Computed tomography (CT) of nasal cavity of *Ikechosaurus sunailinae* (Reptilia: Choristodera)

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Abstract The CT technique was first applied to observing the nasal cavity of *Ikechosaurus sunailinae*. The results indicate that the nasal cavity is very complex, and it was divided into two parts: the posterior-upper part and the anterior-lower one. These control olfaction and thermoregulation respectively. The partial loss of pineal systems suggests that this animal may have been evolving toward endothermy. Therefore, *Ikechosaurus* may have had a strong ability to thermoregulate, thus keeping a high level of activity. But it still did not maintain constant temperature, as the birds and mammals do.

Keywords: **CT scan, thermoregulation, nasal cavity, *Ikechosaurus*.**

A lot of work has been done on living reptiles' nasal cavities[1,2], but there are few references on the nasal cavity of fossil reptiles[3,4]. The main reason for this is that the soft parts and cartilaginous nasal capsules , are not preserved as fossils. All that can be seen is the position of the external and internal nares[1]. The conchae-maxilloturbinals which first appeared in reptiles are cartilaginous projections on the lateral wall of the nasal cavity, which in most cases, are not fossilized. The best evidence for their presence in fossil taxa is the basal ridges by which the turbinates attach to the lateral walls of the nasal cavity[4,5]. Compared with the living taxa, the specimens of fossil taxa are limited. Within these limited specimens, special methods such as serial grindings, or serial cuttings must be used in order to observe the inner structures of the skull. But these methods can destroy the integrity of the fossils, or damage the specimen completely. This is feasible for abundant fossil taxa, but for the rare specimens (especially the monotype specimen), these methods cannot be used. In the 1970s, Hounsfield[6] designed the computed tomography technique for obtaining cross-section images of the human head. Later, this technique was further developed by Ledely *et al*.[7] for examination of other regions of the body. Because this technique can be used to observe fossils (especially skulls) which are embedded in matrix, it may provide a method for studying the inner structures in fossils. In 1984, this technique was first applied to the study of palaeovertebrates by Conroy *et al*.[8], and it has since been used in the study of a variety of taxa of palaeovertebrates. In this study, we applied CT techniques in a preliminary observation on the nasal cavity of *Ikechosaurus sunailinae*.

1 Materials and methods

(ⅰ) Materials. In this study, we chose the well-preserved skull (IVPP V9611-3) of *Ikechosaurus sunailinae*, as the test specimen. The specimen was 175 mm long (the tip of the snout missing small part); the orbits were 15 mm wide and 23 mm long; the distance between the orbits was 13 mm; the long axis and the short axis of the upper temporal fenestra were 51 and 23 mm respectively.

(ⅱ) Methods. The specimen was scanned in three directions: coronary, sagittal and axial with Elscint CT Twin (Haifa Israel). At first, we got the plain film and then the skull was scanned with high resolution CT under the plain film. The scan technique: 120—130 kV, 220 mAs, 1 mm slice thickness; 1 024 × 1 024 matrix; 180 or 250 mm diameter of scanning field; 2 300—2 600 Hu window width; 3 000—4 095 Hu window level.

2 Results

The nasal cavity was divided into two clear parts: the upper part is an olfactory area and while the lower part is a respiratory area (this part has a thermoregulatory function).

The structures on the inner wall of nasal cavity are complex. They are grooves and ridges, for the attachment of the cartilaginous conchae . These ridges demonstrate the existence of the conchae.

From the view of the structures of nasal cavity, its olfactory area is large, and the olfactory nerves were perhaps distributed over most areas of the posterior-upper part to the choana, indicating that this animal's sense of smell may be very developed.

The attenuation coefficients of the walls of nasal cavity was 2 877.0—3 080.8 Hu, it was 2 097.0—2 182.0 Hu within the nasal cavity.

3 Comparison and discussion

Ikechosaurus which belongs in the family Champsosauridae was erected by Sigogneau-Russell in 1981[9]. This test specimen which was studied by Brinkman *et al*.[10] was collected from Early Cretaceous Laohongdong (Luohandong) , Zhidan Group of Ordos Basin (Etuoke Qi). In the study of champsosaurids, most workers were limited to study their osteological morphologies[9,10]. A few workers discussed other aspects, for example, Fox[11] discussed the braincase (cranial nerves) of *Champsosaurus*. Russell[12] mentioned the structures of the nasal cavity, when he described the maxilla and nasal of *Champsosaurus*, but he did not elaborate. A relatively detailed examination of external morphology and function of nasal cavity of *Champsosaurus* was made by Erickson[13], unfortunately, the inner structures of the nasal cavity were not involved.

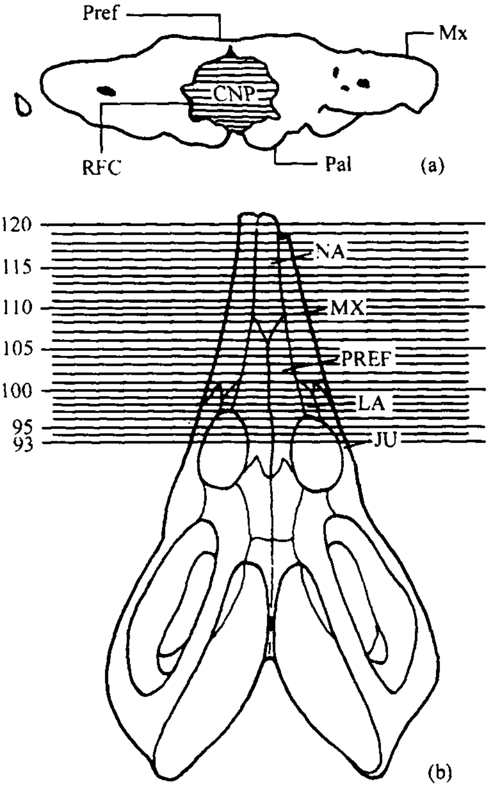

Fig. 1. (a) A line drawing of one slice of CT images (showing basal ridges and other structures). (b) The position of each "slice" in fig. 2. CNP, Cavum Nasi Proprium; Mx, maxilla; Pal, palatine; Pref, prefrontal; RFC, ridge for concha.

According to Parsons[1], the major regions and structures of the reptilian nose were divided into the following 5 parts:

Vestibulum nasi: It is tubular portion of the nasal cavity extending from the external naris to the cavum nasi proprium.

Ductus nasopharyngeus: It refers to any tubular connection between the cavum nasi proprium and the choana.

Cavum nasi proprium: It is the portion of the nasal cavity lying between the vestibulum and the nasopharyngeal duct.

Concha: It refers to any projections of the lateral wall of the nasal cavity into this cavity.

Jacobson's organ: It is distinguished from the remaining sensory portions of the nasal epithelium, it develops more or less ventrally and medially within the nasal cavity.

On the basis of the continuous CT images of nasal cavity of *Ikechosaurus* (fig. 1), every portion of the nasal cavity (fig. 2) is briefly described.

(i) Vestibulum nasi (sequence No. of CT images is 120—113). There was no clear boundary with cavum nasi proprium. It should be a tubular portion between the anterior margin of the internal naris and the external naris. From the view of sequence No. 114 and No. 115, the vertical diameter became smaller, while in the other reptilian, the vestibulum nasi is always clearly separable from more larger Cavum nasi proprium[1]. The transverse section of the vestibulum nasi is irregularly quadrilateral, with its horizontal diameter larger than its vertical one. There was a ridge projecting into the cavity on the outer later of the lower margin, as is the case in the living long-snout *Carettochelys* and Trionychids[1]. In the cross-section picture of the relative positions, (through anterior third of the snout in *Champsosaurus natator* (Russell[11], fig. 3), similar to the position of sequence No. 115 in *Ickechosaurus*), they are very different in shape. In *Champsosaurus*, it is elliptical with its horizontal diameter larger than its vertical diameter (not considering the position of the internarial), and its medial wall is smooth without any ridges. In *Ikechosaurus*, however a groove was formed on the mid-dorsal surface of the nasal cavity. The corresponding position on the ventral surface of the nasal should have a longitudinal ridge, to which the internarial may have attached. Because this animal was young, the internarial may have been cartilaginous and not fossilized. From the view at the broken surface of the tip of snout, there were relatively wide, thin longitudinal grooves on the lateral surface of the endocast, indicating there were wide and narrow ridges near the middle ventral surface of the nasal and maxilla respectively. This is similar to the case in mammal-like reptiles and mammals[4, 5]. These ridges might serve as the attachments of nasal turbinates and maxilloturbinates.

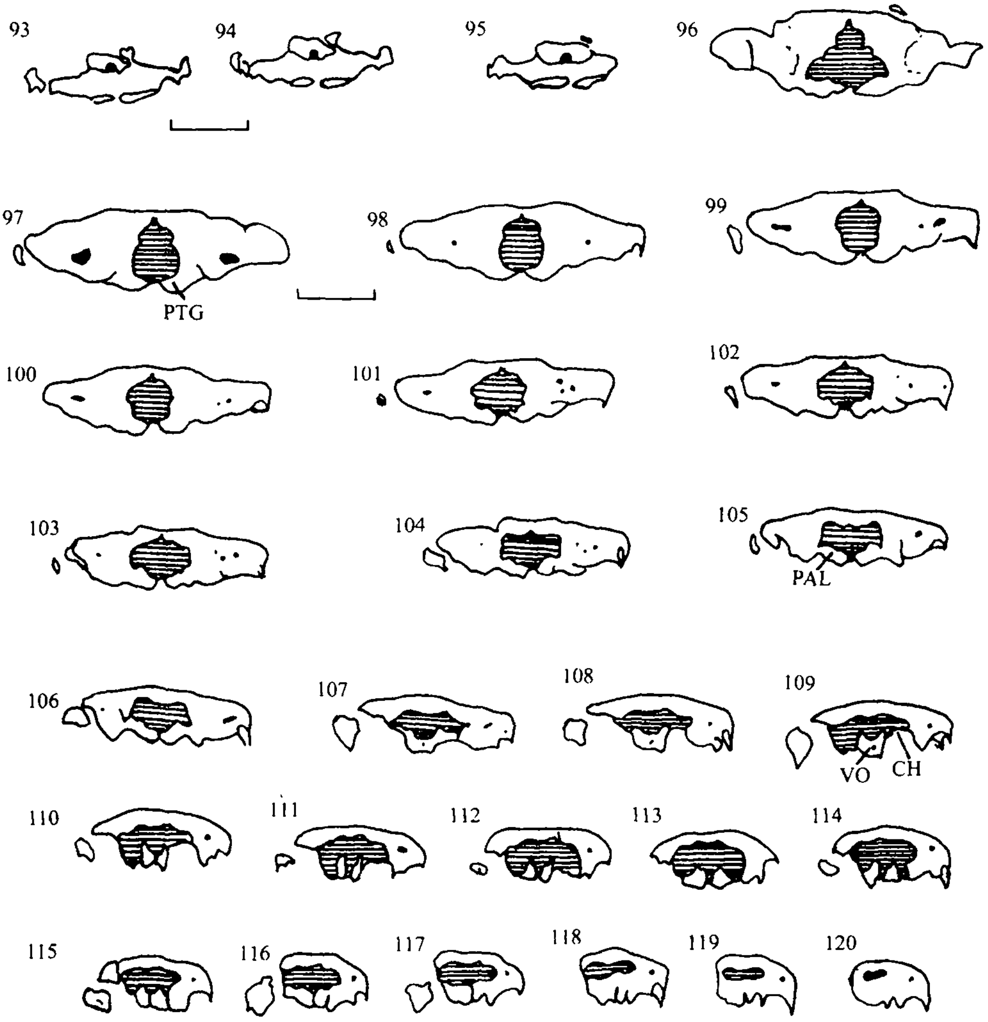

Fig. 2. The line drawings of the changing nasal cavity, redrawn from the continuous CT images (in the above-mentioned drawings, all those which were not connected with the main body were incomplete, e.g. in No. 107, the gap between the left part and main body indicates the naturally missing part. The scale is 2 cm in Nos. 93—95, 1 cm in others).

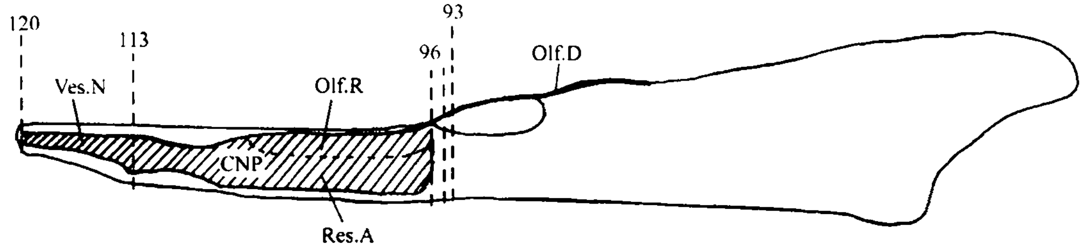

Fig. 3. Illustrations of the structures of nasal cavity of *Ikechosaurus* (along the long axis of the skull). CNP, Cavum nasi proprium; Olf. D, olfactory duct; Olf. R, olfactory region; Res. A, respiratory area; Ves. N, vestibulum nasi.

(ⅱ) Ductus nasopharyngeus: (Nos. 113—108). Because the choana were located anteriory, the ductus nasopharyngeus is fairly short, as in *sphenodon* and most lizards. It is different from that of living crocodiles[1], in which choana is situated quite posteriorly, thus its ductus nasopharyngeus is long. The length of Ductus nasopharyngeus should be equal to the height of the vomer.

(ⅲ) Cavum nasi proprium (Nos. 107—96). Because the concha has a close relationship with Cavum Nasi Proprium, it is discussed together with Cavum Nasi Proprium. The anterior part of Cavum Nasi Proprium was linked with the posterior part of the vestbulum, while its posterior portion approaches anterior to the orbital. There was a deep longitudinal groove on the middle-ventral surface of the prefrontal from No. 89 to No. 104 CT images. The grooves extend forwards and disappear on No. 106 CT image. The groove was about 35 mm long, which was very close to the rear of the choana. It was a semicircle on the No. 93 CT image. This should be the olfactory nerve canal mentioned by Russell[11] and Erickson[13]. The olfactory canal extended forward into an abruptly enlarged space, which functioned for olfaction and thermoregulation[13]. From the view of the continuous CT images, the Cavum Nasi Proprium was very complex in shape. The presence of numerous ridges on the inner surface is good evidence for the existence of the conchae. The ridges may have been covered with cartilaginous projections. Among the continous CT images from No. 96 to No. 98, there developed two remarkable ridges on each inner wall of the middle-upper part of the Cavum Nasi Proprium. These ridges divided the Cavum Nasi Proprium into two chambers: the posterior-upper one was an olfactory part (corresponding to the olfactory chamber mentioned by Erickson[13]); the anterior-lower one was a respiratory part. The inner wall of the olfactory part should be covered with sensory epithelium, for olfaction. The large olfactory area indicates that this animal had a sharp sense of smell. Olfaction is very important in aquatic animal to locate food for odor-sampling, as the case in crocodilians[13,14]. The respiratory space is much larger than the olfactory, and its inner wall was not smooth. The distinct projections and depressions were displayed on some CT images. Those continuous projections formed ridges, which should be covered with conchae. Most ridges were situated on the ventromedial part of the inner wall of nasal cavity. Those ridges were probably covered with respiratory epithelium, which might serve for thermoregulation. This can be further illustrated by the other character——the rest of the epiphyseal complex, which reflected from the CT scanning of the skull. Through observation of the series of CT images at 1 mm thickness, scanning downwards from the top of the skull, there gradually appeared a short seam (perhaps the disappearing vestige of the parietal eyes) within the parietals. It increases in depth ventrally from the top of the skull. The seam changed into a small hole. Ventrally, a second larger hole appeared posterior to the small one. The two holes join with the increasing depth, and then divides into two holes which connect to the braincase. The trace of these holes is not visible on the surface of the parietals, their appearance within the parietals may be an indication of remains of the pineal system. This suggests that the pineal system did not disappear completely. "Current research indicates that temperature regulation is a major function of pineal systems in both ectotherms and endotherms. Therefore, it is reasonable to suggest that possession, partial loss, or absence of pineal system among fossil reptiles provides an indication of thermoregulatory mechanics…. Transitional stages toward retention of the pineal body alone (E-1) may represent animals evolving toward endothermy…"[15]. The existence of remain of pineal system in *Ikechosaurus* suggests that this animal had a relatively strong capability of thermoregulation, and was evolving towards endotherms. Erickson[13] thought that *Champsosaurus* was completely aquatic, inhabiting paleolatitudes of some 30° to 40°N, where the ambient air temperatures probably had clear seasonal or even daily fluctuations. Due to its body was submerged for much of the time, the temperature of inspired air could be adjusted to coincide with body temperature. This could keep its temperature fairly stable, enabling it to maintain a high level activity. The similar nasal cavities of *Ikechosaurs* and *Champsosaurus* suggest that *Ikechosaurs* lived in a similar habit as that of *Champsosaurus*, and may have been adapted to aquatic existence.

(ⅳ) Jacobson's organ. In the CT images of Nos. 114 and 115, there was a canal which extended to the palatal surface anterolaterally between the vomer and the palatine. This canal might be the duct of Jacobson's organ. If this judgment is correct, it means that this animal used its Jacobson's organ and its tongue in identifying food through the odor. This had a certain action for their catching food in water.

The continuous CT scanning of the nasal cavity of *Ikechosaurus* shows that the structure of the nasal cavity was very complex (fig.3). The groove-ridged shape of the inner wall of the Cavum Nasi Proprium indicates that it had developed conchae, which may have played function of thermoregulation. This suggests that the nasal cavity of this animal had a thermoregulatory function. The remains of a pineal system also suggests that it might evolve toward endothermy. It suggests, therefore, that *Ikechosaurus* had greater ability of thermoregulation than that of other reptiles.

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