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Ultraviolet light as a tool for investigating Mesozoic fishes, with a focus on the ichthyofauna of the Solnhofen archipelago

Helmut TISCHLINGER and Gloria ARRATIA

Abstract

A historical review of the discovery and use of ultraviolet light (UV light) in studies of fossils is provided together with a presentation of UV techniques currently used in fossil invertebrate and tetrapod research. Advantages of the use of UV techniques are presented and discussed in detail, as are certain hazards that may derive from the use of these techniques when strict recommendations are not followed. While UV techniques have proven to be important in revealing sutures, other articulations, hidden bones, and/or the presence of soft tissues in fossil tetrapods and invertebrates, they have been scarcely used in fish research. We provide here a few examples documenting the importance of UV techniques in understanding early ontogenetic stages of development, in providing and/or clarifying some morphological characters, and even revealing unexpected new information in fishes (e. g., squamation and formation of vertebral elements in aspidorhynchids; ossification of bones in teleosts). A list of Mesozoic deposits that have given satisfactory results when their fossils have been studied under UV techniques is presented.

Introduction

“The use of ultraviolet fluorescence in the study and photographing of fossils has scarcely received the attention it deserves. By its use, it is said, obscure sutures can be traced, determinations of delicate structures can be made and many other applications are possible.” (CAMP & HANNA 1937: 50). These comments, written as early as in 1937, have to be validated today.

Most skeletal remains and sometimes slightly mineralized soft parts from the Upper Jurassic plattenkalks of southern Germany and from many other Mesozoic deposits are fluorescent under ultraviolet light. During the last 14 years, ultraviolet investigation techniques and ultraviolet-light photography of fossils from the Solnhofen Limestone and other plattenkalks as well as of fossils of the Middle Jurassic to Lower Cretaceous lacustrine deposits of the Jinlingsi and Jehol Group, Northeastern China, have been improved considerably, using powerful UV lamps and enhanced photographic documentation techniques. Predominantly dinosaurs, pterosaurs, lepidosaurs, *Archaeopteryx*, and some invertebrates occupied most of the recent attention (FREY & TISCHLINGER 2000; POLZ & TISCHLINGER 2000; TISCHLINGER 2001, 2005a,b; CZERKAS 2002; TISCHLINGER & FREY 2002; FREY et al. 2003; TISCHLINGER & UNWIN 2004; WELLNHOFER & TISCHLINGER 2004; GÖHLICH et al. 2006; HAUG et al. 2009; HENDRICKS 2009; TISCHLINGER & WILD 2009; FUCHS et al. 2010; HONE et al. 2010; KELLNER et al. 2010; SCHWEIGERT et al. 2010; HAUG & HAUG 2011). During the last few years also a number of fishes from the Solnhofen Limestone and other plattenkalks from the Solnhofen archipelago were investigated (e. g., crossognathiform teleosts: ARRATIA & TISCHLINGER 2010: figs. 3, 6; juvenile teleost: EBERT & KÖLBL-EBERT 2010: fig. 5b, KONWERT 2011: pls. 1A, 2A, 3A; squatinid and aspidorhynchiform: KÜMPEL & TISCHLINGER 2010: figs. 3, 4, 6; chondrichthyans: PFEIL 2010: figs. 23, 24; 2012: figs. 5–6, 8–13, 18). In addition, ultraviolet investigation techniques and UV pictorial documentation were tested successfully on various fossils including fishes from different Mesozoic deposits (e.g., a ichthyodectiform: RIQUELME et al. 2009); however, its use is uncommon among fish paleontologists. Our main goal here is to provide information concerning recommended UV techniques and document our claims with some examples of Jurassic fishes that clearly illustrate the benefit of using UV light in certain cases.

Historical review 1926–2000

Apparently not earlier than in the 3rd decade of the 20th Century the application of ultraviolet light for paleontology was discovered. In 1926 George Gaylord SIMPSON described the discovery that some remains of vertebrates fluoresce when excited by ultraviolet rays (SIMPSON 1926). In the same year and independently from him Ernst WAGNER from Jena, Germany, studied fossils under ultraviolet radiation (WAGNER 1928a,b). Interestingly one of the first ultraviolet images of a fossil showed the anterior half of *Caturus furcatus*, a typical predatory fish of the Solnhofen Limestone (MIETHE & BORN 1928: 349). At this time MIETHE (1927), DREVERMANN (1927), BORN (1928), DAQUÉ (1928) and LAMBRECHT (1928a,b) emphasized the significance of ultraviolet radiation in paleontological research and figured some reptiles and crabs from the Solnhofen Limestone. A few years later, textbooks dealing with fluorescence analysis were available (e.g., RADLEY & GRANT 1933, CAMP & HANNA 1937, DÉRIBÉRÉ 1938) but the acceptance of this new technique lacked popularity among paleontologists and especially among paleoichthyologists for a long time. During the ensuing decades, mainly invertebrates were documented with a focus on crustaceans (e.g., LÉON 1933, 1934). One of the reasons for the reluctance to use ultraviolet light might be the obvious fact that under the available low powered lights and with basic photographic techniques only very brightly fluorescing structures such as carapaces of crustaceans, bones and other hard parts were visible. The 2nd half of the 20th Century provided a substantial increase in publications on ultraviolet investigations (e.g., BEER 1954, FISCHER 1954, ROLFE 1965, KRUEGER 1974) but generally fishes were excluded with few exceptions (e.g., ROLFE 1965: 352, 354). Starting in 1971 Hermann POLZ improved the UV pictorial documentation of Solnhofen crustaceans (cf. POLZ 1996), which greatly influenced the further enhancement and elaboration of UV techniques starting in the last decade of the 20th Century (TISCHLINGER 2002). Overall, publications based on ultraviolet investigations of fishes were not very common in the 20th Century, but nevertheless during this time the use of fluorescent lamps has remained an important and consistently utilized tool for detecting restorations and artificially enhanced or totally forged fossil fishes. In one of the very first papers on the uses of ultraviolet rays in paleontology, the authors emphasized the usefulness of ultraviolet light to identify forgeries of any kind (MIETHE & BORN 1928).

Artificial ultraviolet light

UV Lamps. Ultraviolet light is an electromagnetic radiation with a wavelength shorter than that of visible light, but longer than X-rays, in the range 10 nm to 400 nm. Artificial ultraviolet lamps in principle consist of a power supply, the UV bulb, the mechanical enclosure, and a UV filter. UV bulbs and filters are optimized for best operation in a specific fraction of the UV spectrum. Lamp emissions typically range from 100–280 nm (UV-C, short wave ultraviolet, maximum at 254 nm), from 280–320 nm (UV-B, midwave ultraviolet, maximum at 312 nm) and from 320–400 nm (UV-A, longwave ultraviolet, Black Light or Woods Light, maximum at 365 nm).

Information on ultraviolet radiation, fluorescence, luminescence, different types of UV bulbs, and lists of dealers selling UV lamps is available comprehensively online.

Hazards and safety precautions. Like the sun's electromagnetic radiation, artificial UV can be dangerous, causing permanent and harmful skin conditions, e.g., malignant melanoma or other skin cancers. All categories and wavelengths of ultraviolet radiation including UV-A, which in the past was considered less harmful, can contribute to skin cancer via indirect DNA damage (free radicals and reactive oxygen species); artificial UV-lamps therefore can be a major concern for human health (cf. MATSUMURA & ANANTHASWAMY 2004). Short-wave and midwave UV sources and, to a minor degree, UV-A sources produce ample amounts of ozone. Working in a small room for a longer time will increase the ozone level. Ventilating the workplace and getting some fresh air is essential. Especially when working near short wave (UV-C, ~254 nm) and medium wave (UV-B, ~312 nm) UV radiation, it is imperative to wear gloves, long-sleeved clothing, and UV-blocking goggles. Even short and indirect exposure to UV-C and UV-B on unprotected skin or eyes should be avoided. Long-wave radiation (UV-A, ~365 nm) is less dangerous but protective goggles should also be worn, since some specimens are highly reflective, especially when illuminated with high-intensity UV-A sources. When unprotected eyes and skin are exposed to artificial UV-A, the recommended T_{max} values of the manufacturers, usually between 5 and 20 minutes, must not be exceeded. In any case it is safer to cover skin and eyes with clothing and UV-blocking goggles right from the start of any UV investigation.

Ultraviolet light investigations on Mesozoic fishes

In a considerable number of Mesozoic fishes, many details of skeletal remains as well as soft parts can be more precisely investigated in ultraviolet light than in visible light. Occasionally the contrast between the fossil and the matrix is enhanced enormously. Delicate skeletal elements including different bony components, scales, and remains of soft parts sometimes are poorly or not discernible in visible light, but are revealed conspicuously under UV. The luminescence ceases when the UV radiation is removed. This type of luminescence is known as fluorescence. Calcium carbonate, calcium phosphate (fluorapatite), fossils with traces of organic material or remains of uranium-bearing minerals tend toward significant fluorescence emission. Elemental composition analysis (EDX analysis) performed by HAUG et al. (2009) showed significant differences in element composition between fossils and the matrix of specimens from Solnhofen and Lebanon. While both the matrices and the fluorescent arthropod cuticles contained oxygen, carbon, and calcium, the fossils, but not their matrices, contained phosphorus, about 6 % in the Solnhofen specimen and about 14 % in the arthropod from Lebanon (HAUG et al. 2009). Bones of vertebrates usually contain a much higher percentage of phosphorus. Therefore at various localities it is possible to search for vertebrate fossils with ultraviolet lamps in the field at night. This may result in significantly more specimens than searching during daylight hours (CROFT et al. 2004, HECKER & HEYNG 2011). In fossil fishes, the presence of apatite results in excellent fluorescence and facilitates optimising the visualisation of the specimen. If the fossil remains are not fluorescent, another method to enhance visiblity is sometimes possible: by accentuating the fluorescence of the sediment, details of the fossil are sometimes seen as prominent dark areas.

UV techniques can be used to show hidden bony sutures, and to separate bones, scales or soft parts from the underlying matrix or each other. It is advisable to study the details under a stereo-microscope equipped with special compensation filters. The filters are placed on the microscope objective lens. The filters on the lens do not alter the wavelength of the UV source but their proper application allows maximum contrast between fluorescent bones, scales, or soft parts and non-fluorescent or poorly fluorescent matrix. The last filter must be a UV Filter, which blocks UV light up to 390 nanometers (e. g., see figs. 12A, 13A,B in SCHULTZE & ARRATIA this volume). The optimum wave length of the UV lamps as well as the number and character of the compensation filters should be tested experimentally and substantially depend on the sediment and the nature of the fossil (TISCHLINGER 2002). The right combination is needed to highlight the area of interest in each specimen. Interestingly, as a rule, rarely will two specimens from the same layer fluoresce equally strongly. For our investigations in the Solnhofen Lithographic Limestone and other plattenkalks of the Solnhofen archipelago, we predominantly use high-performance UV-A lamps with a wavelength of 365−366 nm. Powerful modern UV-A lamps guarantee a UV intensity between 4000 and more than 90 000 microwatts per cm², depending on the distance concerned and the number of lamps.

In contrast to the several publications using UV techniques with tetrapods that have been recovered in the Solnhofen limestones, the technique has been rarely used in fish research. One example is the publication regarding the first record of a Jurassic crossognathiform *(Bavarichthys incognitus)* from Europe by ARRATIA & TISCHLINGER (2010). Using the UV technique, ARRATIA & TISCHLINGER (2010: figs. 3 and 6) demonstrated the presence of a complete series of supraneurals and other bones in the precaudal region of the crossognathiform *Bavarichthys*, and also the presence of thin intermuscular bones and fine elongate epineural processes in the caudal region. The same UV techniques can be used in a variety of fishes to reveal details, or to clarify uncertain morphological descriptions and characters, and to provide valuable information about ontogenetic transformations.

Larvae, small young fishes, and juveniles are commonly disregarded by collectors and researchers, so that few are catalogued in museums worldwide. Despite the fact that larvae and small young fishes seem to be uninformative under “normal” light, they may reveal some remarkable and new features when they are photographed under UV light. To support this statement we will introduce the reader to new

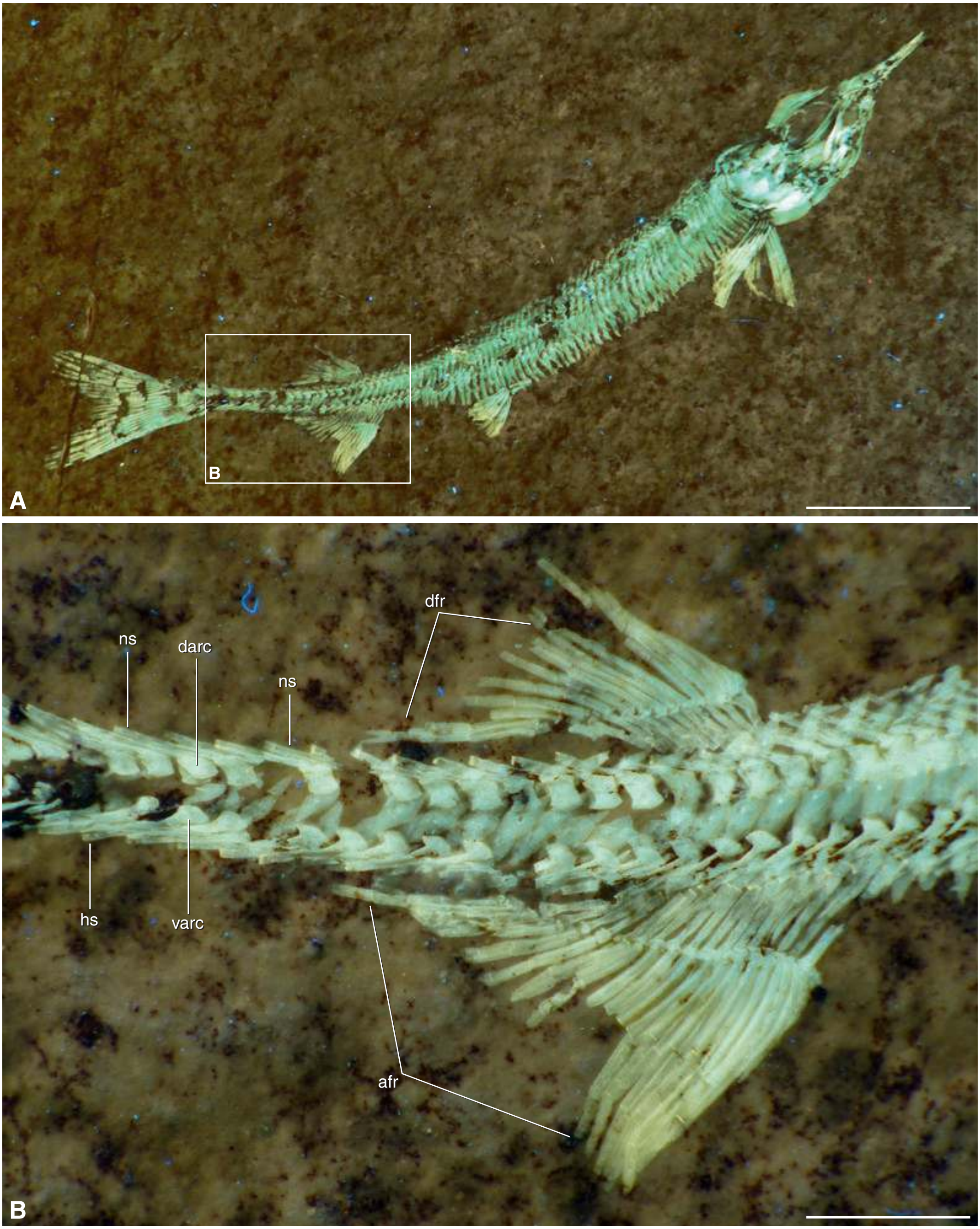

Fig. 1.
Indeterminate aspidorhynchid under UV light. Specimen of about 58 mm standard length from the Upper Jurassic of Eichstätt, Bavaria, Germany. **A,** complete specimen. Note the complete and heavily ossified squamation in the anterior part of the body in contrast to the incomplete squamation in the caudal region. Scale bar = 10 mm. **B,** dorsal and ventral arcocentra and spines in the caudal region. Arrows point to the paired condition of the neural spines. Scale bar = 2 mm. Abbreviations: **afr**, anal fin rays; **darc**, dorsal arcocentra; **dfr**, dorsal fin rays; **hs**, haemal spine; **ns**, neural spine; **varc**, ventral arcocentra.

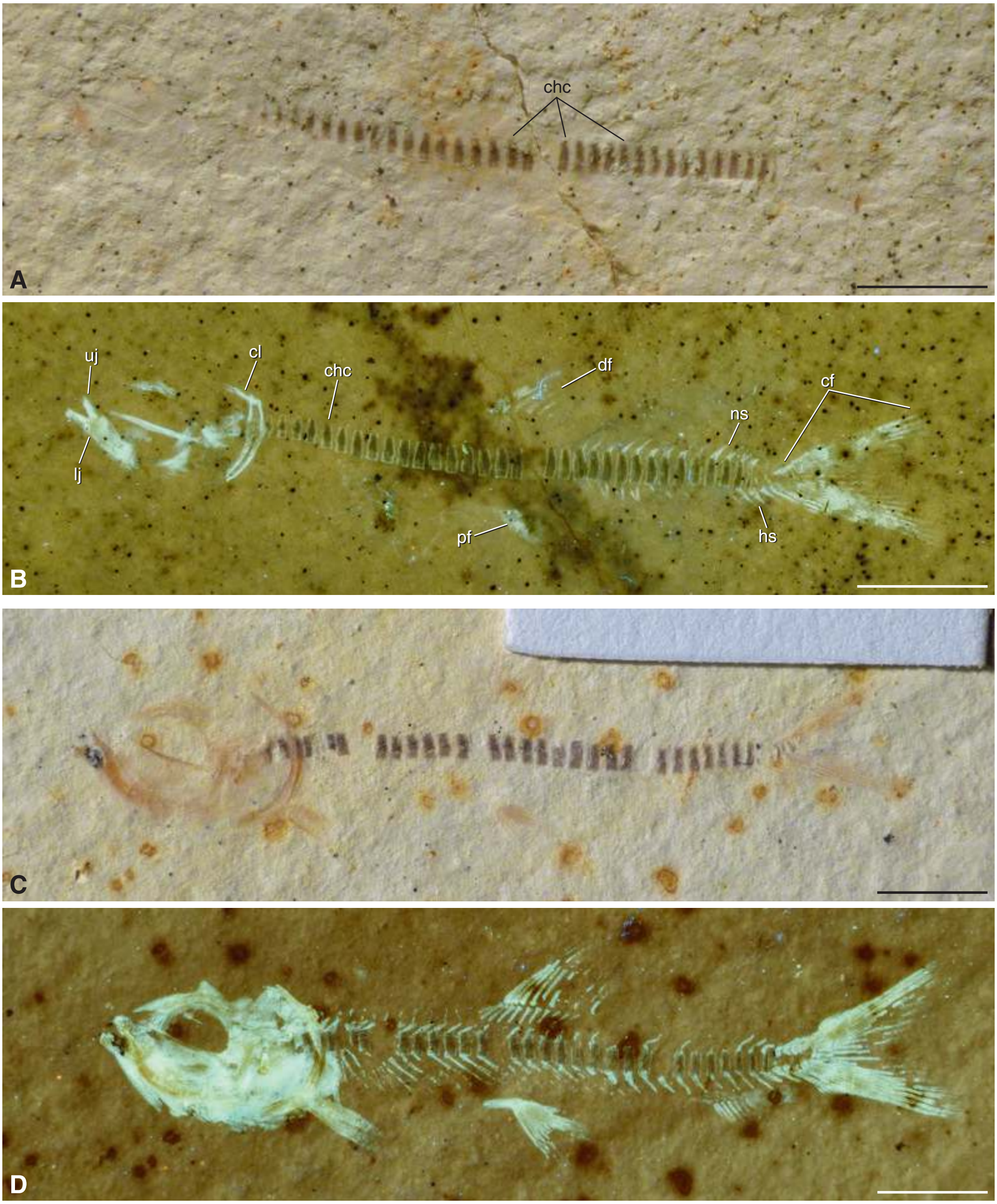

Fig. 2.
Orthogonikleithrus hoelli ARRATIA, 1997 from the Upper Jurassic of Ettling, Bavaria, Germany. **A,** specimen JME-ETT365 (about 12.5 mm SL) under "normal" light. **B,** the same specimen illustrated in A, but photographed under UV light. **C,** specimen JME-ETT783 (about 14 mm SL) under "normal" light. **D,** the same specimen illustrated in C, but photographed under UV light. Abbreviations: **cf**, caudal fin; **chc**, chordacentra (see text for explanation); **cl**, cleitrum; **df**, dorsal fin; **hs**, ossified haemal spine plus arch; **lj**, lower jaw represented by lateral portions of dentary and angular; **ns**, ossified neural spine plus arch; **pf**, basipterygium and pelvic fin; **cl**, supracleithrum; **uj**, upper jaw represented by maxilla; **vc**, vertebral centrum including chordacentra surrounded by autocentra. Scale bars = 2 mm

information on some early stages of development in Late Jurassic aspidorhynchids and the basal euteleost *Orthogonikleithrus hoelli*.

Example 1: Late Jurassic aspidorhynchid

The smallest aspidorhynchid that we are able to report from the Solnhofen limestone is about 58 mm in standard length (SL; see Fig. 1A). It was illustrated first by KÜMPEL & TISCHLINGER (2010: fig. 6), and is currently under study by us. This specimen, which under "normal" light provides modest information about its characteristics, is especially important when studied under UV light. We provide two examples of relevant new information, the first concerning scales and the second on the vertebral column.

The ~58-mm SL aspidorhynchid reveals that its scales (Fig. 1A) are highly developed and strongly ossified in the anterior part of the body, especially behind the pectoral girdle (site 3 of SIRE & ARNULF 1990), indicating a process of development advancing from an anterior-to-posterior direction. At this stage of growth the fish has ossified most of its ganoid-type scales (sensu SCHULTZE 1966, 1996), with the exception of those of the caudal region, especially the caudal peduncle, where the small scales are just appearing or are still absent. A similar antero-posterior pattern is observed also in a slightly longer aspidorhynchid of about 62 mm SL, indicating that the caudal peduncle is the last region to be covered by scales. The lateral-line scales present in the caudal region are comparatively thinner than those of the anterior part of the body and they are missing completely near the tail (Fig. 1B). In contrast, in most teleosts and other fishes (SIRE & ARNULF 1990 and references therein) the common pattern of the beginning of development of scales is in the lateral line in the tail region; however, the pattern varies among fish groups and even within a family and within species (e. g., WADE 1935, ARMSTRONG 1973, SCHULTZE & BARDACK 1987, SIRE & ARNULF 1990). The pattern shown by the young aspidorhynchids reported here seems to be similar to that present in *Amia calva*, in which the scales appear at the lateral line just posterior to the pectoral girdle and from there develop posteriorly (JOLLIE 1984a). In contrast, in *Lepisosteus* the scales appear in the lateral line in the region of the tail and from there extend anteriorly (JOLLIE 1984b), as it has been reported for many teleosts (see SIRE & ARNULF 1990: tb. 1).

Adult aspidorhynchiforms are interpreted as possessing unpaired, median neural spines in the caudal region, a generalized condition present in most but not all actinopterygians (for more information see ARRATIA et al. 2001: 149). Our ~58-mm SL specimen exhibits several conditions: (1) the notochord is persistent and unchanged, (2) the chordacentra are not yet formed, and (3) pairs of dorsal and ventral arcocentra (Fig. 1B) are already well developed and ossified and they are the main elements forming the vertebrae. Each dorsal arcocentrum extends postero-dorsally in a short projection or neural spine that is perichondrally ossified. Left and right neural spines are unfused medially. In a slightly longer specimen (62 mm SL) the neural spines of the most posterior caudal region are long and seem to be fused medially. However, the neural spines are paired in arcocentra that are positioned just below and immediately posterior to the dorsal fin. This new information suggests that the condition of the neural spines of the whole caudal region in Jurassic aspidorhynchiforms is poorly understood. Are all caudal neural spines unpaired or is the unpaired condition retained at the beginning of the caudal region in adult aspidorhynchiforms? To answer this simple question may be a difficult task given that large, well-developed flank scales obscure the vertebral column in most large specimens of aspidorhynchids.

Example 2: Late Jurassic euteleost

An ontogenetic series of the basal euteleost *Orthogonikleithrus hoelli* ARRATIA, 1997, is our second example. The beginning of ossification of dermal and chondral bones is a field that has caught the attention of numerous ichthyologists for a long time (e. g., PARKER 1873, GEGENBAUER 1978, GAUPP 1903, BEER 1937). The appearance of different bones of the head or of the postcranial skeleton is currently presented in detailed tables where the beginning of chondrification and of ossification for each bone of the skeleton is reported (e. g., percomorph *Betta*: MABEE & TRENDLER 1996; cypriniform *Danio rerio*: CUBBAGE & MABEE 1996; gonorynchiform *Chanos chanos*: ARRATIA & BAGARINAO 2010; esociform *Esox*: BURDI & GRANDE 2010). As far as we know, there is no information from fossil teleosts comparable to that in Recent teleosts regarding the beginning of bone appearance. However, the UV techniques are a major help when studying larval stages or very young and juveniles of some fossil teleosts. An ontogenetic series of *Orthogonikleithrus hoelli* shows some results of our studies under UV light. The material is deposited at the Jura-Museum in Eichstätt, Germany (JME).

Orthogonikliethrus hoelli is a small fish that may reach about 50 mm in maximum length (ARRATIA 1997: 80). When our smallest specimen (about 12.5 mm standard length) is observed under "normal" light, the presence of chordacentra is somehow the only indication that these remnants could represent a fossil fish. When the fossil (Fig. 2A) is observed under a microscope, evidence of certain thin ossifications in the head and tail can be detected. However, when the fossil is observed under a microscope equipped with UV light, it confirms that this is a fish (Fig. 2B). In addition, observation using UV light gives significant information about its early development. For instance, the fish has already ossified cranial dermal bones such as the parasphenoid, maxilla, and lower jaw (dentary and angular regions preserved in lateral view; Fig. 2B). However, the premaxilla seems to be unossified, or else it was not preserved. In contrast, other dermal cranial bones are just beginning to ossify, e. g., the parietal bone [= frontal bone of traditional terminology], entopterygoid, opercle, and preopercle. Among the chondral bones, the basioccipital and the exoccipital are ossifying. The degree of ossification confirms that the parasphenoid is one of the first bones to ossify, a condition that is known also in modern teleosts (e. g., *Esox*: PEHRSON 1944, JOLLIE 1984c; *Barbus*: VANDEWALLE et al. 1992; *Danio*: CUBBAGE & MABEE 1996; *Chanos*: ARRATIA & BAGARINAO 2010).

In the postcranial skeleton we observe that the vertebral column is represented by chordacentra (Fig. 2B) apparently surrounded by thin, almost translucent autocentra with the neural and haemal arches and small spines of the mid-caudal region already ossifying. However, the neural arches and spines and parapophyses of the abdominal region are not yet ossified. The dermal supracleithrum and cleithrum (completely formed), and endochondral pelvic basipterygium are ossified, as are the pelvic rays and anterior-most dorsal fin rays. It is unclear whether the absence of ossifications of pectoral rays and anal rays is an artefact of preservation or not, because generally the pectoral rays ossify before the pelvic ones in various teleosts (see references in ARRATIA & BAGARINAO 2010). It is noteworthy that the basipterygium is partially ossified, but not the chondral elements of the pectoral girdle, a different pattern from that in recent teleosts (see references in ARRATIA & BAGARINAO 2010). The chordacentra of the caudal endoskeleton of the preural and ural vertebrae are represented by thin, tiny, ventral hemi-chordacentra, whereas the chordacentra are thin and ring-like in the vertebrae immediately preceding the preural region. Chondral elements such as the neural and haemal arches and spines of the preural centra are ossifying but it is unclear if the large element dorsal to the ural chordacentra is the stegural (see Fig. 2B). Apparently all principal caudal rays are already ossified.

Specimens of about 14 mm SL, observed under "normal" light, give misleading information because under the microscope the fish looks incompletely ossified (Fig. 2C); however, at this stage of growth, all head bones, including chondral bones, seem to be ossified as well as neural and haemal arches and their spines, girdles, radials, and all fin rays, including the anal rays (Fig. 2D). The chordacentra of the abdominal and mid-regions of the body are surrounded by autocentra, but still the preural and ural regions are represented only by small ventral hemi-chordacentra.

From these observations we have learned that the teleostean larvae from the Solnhofen limestones are more informative when observed under UV light. In addition, if we want to learn about the first bones to begin to ossify in *Orthogonikleithrus hoelli*, we need to find specimens under 12 mm SL, and probably under 10 mm SL. We have also learned that, as with extant teleosts, the process of ossification proceeds very quickly and a difference of about one millimetre or less can be crucial in the understanding of the ossification process. We also have learnt that we are not able to get information on the chondrification process because our current UV techniques seem to be unable to detect small cartilaginous elements. In addition to these general observations, we have gathered new information about numerous morphological character states of the early development of the extinct basal euteleost *O. hoelli.* These results will be published elsewhere.

The use of UV techniques also allows confirmation of some previous observations and rejects others. For instance, *Orthogonikleithrus hoelli* was diagnosed and described by ARRATIA (1997: 80, 85, 88) as a fish lacking scales (having a naked body) and lacking teeth on the jaws. As far as we know, other Jurassic teleosts with such morphologies are unknown; consequently, these two characters seem unlikely. However, UV techniques have confirmed ARRATIA's observations done under "normal" light: teeth and scales are absent even in the largest specimens of this species.

In summary, we can mention that the use of UV light in fishes recovered in certain localities (see below) can be very successful revealing new morphological information that is not observed under "normal" light. This is especially significant when studying larvae and juveniles of fossil fishes, and also it can be very useful in the identification of remnants of structures such as muscles, intestines, branchial lamellae, and others.

Other examples

We list below some examples of Mesozoic deposits where according to our investigations and those of other researchers, UV techniques can be applied effectively. It should be pointed out that ultraviolet sources probably will not work properly in every fish specimen from these deposits, but at least in many of them UV will function satisfactorily.

Triassic: Wapiti Lake (Canada); Lower Triassic, Smithian–Spathian.
Triassic: Monte San Giorgio (Switzerland); Middle Triassic, Ladinian.
Jurassic: Holzmaden (Germany); Lower Jurassic, Toarcian.
Jurassic: Jinlingsi Group (China); Middle to Upper Jurassic.
Jurassic: Talbragar River Fish Beds (Australia); Upper Jurassic.
Jurassic: Cerin (France); Upper Jurassic, upper Kimmeridgian.
Jurassic: Nusplingen (Germany); Upper Jurassic, upper Kimmeridgian.
Jurassic: Canjuers (France); Upper Jurassic, lower Tithonian.
Jurassic: Solnhofen Limestone (Germany); Upper Jurassic, lower Tithonian, and other plattenkalks from the Solnhofen archipelago of Bavaria (Germany) from Wattendorf, Brunn, Painten, Ettling, Mühlheim and Daiting; Upper Jurassic, upper Kimmeridgian to lower Tithonian.
Cretaceous: Yehol Group (China); Lower Cretaceous.
Cretaceous: Massif Des Bauges (France); Lower Cretaceous, Hauterivian; cf. FILLEUL (2001).
Cretaceous: Crato and Santana Formations (Brazil); Lower Cretaceous, Aptian and Albian.
Cretaceous: Pietraroja (Southern Italy); Lower Cretaceous, Albian; cf. SIGNORE et al. (2005)
Cretaceous: Tlayùa Konservat-Lagerstätte (Mexico); Albian; cf. RIQUELME et al. (2009).
Cretaceous: Hakel, Namoura, Sahel Alma (Lebanon); Upper Cretaceous, Cenomanian to Santonian; cf. PFEIL (2012).

UV-Photography

Sometimes essential details of bones and soft parts can exclusively be demonstrated by UV-light photography due to the fact that the researcher will not be able to differentiate tiny structures and differences in colour and composition under ultraviolet light with the naked eye or with the microscope. The human eye is very sensitive but it has its limitations. Very often important details are not detected while investigating the specimens under UV-light but finally revealed in the pictorial documentation. The visibility of details is enhanced considerably by an established filtering technique, crucial for the photographic documentation. The application of different filters allows a selective visualisation of peculiar fine structures. Color compensation filters (yellow, cyan and magenta of different types and densities) are made from special colored glass or gel. They are adjusted in front of the camera lens or under the microscope objective lens (if pictures are taken through the microscope). In most cases a selection of different color-compensation filters is necessary. The frontmost filter must be a UV Filter, which blocks UV light up to 390 nanometers. For our work we prefer Hama O-Haze (Hama UV-390) or Hoya O-Haze (HMC-UV[0]). Keeping in mind that any piece of glass or gel in front of the camera lens will increase exposure time and reduce the quality of the photo a little bit, the number of filters should be minimized if possible. The predominant color of luminescence is of minor importance. Rather, the essential decision on the amount of filtering is the perfect visibility of details and their differentiation from surrounding structures and the matrix.

On each stone slab, bone or tissue may react differently to different light wavelengths and will be captured differently with varying exposures and filters; a blanket approach to formations or even horizons is not advised. This appears to be true even of parts and counterparts of single specimens in some cases, and not just more predictable differences between different horizons or formations of rock. Thus, proper combinations of filters and lighting must be used to provide the details of the structures that are of interest. The optimum wave length, exposure time and filtering should be tested in a series of experiments (TISCHLINGER 2002). On the Solnhofen specimens, best results were obtained with a wavelength of 365–366 nanometers (UV-A). For specimens recovered in the Solnhofen limestones, the number and combination of filters varies greatly and exposure times range between a few seconds to 10 minutes, depending on the nature of the fossil material and the magnification, intensity, and incident angle of the ultraviolet lamps, as well as on the type of camera in use. Both digital cameras and chemical cameras (analogue cameras) can be used. Most of the pictorial documentation between years 2000 and 2010 (for references see introduction) was taken by means of chemical photography on daylight slide film. Kodak Professional Elite Chrome ISO 100/21° and Kodak Elite Chrome Extra Color 100 were used. Filtering works optimally with chemical photography and frequently very tiny soft parts apparently turn out significantly better with this technique than with digital photography. But digital cameras are much easier to handle and working with them is by far less time consuming than chemical photography. In many cases the same filters work properly, too, and mostly with satisfactory results. For high-resolution composite imaging of small fossils under the fluorescence microscope using UV-A (358 nm) and green light (546 nm, green-orange-fluorescence), see HAUG et al. (2009); this method has mainly been tested on small crustaceans from the Solnhofen Limestone and Lebanon.

In order to enhance pictorial quality it is advisable to wear black gloves and cover the forearms with clothing during photographic documentation because the human skin fluoresces under UV and consequences might influence the lower contrast of the images. It is also highly recommended to dress in black or very dark gray while working, since many light-colored fabrics also fluorescence under UV and most bright fabrics give off strongly fluorescent lint.

Detecting forgeries by pictorial documentation

The use of UV light to discover forgeries of fossils occurred very early in paleontological history and many forgeries could be easily identified using ultraviolet lamps (MIETHE & BORN 1928). Within the last two decades, the number of fossils including fishes which were artificially enhanced, unrecognizably restored, or totally forged, to increase their commercial value, has increased at an alarming rate. The most problematic forgeries to detect are based on original fossils that are artificially assembled (MATEUS et al. 2008). Among other techniques for detecting hoaxes, including detailed visual examination, chemical analysis, Xray or CT-scanning, the use of ultraviolet light still ranks among the most important. Primarily specimens from Holzmaden, Solnhofen, Lebanon, Brazil, and China are artificially enhanced or hoaxed. The production of forged fossil specimens is not unusual in areas where fossil trading can contribute significantly to economical survival, as in China (MILNER et al. 2001, ZHOU et al. 2002) or Brazil (MARTILL et al. 2007). Also, a considerable quantity of fraudulent specimens including fishes is known from the other deposits mentioned above. Some of them can still be detected simply by visual examination under UV. However, many forgers are working to improve their techniques to make it difficult to identify fakes.

Sometimes it is very difficult to decide just by inspection under UV with the naked eye if unavoidable preparation artefacts such as glue, stabilizing materials, transfer artefacts, preparation fluids etc. of a genuine fossil are present, or if “camouflaged” faked parts exist. Even in pictorial documentations of some specimens taken under “normal UV conditions”, the matrix as well as putatively all the bones and scales are shining equally bluish, just as they appear to the naked eye under UV, and therefore they seem to be genuine fossils. However using a selective filtering for the images (see previous chapter), and trying to improve filtering until one is able to demonstrate clear and distinct differences in the luminescence of some bones, scales and matrix, may show that an artificially enhanced, extensively restored or even forged fossil is on hand.

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Authors' addresses:
Helmut TISCHLINGER, Tannenweg 16, 85134 Stammham, Germany; e-mail: htischlinger@online.de
Gloria ARRATIA, University of Kansas, Natural History Museum and Biodiversity Institute, Lawrence, Kansas 66045, U.S.A.; e-mail: garratia@ku.edu