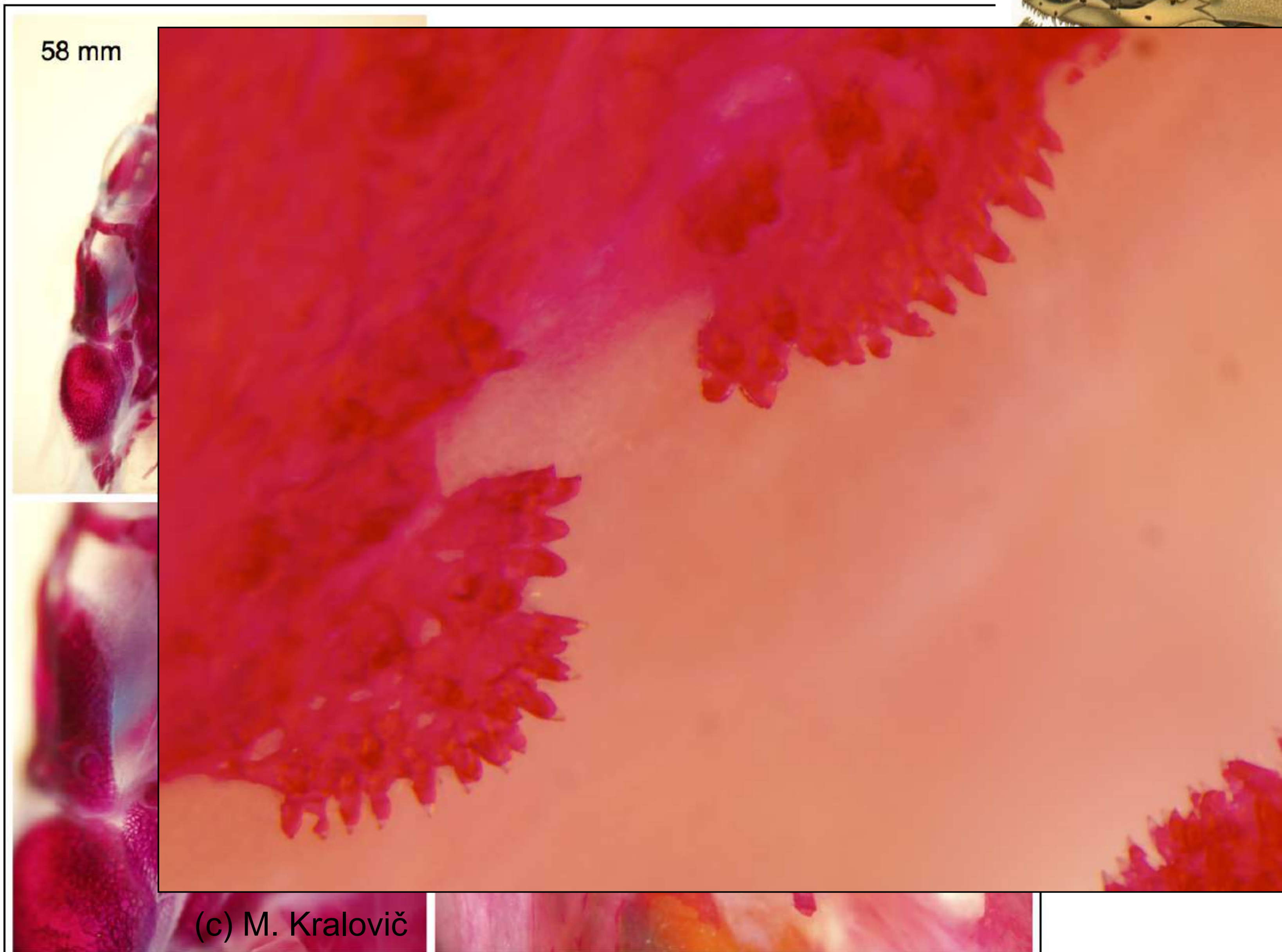
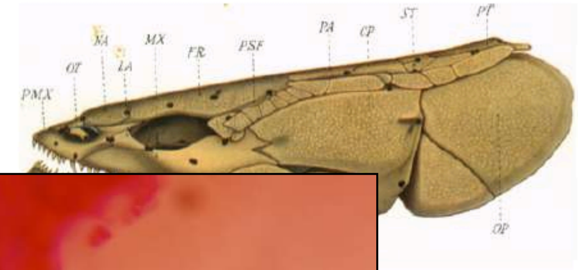


Fig. 5. Lateral view of entire skull of a 49 cm. *Polypterus bichir*. ×2.
Fig. 6. Dorsal view of same. ×2.

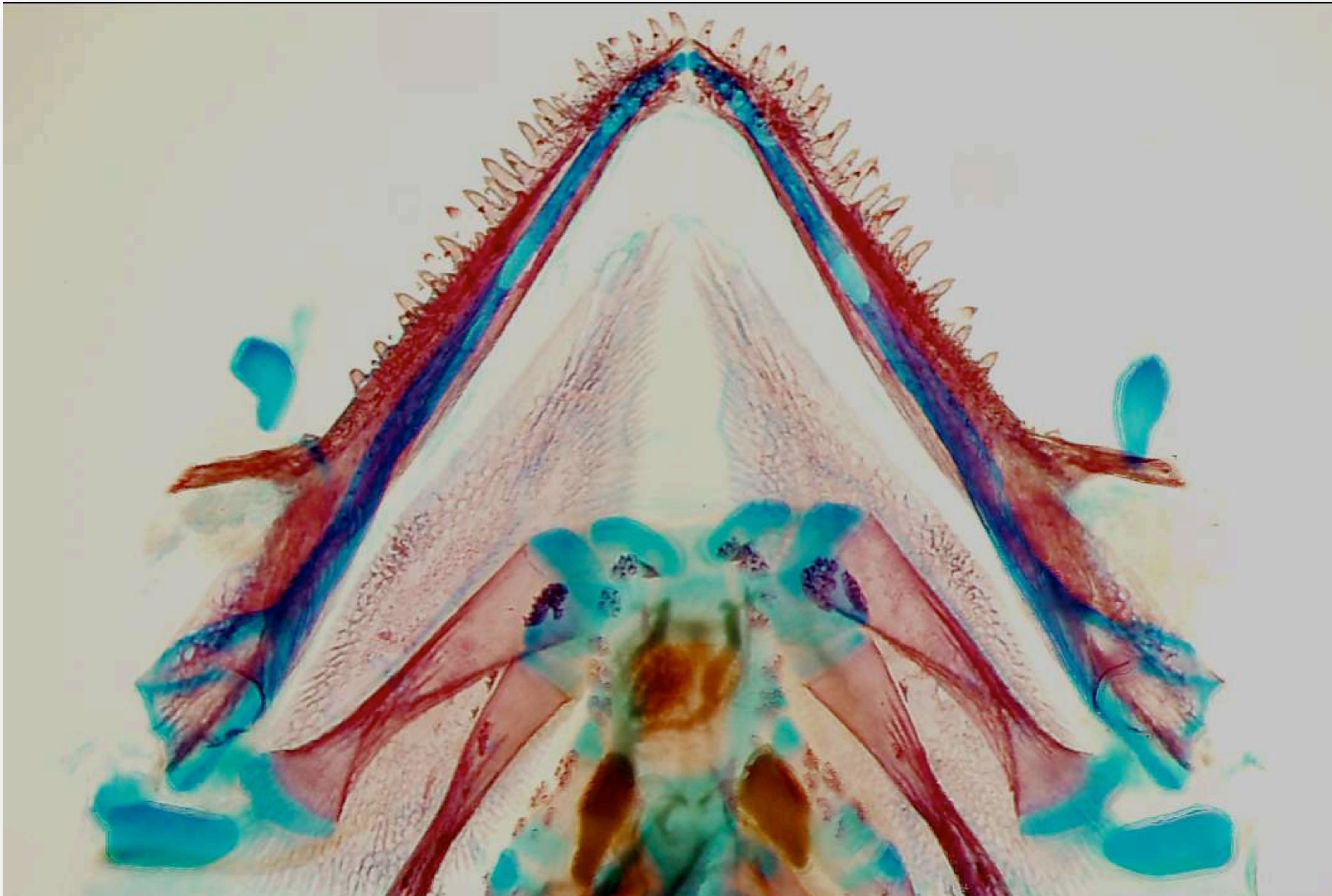
bichir *Polypterus senegalus*: zuby ve spirakulu



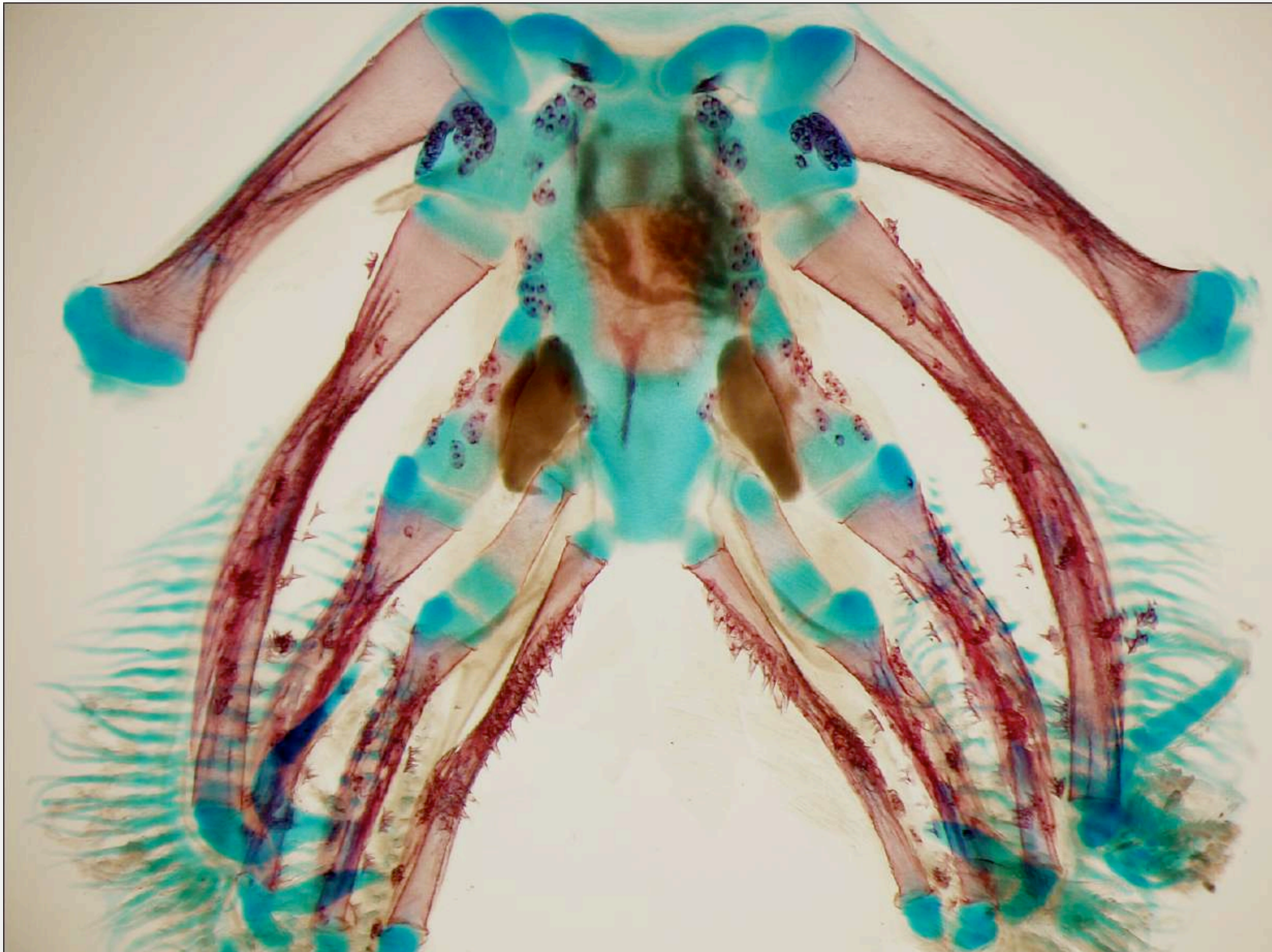


olypterus bichir. ×2.

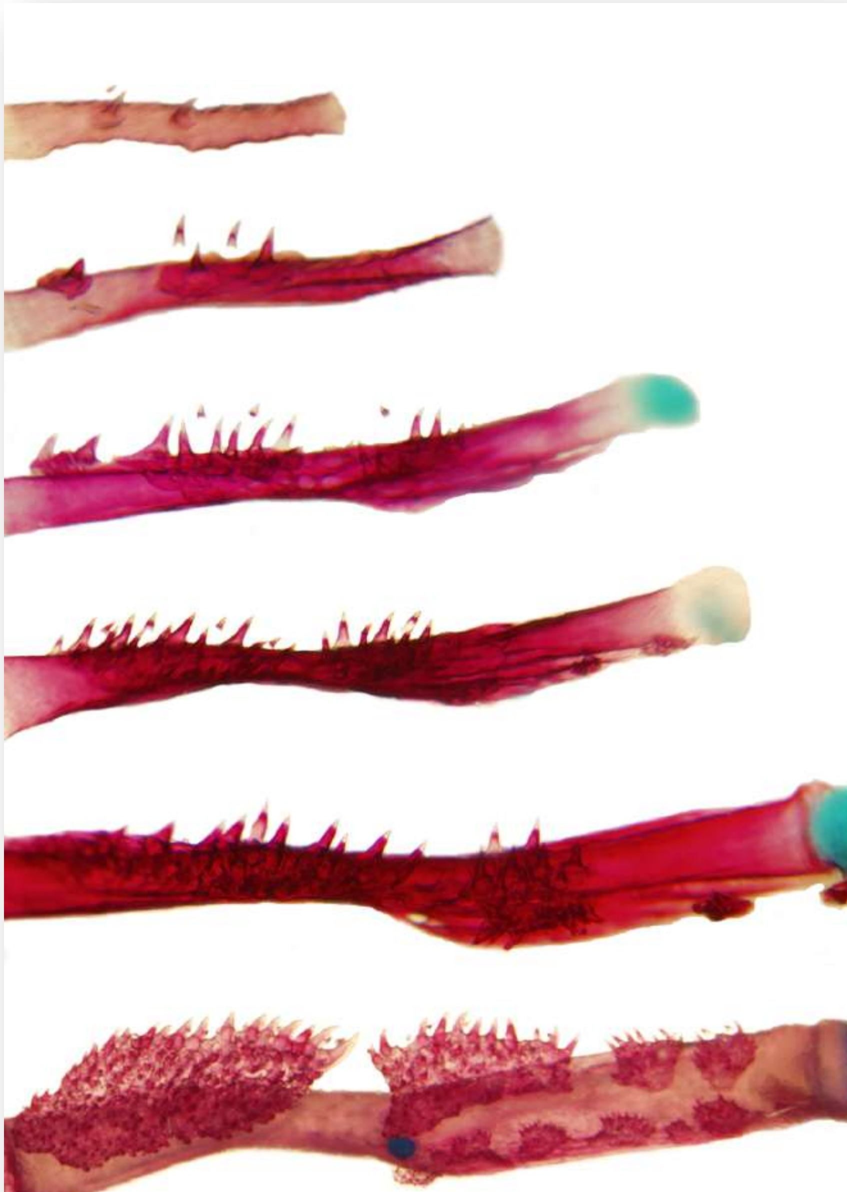
bichir *Polypterus senegalus*:
spodní čelist, alizarin red (kost), alcian blue (chrupavka)



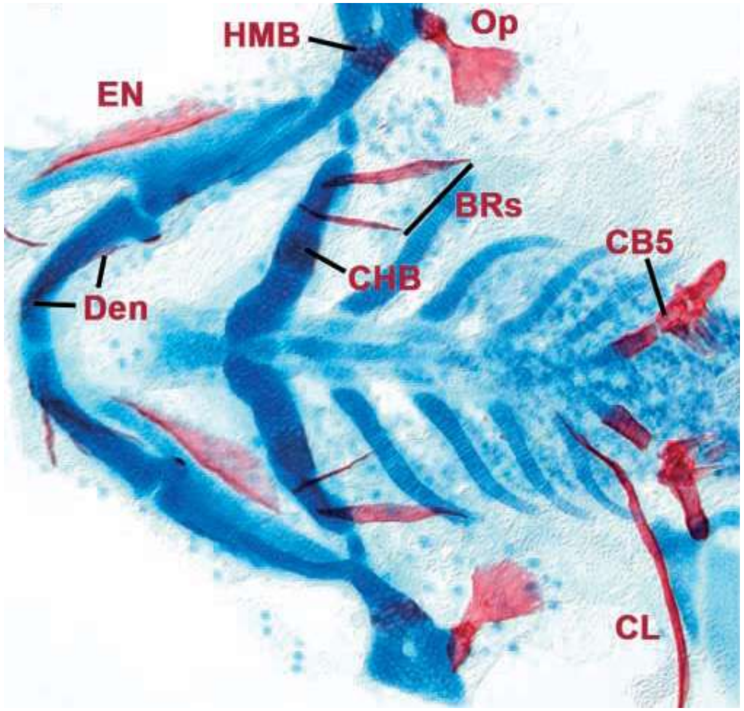
bichir *Polypterus senegalus:*
ozubené elementy faryngeálních oblouků; *pharyngobranchialia*

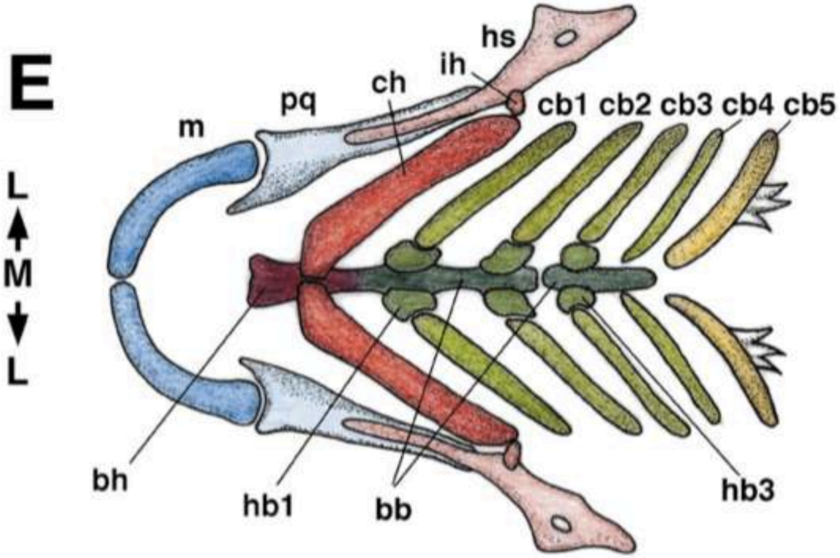


bichir *Polypterus senegalus:*
vývoj faryngeálních čelistí a jednotlivých zubních desek

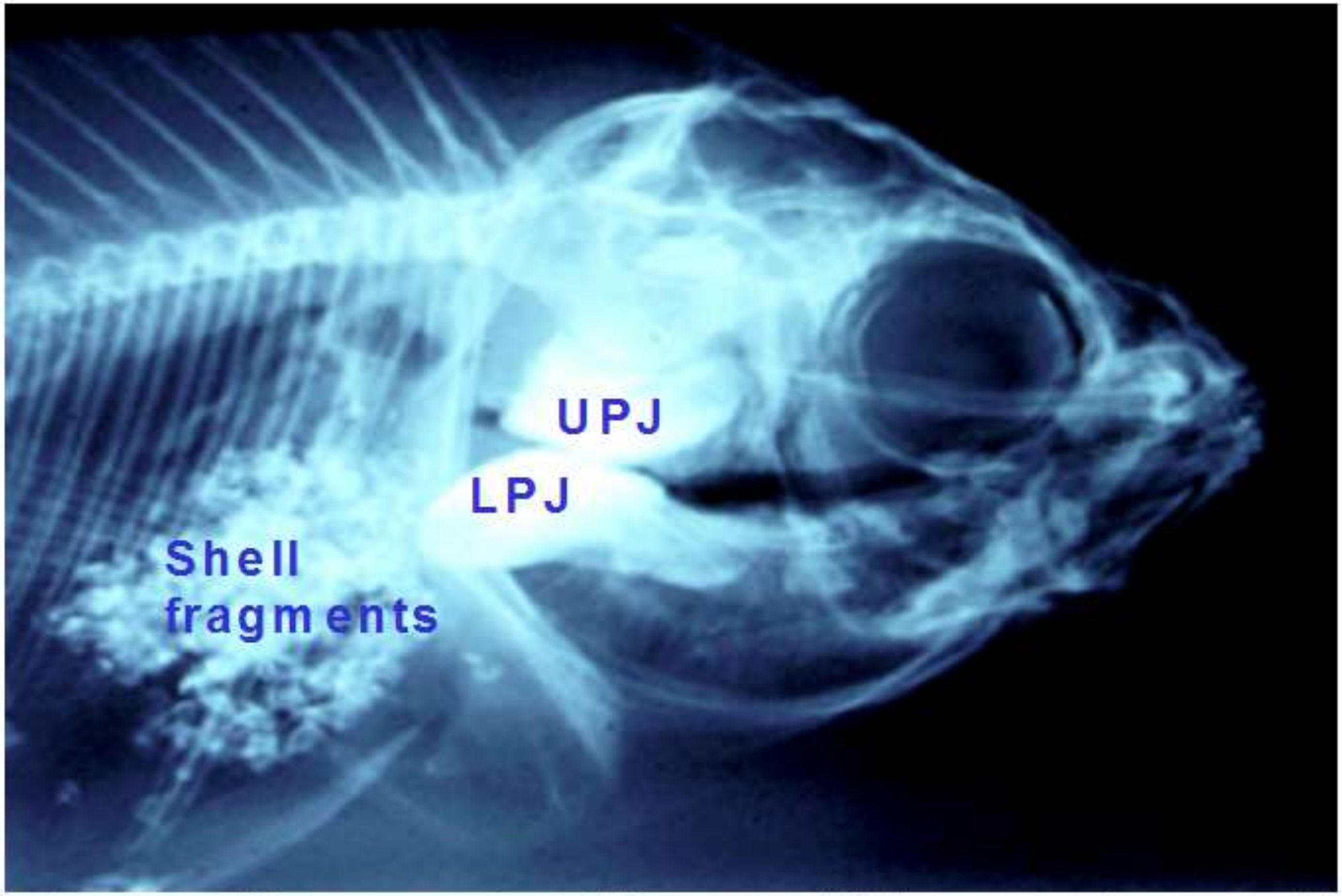


Faryngeální čelisti a dentice





Faryngeální čelisti a dentice



The pharyngeal jaw apparatus of R. vacca. UPJ = upper pharyngeal jaw. LPJ = lower pharyngeal jaw. Together, the UPJ and LPJ shear gastropod shells into tiny fragments, allowing digestive enzymes to break down food, which would otherwise be protected by an intact shell and operculum. Photo by Jeff Jensen.

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LETTERS

Raptorial jaws in the throat help moray eels swallow large prey

Rita S. Mehta[1] & Peter C. Wainwright[1]

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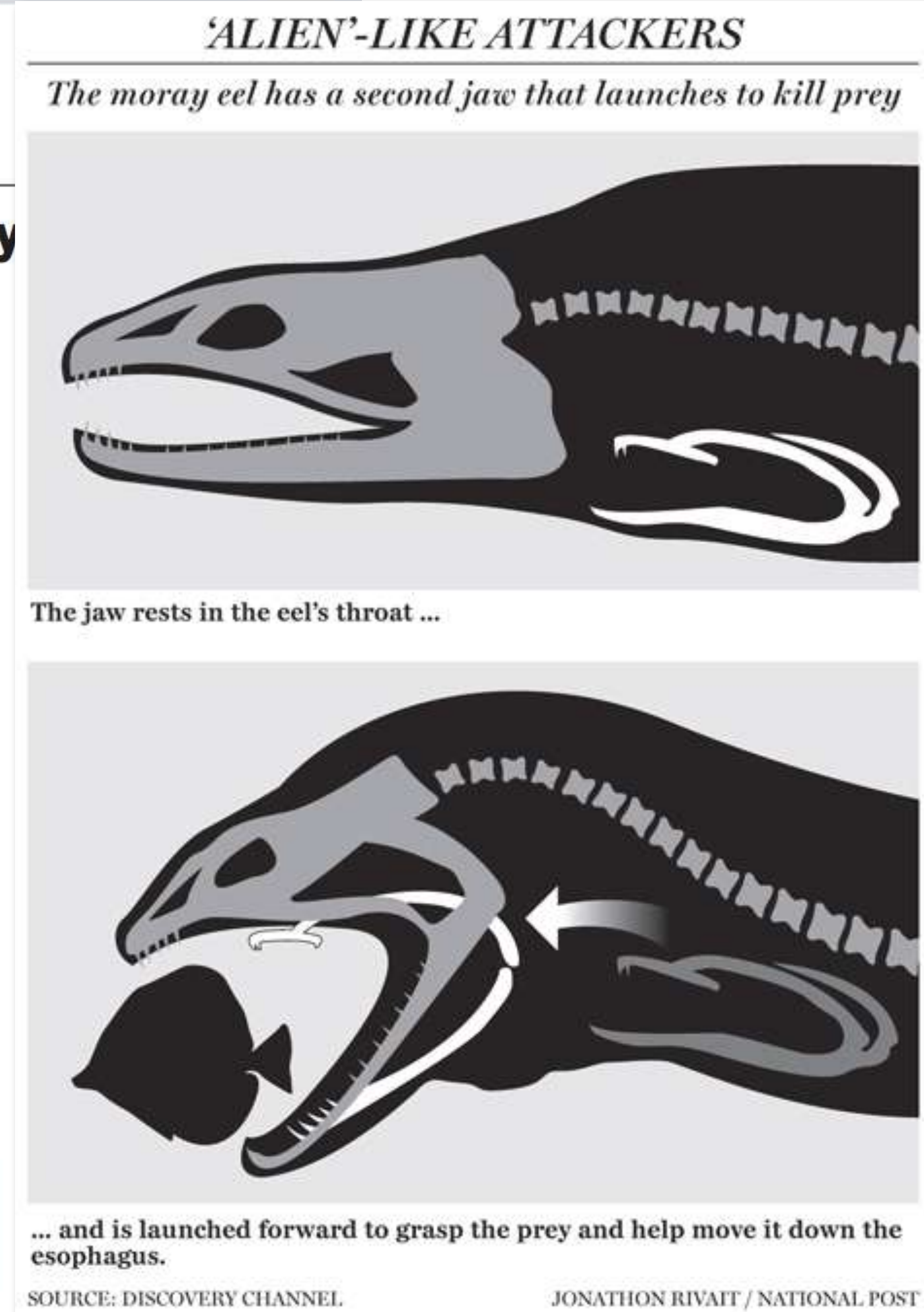


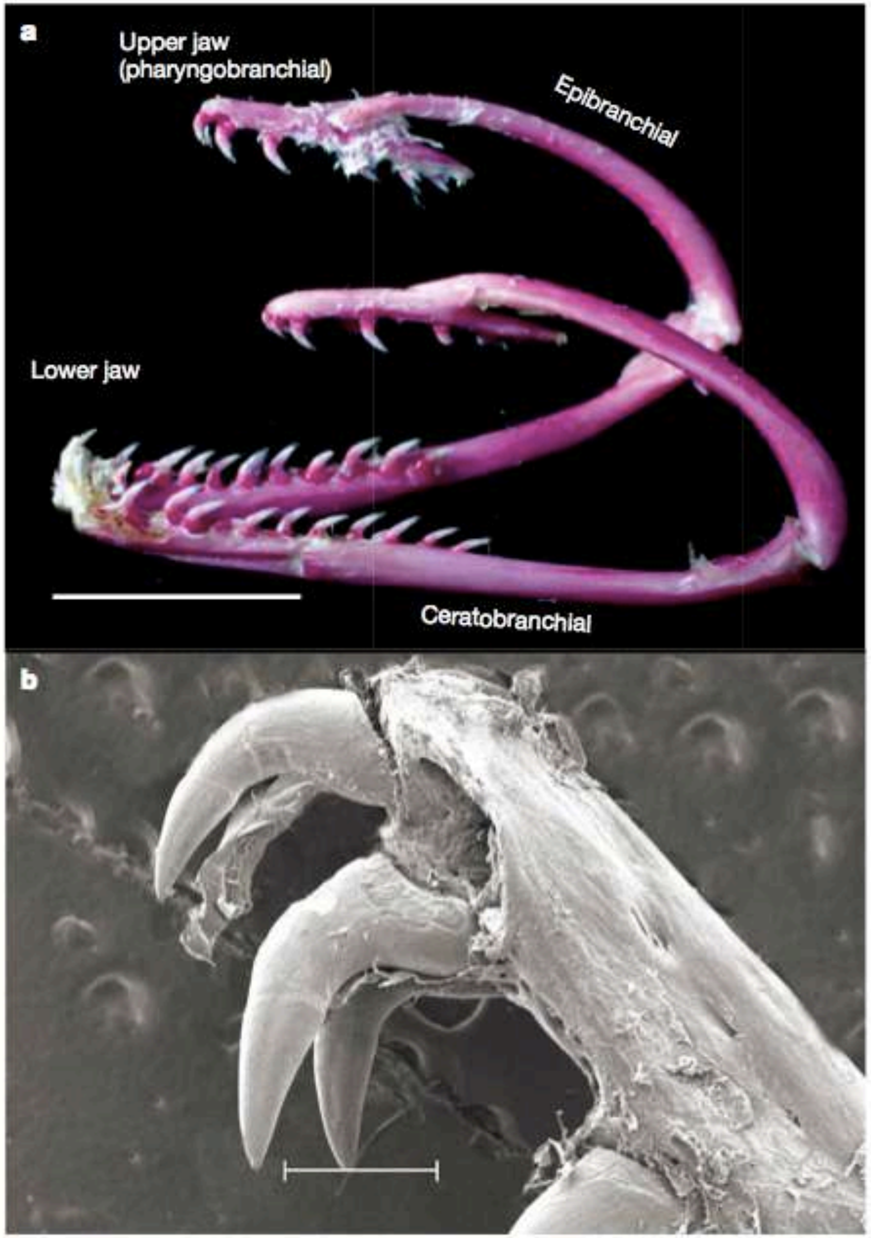


Figure 3 | Detailed anatomy of the pharyngeal jaw apparatus in *M. retifera*. **a**, Left lateral view of a cleared and alizarin red-stained pharyngeal jaw apparatus, illustrating the sharp, recurved teeth on the pharyngobranchials used to grasp prey. Scale bar, 1 cm. **b**, Left anterior upper pharyngobranchial revealing highly recurved teeth. Scale bar, 500 µm.

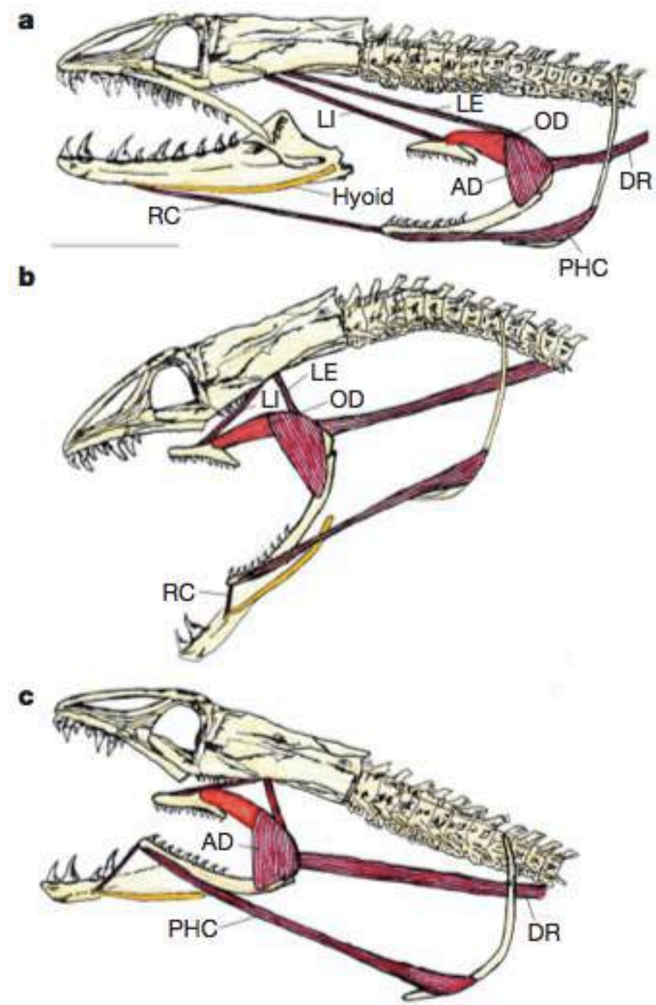
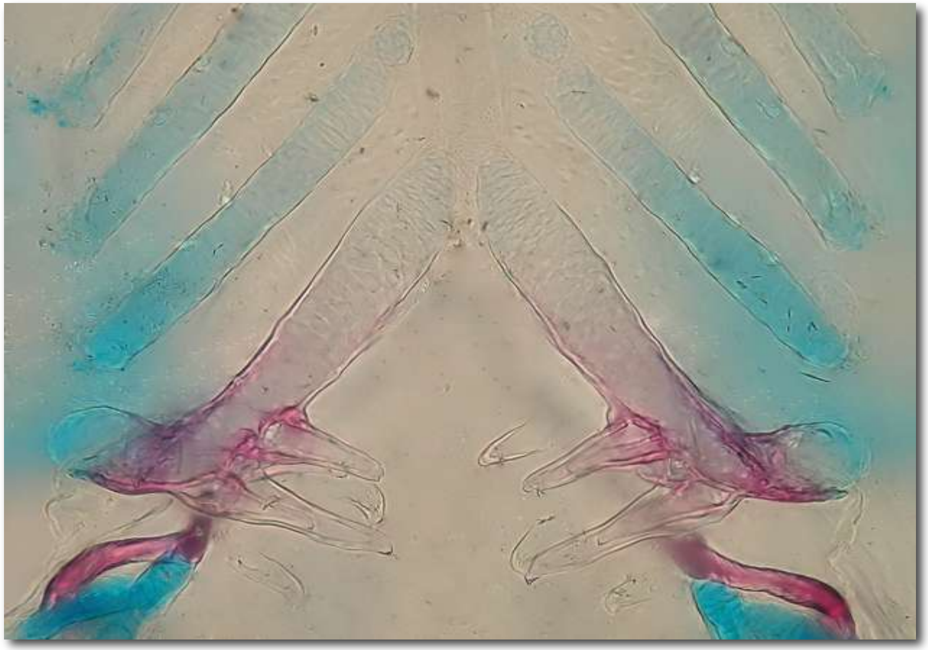


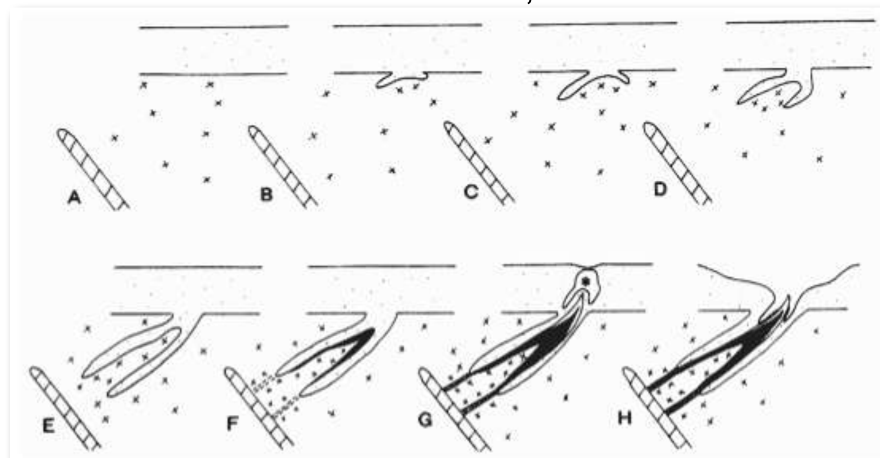
Figure 4 | Functional morphological model of pharyngeal jaw movement in *M. retifera*. The left dentary has been removed in **a–c**, and the left maxilla has been removed in **b** and **c**. **a**, Pharyngeal jaw apparatus at rest. **b**, Pharyngeal jaw protracted: the levator internus (LI) and levator externus (LE) protract the upper jaw into the oral cavity, whereas the rectus communis (RC) protracts the lower jaw. During protraction, the upper pharyngobranchial is dorsally rotated by contraction of the LI and the obliqus dorsalis (OD). **c**, After prey contact, the adductor (AD) contracts to bring the upper and lower jaws together to deliver a second bite. The dorsal retractor (DR) and pharyngocleitheralis (PHC) retract the pharyngeal jaws back to their resting position behind the skull. Scale bar, 1 cm.

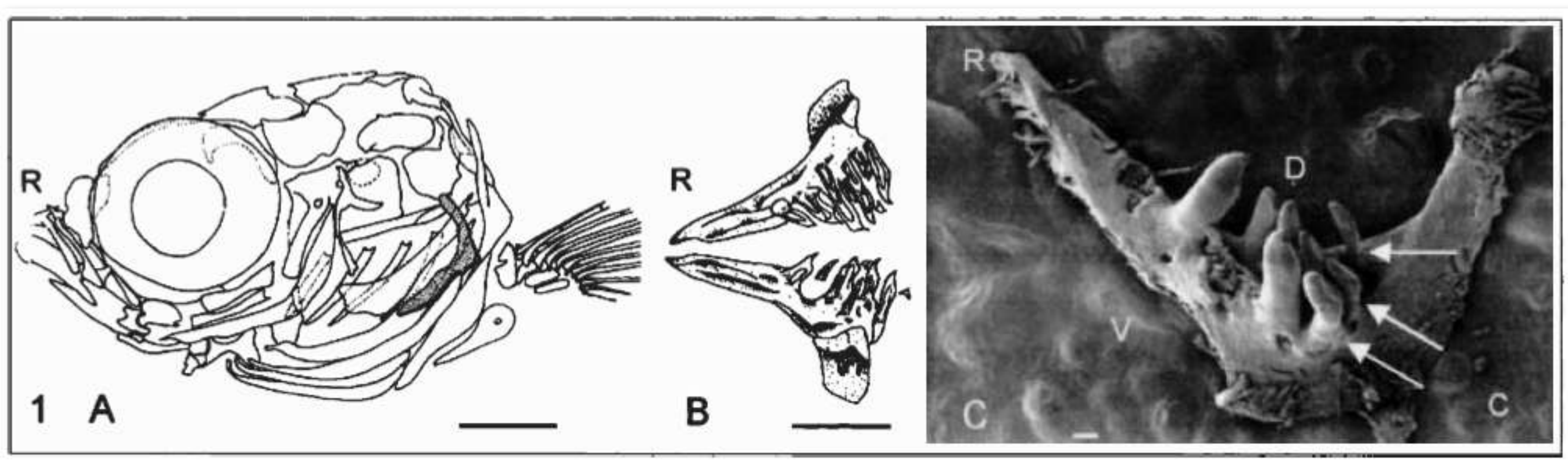


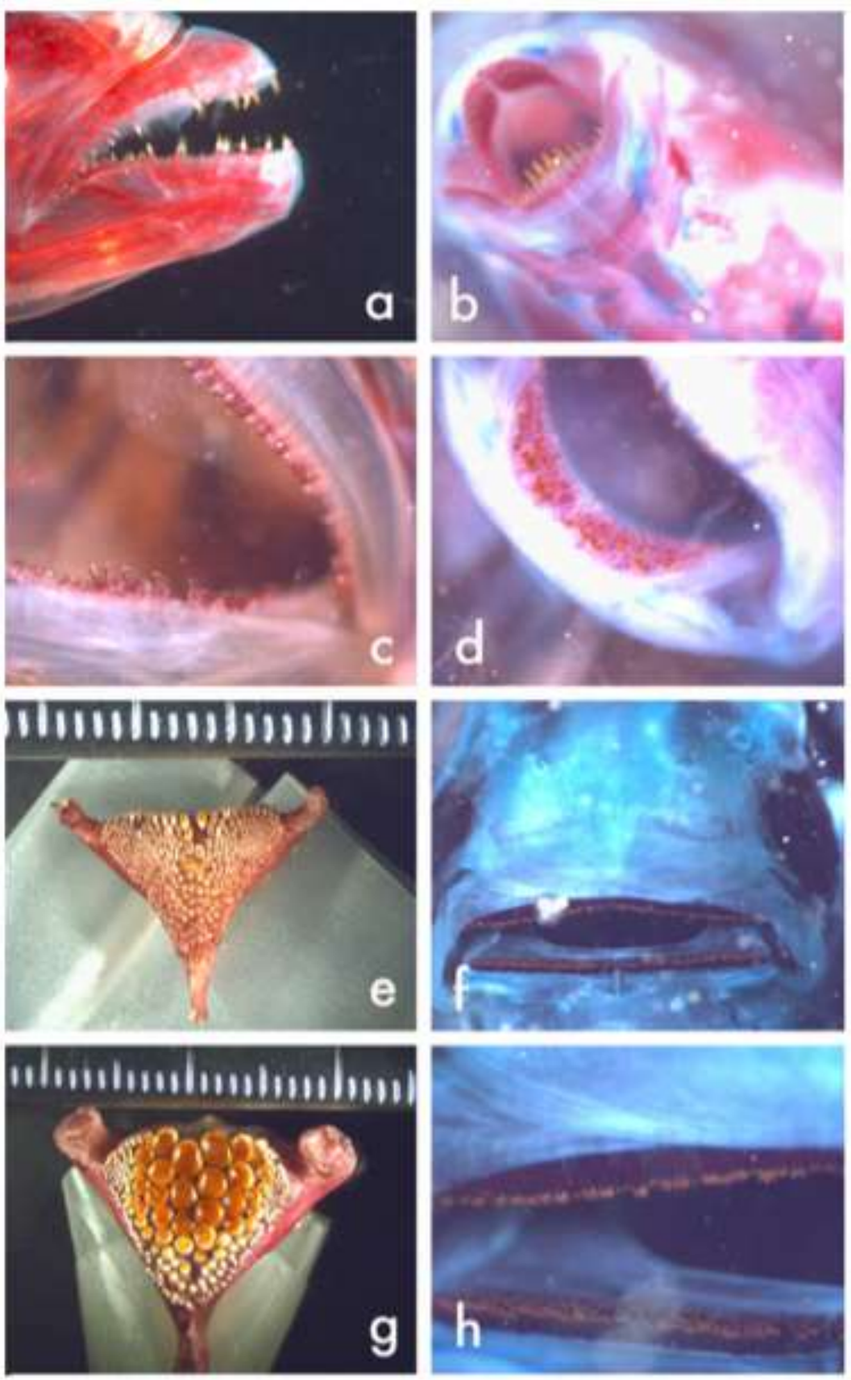
požerákové (faryngeální) zuby: bolen

Kde všude jsou zuby?
Cypriniformes: zuby pouze faryngeální

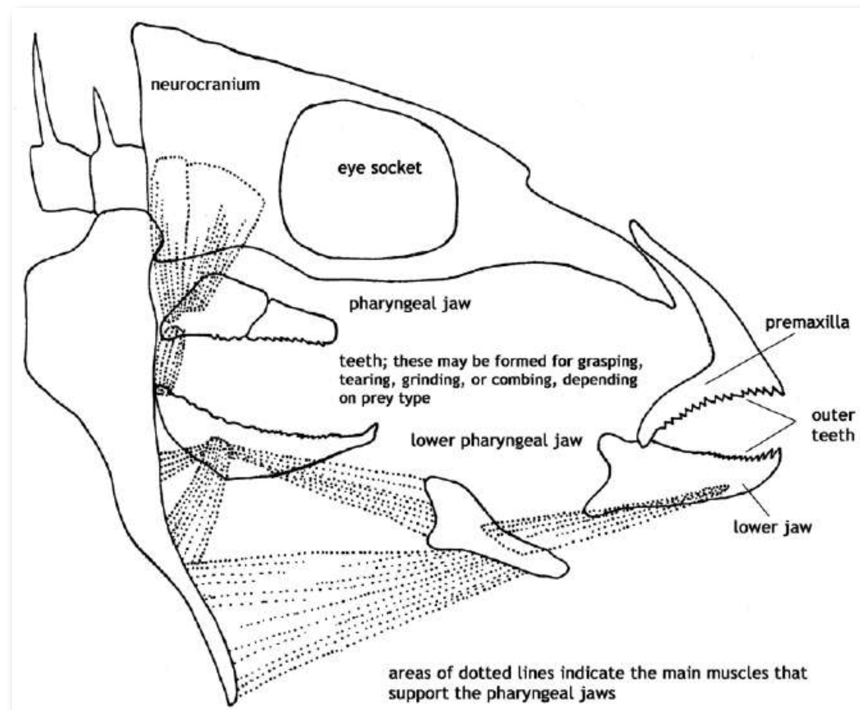
Cypriniformes ztratili orální zuby před cca 50-80 mil lety;
Přes 5 000 druhů v 5-ti čeledích;







Kde všude jsou zuby?
Cichlidy: orální i faryngeální čelisti



Research article

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Independent evolution of the specialized pharyngeal jaw apparatus in cichlid and labrid fishes

Kohji Mabuchi[1], **Masaki Miya**[2], **Yoichiro Azuma**[1] and **Mutsumi Nishida**[1]

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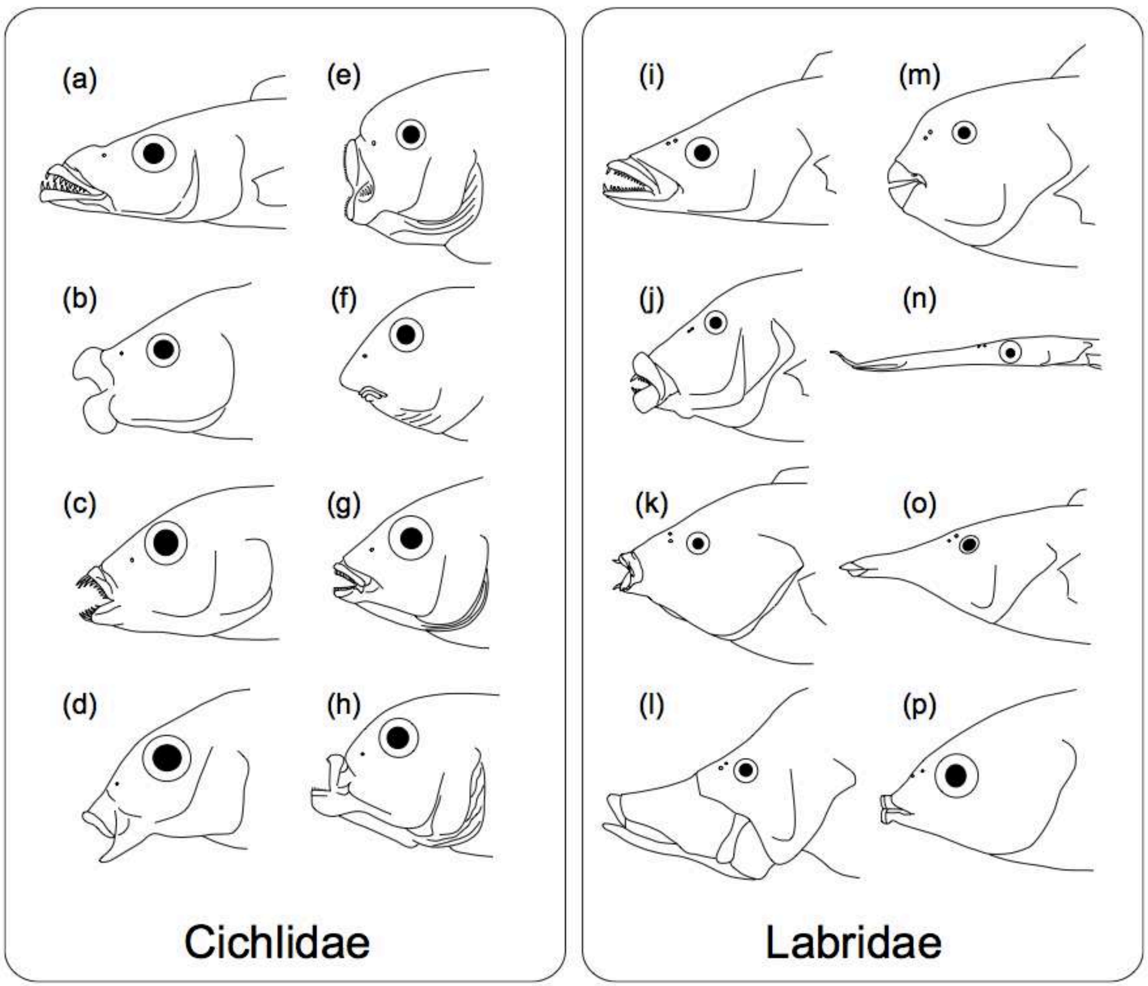
[2]Department of Zoology, Natural History Museum & Institute, Chiba, 955-2 Aoba-cho, Chuo-ku, Chiba 260-8682, Japan



Cichlidae + Labridae
1478 vs. 576 sp.
(suborder Labroidei)

- obrovská druhová diversita
- jedna klíčová inovace: specialisovaný faryngeální aparát
- Unikátní preadaptace?

Research article

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author email, corresponding author email

BMC Evolutionary Biology 2007, **7**:10 doi:10.1186/1471-2148-7-10

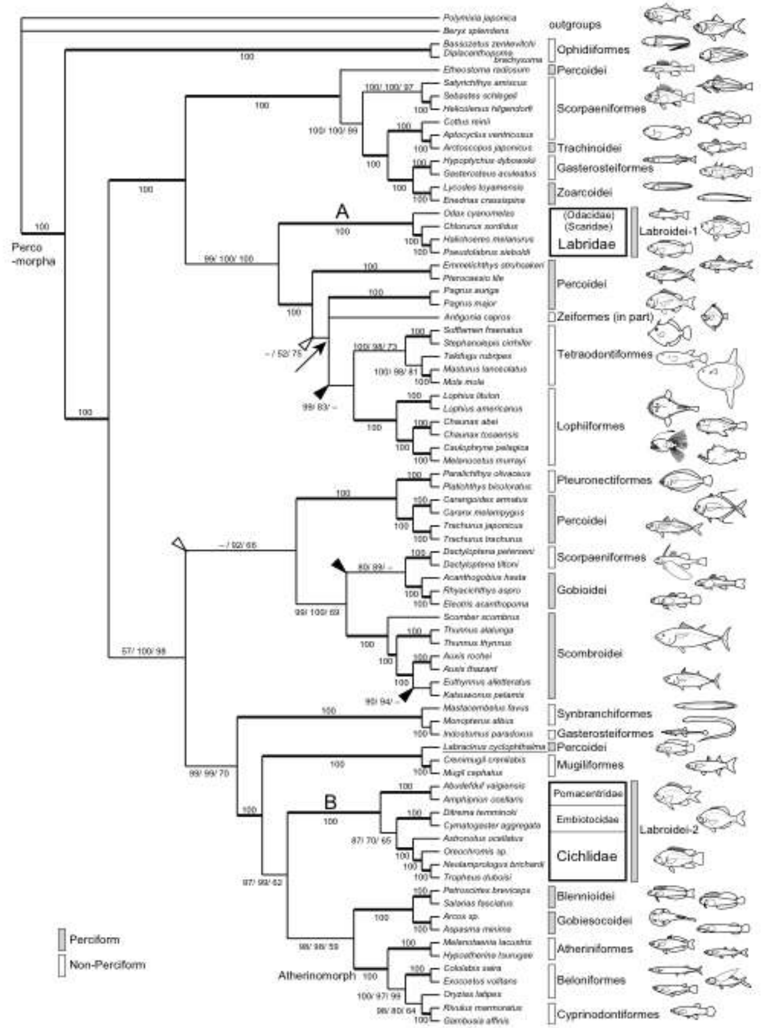
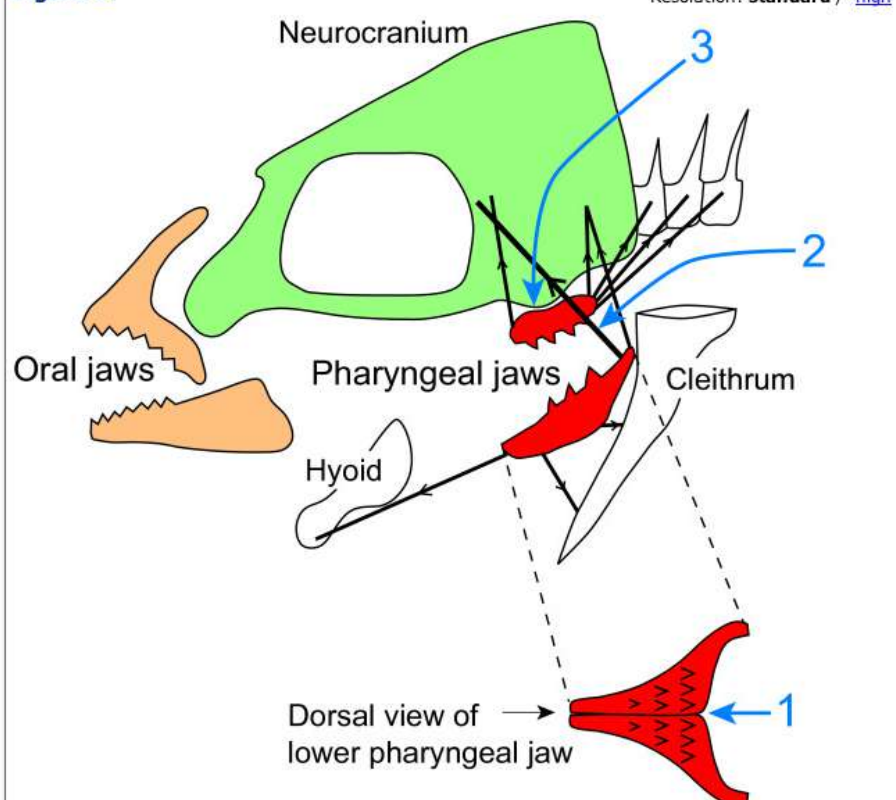


Figure 3
Phylogenetic relationships among Labroid families, based on whole mitochondrial DNA sequences

Figure 2.

Resolution: **standard** / high



Diagrammatic representation of the principal components of the specifically modified PJA of cichlids. Red elements are the upper and lower pharyngeal jaws. The muscles organizing the PJA (pharyngeal jaw apparatus) are represented as black thick lines, and the principal directions of force has been indicated by arrows. The drawing modified from Liem & Greenwood [32]. Numbers indicate three major features of the specialized "labroid" PJA: 1) the left and right lower jaw elements are fused into a single structure, 2) the lower jaw is suspended in a muscular sling that runs from the neurocranium to the posterior muscular arms of the lower jaw, and 3) the upper jaw elements have a diarthrotic articulation with the underside of the neurocranium.

Mabuchi *et al. BMC Evolutionary Biology* 2007 **7**:10 doi:10.1186/1471-2148-7-10

Download authors' original image

Mechanika čelistních struktur Teleostei:

svaly, kosti, zuby a klouby tvoří (překvapivě kinetický) modulární systém se vzájemně propojenými prvky

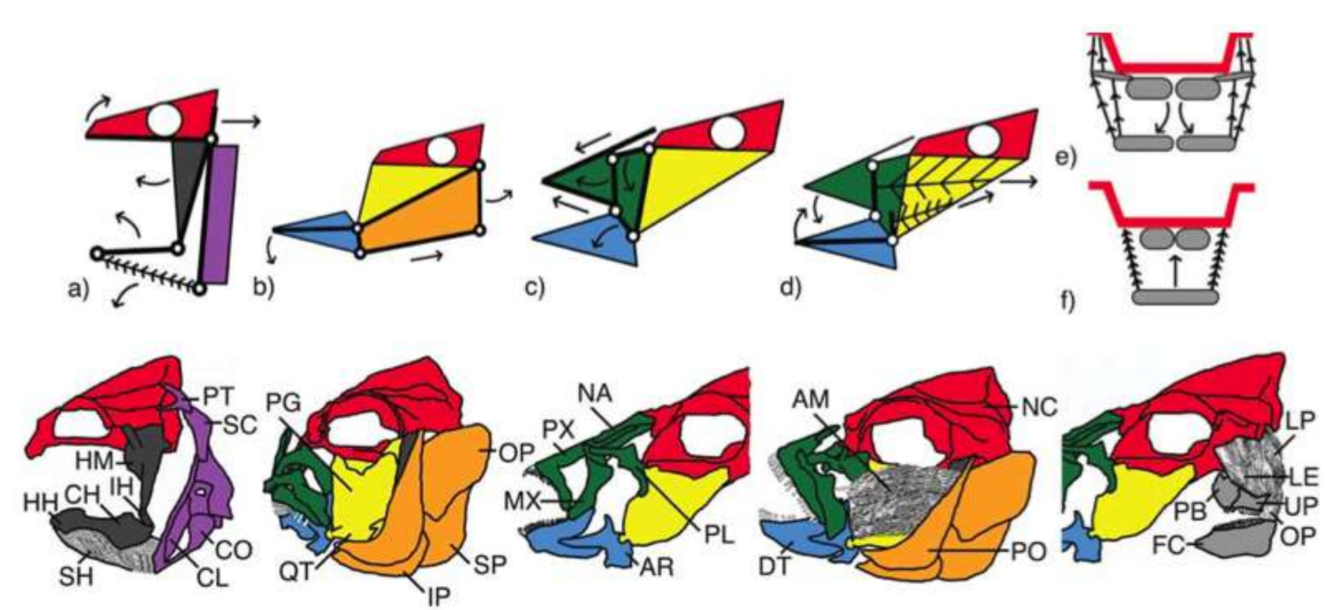
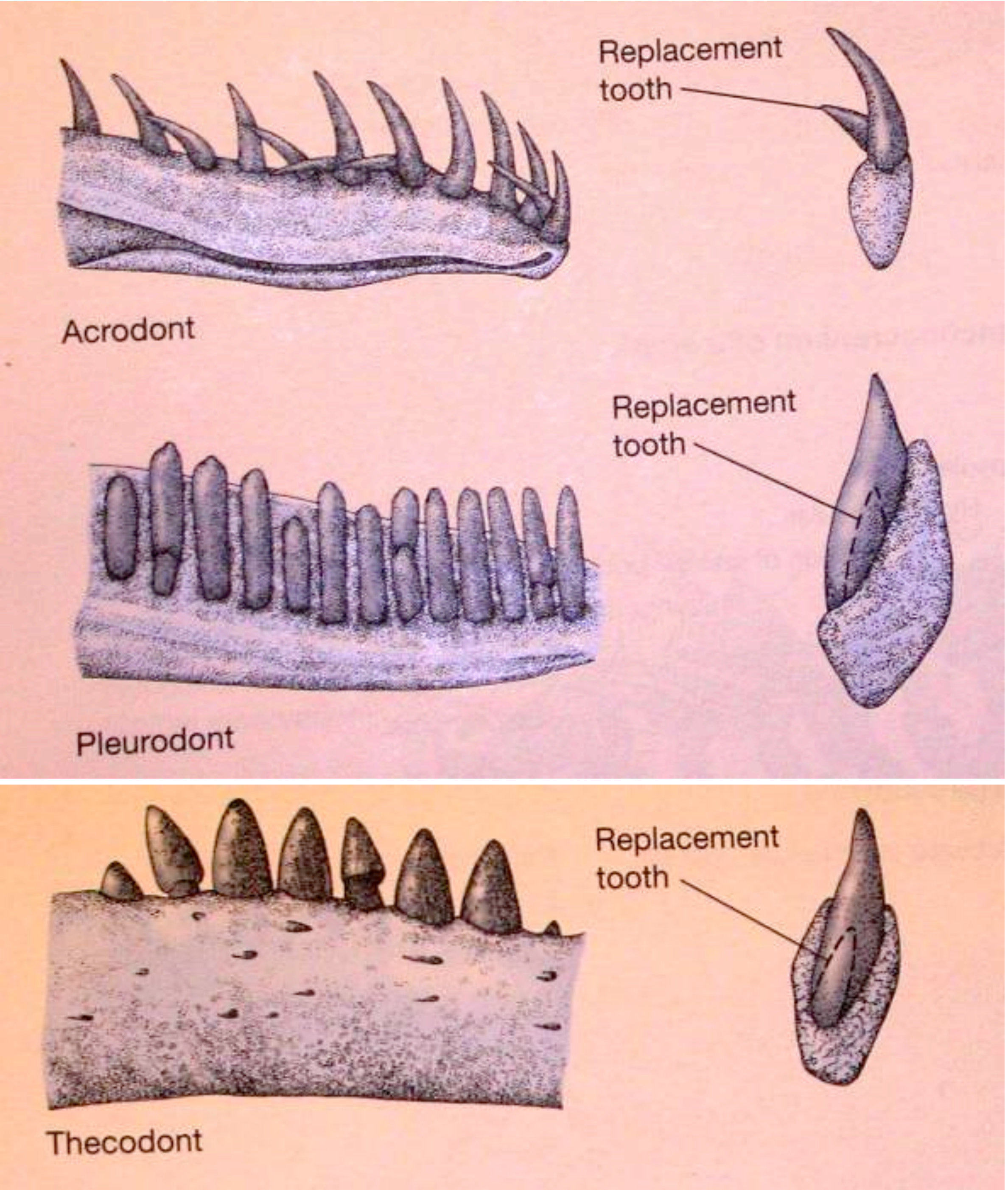


FIG. 2. The bones and muscle that operate during an adult teleost feeding strike can be thought of as functioning like a series of fairly modular but inter-connected mechanical systems. A map of the numerous links (*heavy bars*), joints (*open circles*), muscles (*hashed lines*), and the general direction particular elements move (*arrows*) during the strike for several mechanical levers and linkages in the teleost skull are diagrammed. The morphology of the neurocranium (*red*), hyoid (*dark gray*), pectoral girdle (*purple*), opercular series (*orange*), suspensorium (*yellow*), lower jaw (*light blue*), anterior jaw elements (*dark green*), and pharyngeal jaw elements (*light gray*) are depicted in different colors. Although the elements comprising the particular links and muscles are described in more detail in the text, a basic overview of how the lever systems operate is given here. The feeding strike is initiated (**a**) as the skull is pulled posteriorly via the simple lever-like cranial levation system. As the neurocranium rotates upwards it pulls open the hyoid four-bar linkage system, and the sternohyoideus muscle fires resulting in depression of the hyoid linkage. The depression of the hyoid results in expansion of the buccal cavity and in many fishes (**b**) the initiation of the movement in the opercular linkage. As the opercular series is pulled posteriorly, tension is applied to the interopercular ligament connecting the opercular series to the lower jaw. The lower jaw opening lever system is then depressed and rotates ventrally. The rotation of the lower jaw inputs motion into the anterior jaw four-bar linkage (**c**) resulting in maxillary

Spojení zubu s čelistí



akrodontní (připojovací acelulární kost)

pleurodontní (plná plocha, kolagení spojení, mineralisující cementem

thecodontní - kořeny v alveolech (+cement)

Zcela zásadní inovace chrupu: **Savci**

- **heterodontoní chrup**
- **monofyodontní vícehroté zuby – stoličky s obrovským adaptačním potenciálem**
- **prismatická sklovina**
- **dlouhý postnatální vývoj s mléčnou výživou – dostatek času pro růst a diferenciaci zubů**

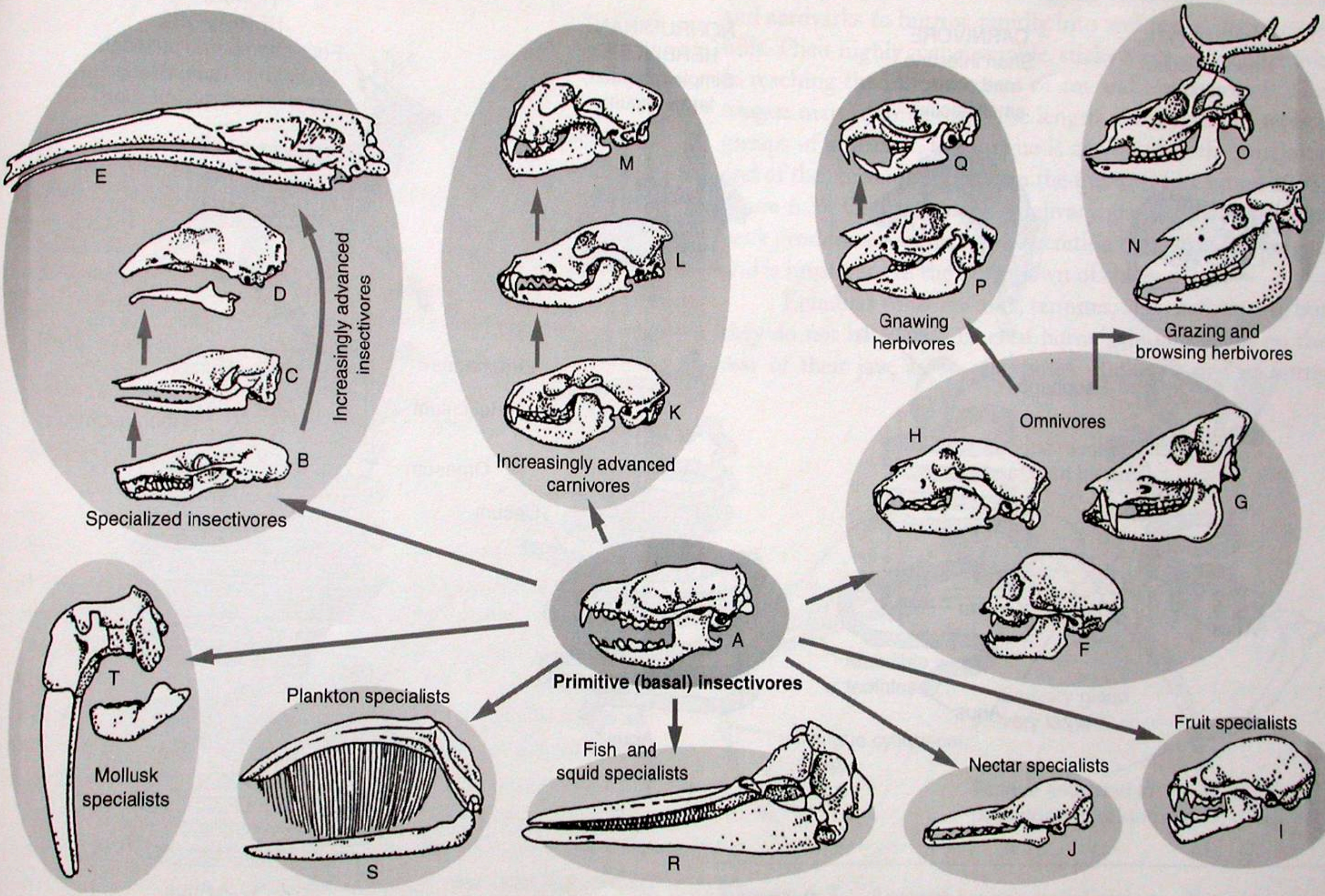


Figure 6.1 **Skull and dentition specialization.** Feeding specializations in the dentition and skulls of mammals relate to their dietary habits: (A) hedgehog, (B) mole, (C) armadillo, (D) anteater, (E) giant anteater, (F) marmoset, (G) peccary, (H) bear, (I) fruit-eating bat, (J) nectar-eating bat,