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Functional morphological study of the choana in different bird species

Fatma A. Mahmoud^{1*}, Ali G. Gadel-Rab² and Nahed A. Shawki¹

Abstract

Background: The anatomical information about the structure of the choana is lacking in literature, and its role in the olfactory and feeding mechanism is still unknown

Results: The present study discusses the adaptation of choana to cranial kinesis during feeding process in different bird species: kestrel, common moorhen, and hoopoe. Kestrel possesses a kinetic skull while the hoopoe and common moorhen have kinetic one; however, the common moorhen skull seems highly kinetic more than that of the hoopoe that properly effect on the choanal epithelium. The choana of kestrel and hoopoe are lined by pseudostratified ciliated columnar epithelium, while choana of common moorhen have transitional epithelium beside pseudostratified ciliated columnar epithelium. The choana epithelium of each bird species provides with simple alveolar glands and numerous goblet cells. In kestrel and hoopoe, the secretion products of choanal glands contain neutral and sulfated mucin, while in the common moorhen, these glands secrete neutral and carboxylate mucopolysaccharides.

Conclusion: The choana of the three studied bird species appears adaptation to the olfaction process but also affects the movement of skeletal elements of the skull during the feeding process

Keywords: Choana, Cranial, Kinesis, Bird, Feeding process

Background

Birds have variation in the form and function of their feeding system which are amenable to comparative analysis because they represent modifications of the same basic structure of this apparatus among different species without a doubt that reflected the success of birds to survival and occupy a wide range of habitats. Many of the literature has studied the avian feeding system (Jackowiak & Godynicki, 2004; Mahmoud, Shawki, & Wahba, 2009; El-Bakary, 2011, 2012; Al-Zahaby & Elsheikh, 2014; Erdogan & Iwasaki, 2014; and Shah & Aziz, 2014; Gadel-Rab, Shawki, & Saber, 2017), but still the feeding mechanics and functional morphological information about most bird species remain poorly understood.

The roof of buccal cavity is considered as a part of feeding system and was given little attention in literature. It is interesting to state that only Shawki, Abdeen, and Mahmoud (2016) gave a clear description of the roof of buccal cavity of the kestrel and discussed its

role in the feeding mechanism. Mahmoud, Gad-Rab, and Shawki (2017) pointed out the effect of different feeding behaviors on the lining epithelium of the roof of buccal cavity of two bird species.

The feeding and sensory systems are considered integrating systems and reflect a general historical trend of increasing cephalization in vertebrate evolution (Schwenk, 2000). The avian olfactory system consists of the choana which appears in birds and reptiles related to the incomplete secondary palate, through which the nasal and oral cavities communicate with each other (Kent & Carr, 2001). The anatomical information about the structure of the choana is lacking in literature, and its role in the olfactory and feeding mechanism is still unknown.

Thus, the present study gives attention to the functional morphological structure of the choana in three different bird species to exhibit the adaptation of the choana to the feeding process.

The selected bird species are kestrel, hoopoe, and common moorhen that belong to different avian's orders: Falconiformes, Bucerotiformes, and Gruiformes, respectively, each of them have own feeding behavior.

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Methods

The specimens of three bird species in the present study were collected from Abou-Rawash area of Egypt and brought alive to the comparative anatomy of vertebrate lab. The specimens were anesthetized by ether then dissected under wild stereomicroscope to separate the head from the rest of the body. Some specimens were carefully investigated by wild stereomicroscope to clarify the anatomical features of roof of mouth; the skull the was prepared; and then photos were photographed by using a digital camera. Some specimens were fixed in 10% neutral formalin for 3 days and prepared to paraffin embedding. Tissues were sectioned at 7 μm and stained with Hematoxylin and Eosin, Masson’s trichrome, Bromophenol blue, PAS and PAS-Alcian blue (Bancroft & Stevens, 1996).

Results

The buccal cavity of the three studied bird species is bounded externally by their beak while internally, it can be distinguished into the floor of mouth, which includes the tongue, and the roof of mouth which contains two regions: the palate and pharyngeal region. The palate region (PL) occupies the choana that faces the glottis within the tongue. The choana (C) of each studied bird species exhibits different shape; in kestrel, it appears to be formed from two parts, a short narrow anterior part and long-wide posterior one separated by a constriction (Fig. 1). In common moorhen, the choana is formed from two equal parts, an anterior tapering part and a

posterior wide one (Fig. 2). Meanwhile, the choana of the hoopoe has pear-shape with posterior wide half and slightly anterior narrow one (Fig. 3). The pharyngeal region (Ph) of kestrel and common moorhen is situated posterior to the palatine wing which is not distinguished in the hoopoe. The pharyngeal region in the three studied bird species incubates the oval-shaped fissure which is known as the infundibular fissure (IF). In the present study, the infundibular fissure of the kestrel and hoopoe is located posterior to the choana ridges (Chr), while in the common moorhen, it lies within the choana ridges. The margins of infundibular fissure of the kestrel carry a longitudinal row of posteriorly directed papillae, whereas these

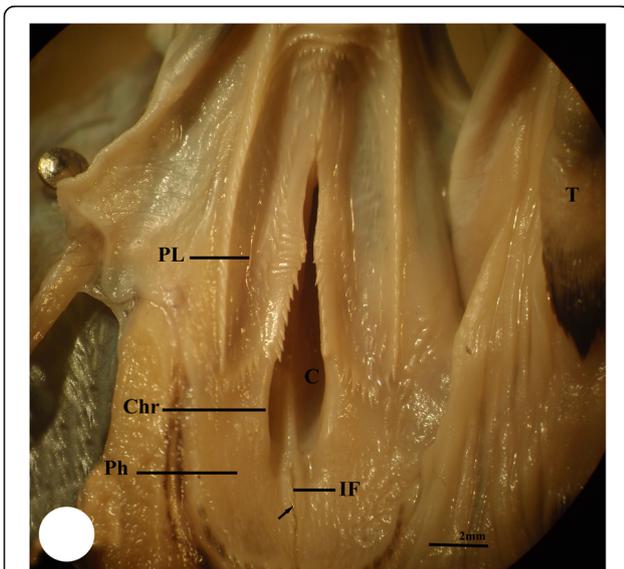


Fig. 1 Photomicrograph of the buccal cavity of kestrel shows palate region (PL), choana (C), pharyngeal region (Ph), infundibular fissure (IF), choana ridges (Chr), margins of infundibular fissure (arrow) with papillae, and tongue (T)

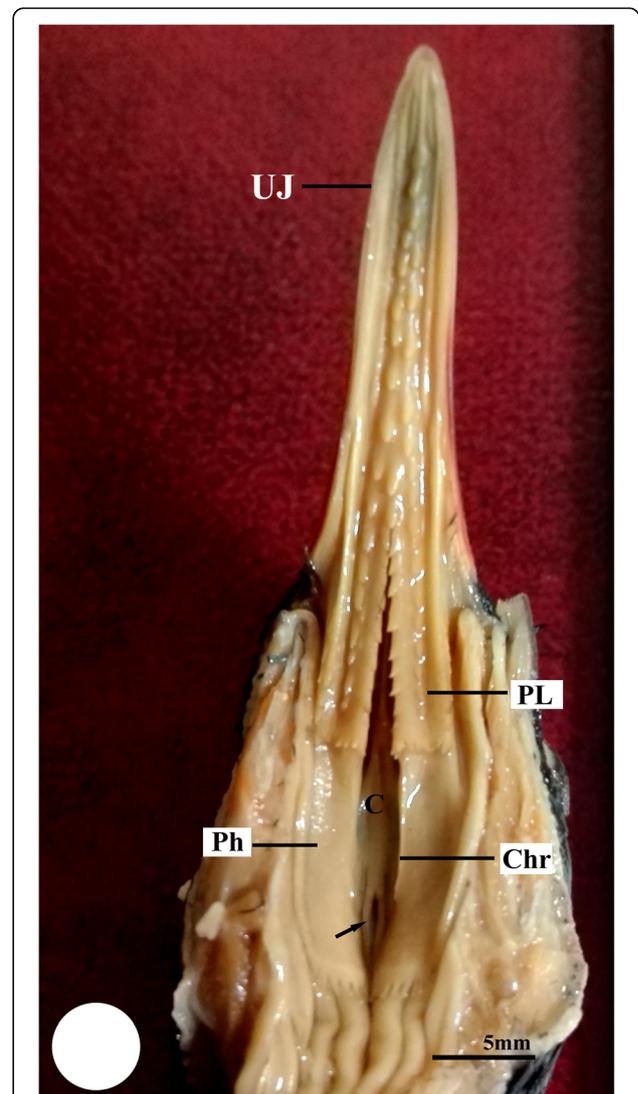


Fig. 2 Photomacrograph of the buccal cavity of common moorhen shows upper jaw (UJ), palate region (PL), choana (C), pharyngeal region (Ph), choana ridges (Chr), and margins of infundibular fissure (arrow) without papillae

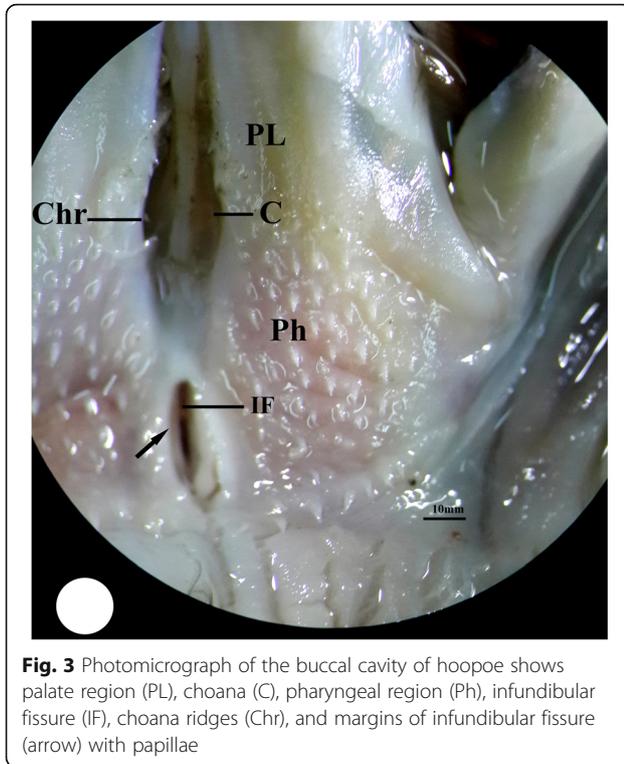


Fig. 3 Photomicrograph of the buccal cavity of hoopoe shows palate region (PL), choana (C), pharyngeal region (Ph), infundibular fissure (IF), choana ridges (Chr), and margins of infundibular fissure (arrow) with papillae

papillae disappear in the case of hoopoe and the common moorhen (Figs. 1, 2, and 3).

The roof of the mouth is supported by the palatine bone (Os palatinum) which exhibits anatomical variation in the three studied bird species. The palatine bone have paired anterior portion (the maxillary process of the palatine bone, Map) which appears thick and narrow in the kestrel and broader in the hoopoe (Figs. 4 and 5), while in the common moorhen, it is long, thin, and dorso-medially curved. Moreover, this portion is fused laterally with the posterior portion of the maxillae “upper jaw, UJ” through the maxillopalatine process (Fig. 6 and 7). Meanwhile, in the kestrel and hoopoe, this process is completely fused with the ventral surface of the upper jaw (UJ) (Figs. 8, and 9).

Dorsally, the vomer bone is located between the anterior portion of palatine and extends posteriorly to fuse with the parasphenoid bone. In the kestrel, the vomer bone has club shape with rounded head which fuse anteriorly with maxillopalatine process (MP), and extends posteriorly as rod-shape to fuse with the parasphenoid bone (Fig. 8). Meanwhile, in the common moorhen, the vomer bone initiates as narrow unpaired bone, then forks posteriorly towards the parasphenoid bone (Figs. 6 and 7), whereas in the hoopoe, the vomer bone is absent and replaced by a longitudinal ribbon of collagenous connective tissue which extends posteriorly cross the ventromedial surface of the parasphenoid bone (Fig. 9).

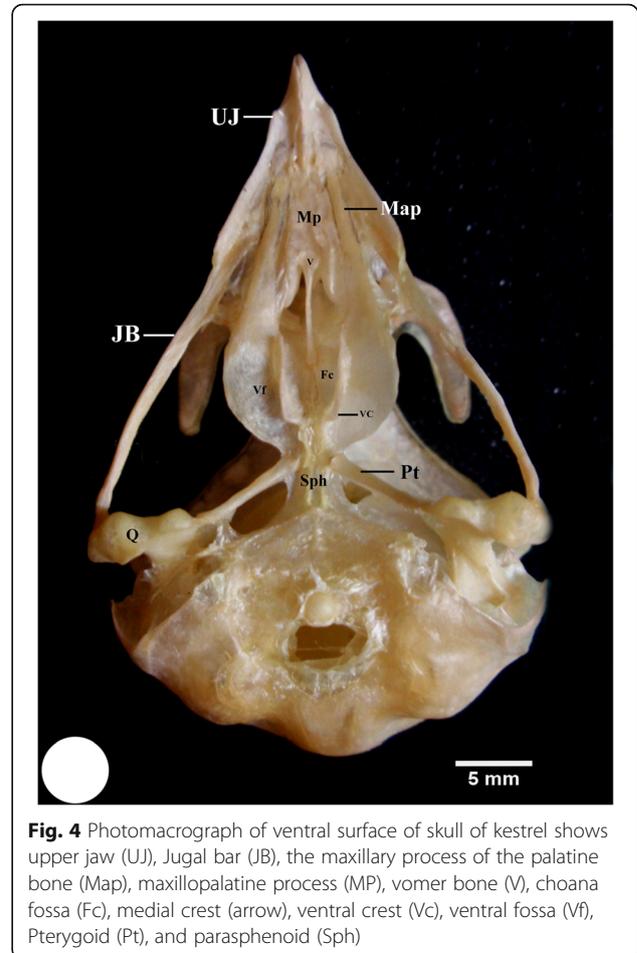
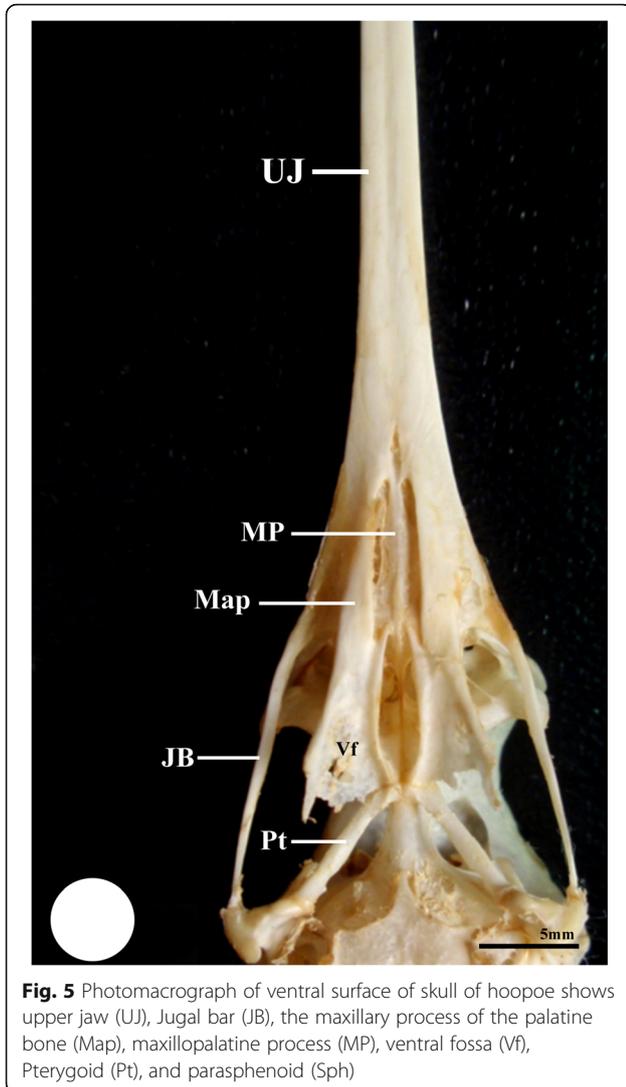


Fig. 4 Photomicrograph of ventral surface of skull of kestrel shows upper jaw (UJ), Jugal bar (JB), the maxillary process of the palatine bone (Map), maxillopalatine process (MP), vomer bone (V), choana fossa (Fc), medial crest (arrow), ventral crest (Vc), ventral fossa (Vf), Pterygoid (Pt), and parasphenoid (Sph)

Posteriorly, the palatine bone broads to form the pars lateralis which contains the ventral fossa. This fossa appears deeper in the common moorhen than that of the kestrel, while in the hoopoe, it appears shallow (Figs. 7, 8, and 9). The pars lateralis possesses medial and ventral crest which enclose the choana fossa between them. The choana fossa is narrow and shallow in the kestrel, broad and slightly deep in the common moorhen, and narrow and deep in the hoopoe (Figs. 7, 8, and 9).

Moreover, the kestrel and common moorhen have paired medial crest (Figs. 7 and 8) that is absent in the case of hoopoe and replaced by fibrous connective tissue (Fig. 9). The ventral crest that forms the lateral wall of the choana protrudes ventrally in the kestrel and the common moorhen more than in the hoopoe.

The histological investigation of the roof of the mouth of three studied bird species revealed that the roof is covered by stratified squamous epithelium with variation in keratinization; in the kestrel and the common moorhen, the lining epithelium of the roof is keratinized (Figs. 10 and 11), while the roof of the hoopoe is covered by non-keratinized epithelium with appearance of keratinization on the palatine papillae (Fig. 12). However,



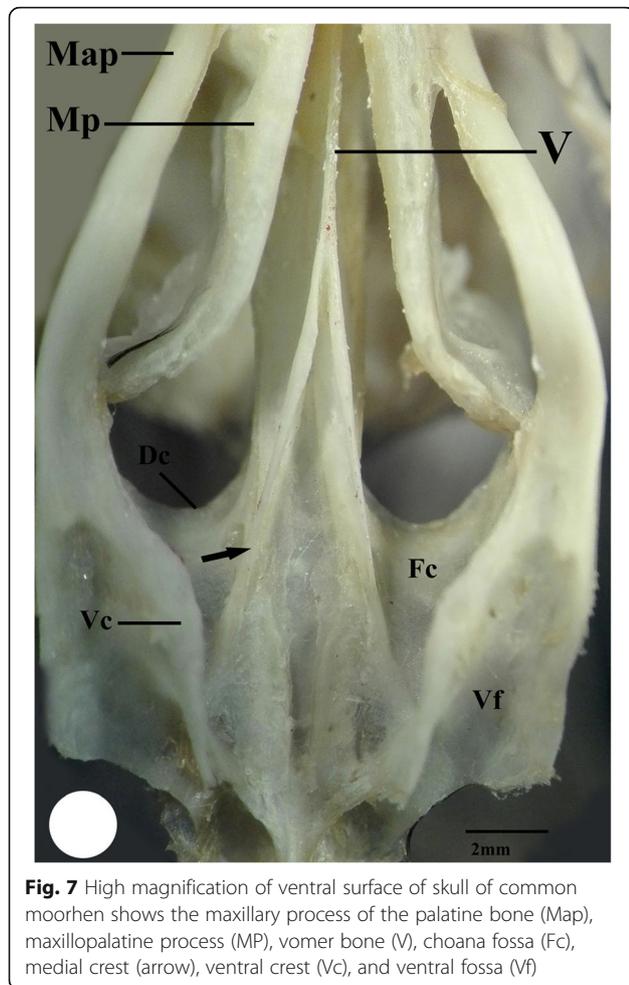
in the studied bird species, the epithelium layer of the roof lines the choana extends dorsally and changes gradually from stratified squamous epithelium into pseudostriated ciliated columnar epithelium (Figs. 10, 11, 12, and 13). Moreover, in the common moorhen, the dorsomedial surface of choana is covered by transitional epithelium (Fig. 13b).

The simple alveolar gland and goblet cells are distributed within the lining epithelium of the choana of all species analyzed. In the common moorhen, compound-branched alveolar glands were observed embedding dorso-medially within the epithelium of the choana (Fig. 13a).

In all investigated species, the glandular cells of the choanal gland are strongly reacted with PAS indicating the presence of neutral mucopolysaccharides (Fig. 14b, c) and give positive reaction with PAS-Alcian blue that indicate the presence of neutral and acid mucopolysaccharides (Fig. 14a).

The glandular cells of the choanal glands of kestrel and the hoopoe exhibited a slight positive staining affinity with Alcian-blue PH 2 (Fig. 15a, c), while moderate in the common moorhen (Fig. 15b). This indicates the presence of carboxylate mucopolysaccharides. In kestrel and hoopoe, the glandular cells of the choanal glands give deep-bluish color with Alcian-blue PH1 (Fig. 15d, f) which mean the presence of sulfated mucopolysaccharides. In the common moorhen, the glandular cells within the epithelium covering the dorso-medial surface of choana give deep blue color with Alcian-blue PH1 while that covering the lateral surface give faint blue color (Fig. 15e, g).

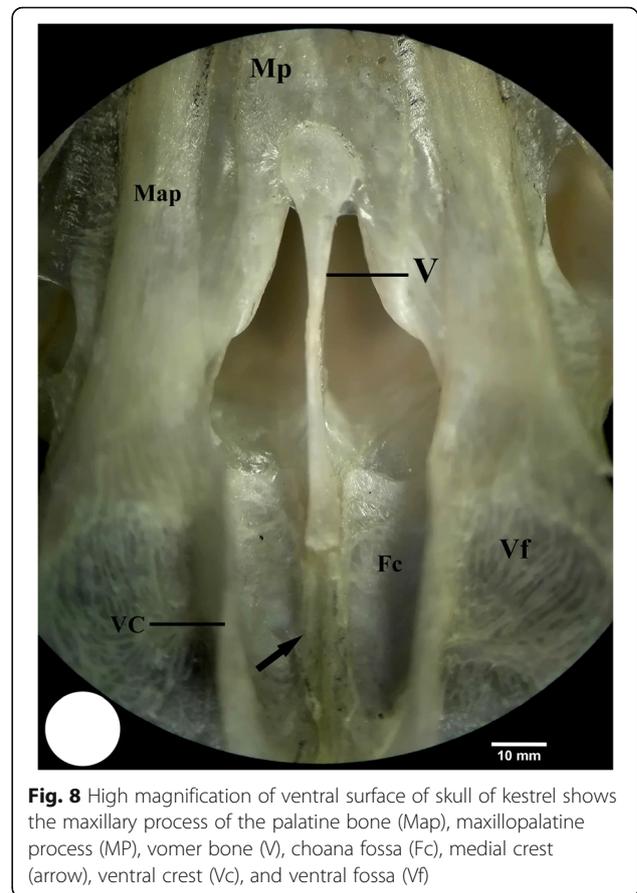
Moreover, in kestrel and hoopoe, the choanal glands showed moderate reaction with mercuric bromophenol blue (Fig. 14d, f) indicating the presence of protein secretory materials, while in the common moorhen, the choanal glands gives slightly react with mercuric bromophenol blue (Fig. 14e).



Discussion

The kestrel, common moorhen, and hoopoe are three different bird species with different feeding behaviors: kestrel is prey-predator bird which possesses hard curved beaks to cut their prey while the hoopoe and common moorhen are probing birds that catch their prey by different strategies. Shawki and Ismail (2006) and Mahmoud et al. (2009) mentioned the functional morphological structure of the lingual apparatus of the common moorhen and kestrel respectively and confirmed that these bird species mainly rely on their lingual apparatus in feeding process, while the hoopoe depends on the jaw apparatus in manipulating their prey than its tongue (Gadel-Rab, Shawki, & Saber, 2012) which agree with those mentioned by Rawal (1968) who concluded that the long arms of hoopoe’s bill confer greater advantage in thrusting the bill into soil.

The cranial kinesis is an important character of the feeding behavior of birds (Bout & Zweers, 2001). The kestrel, hoopoe, and common moorhen are prokinetic birds like most bird species, in which the bending



zone is situated at the nasal-frontal hinge that allows the movement of the upper jaw up/down relative to the skull.

Mahmoud, Shawki, and Abdeen (2017) clarified that there is no flexible zone appearing at the nasal-frontal hinge in the kestrel’s skull. In the hoopoe, this hinge is movable that confirmed practically during the skull preparation; also in the common moorhen, the upper jaw can depress downward relative to skull. The movement of the upper jaw (depression) occurs as resulting of the contraction of pterygoid muscle complex of each bird species. The pterygoid muscles are originated from the palatine bone “pars lateralis” and insert on the lower jaw “posterior portion of the mandible”. The contraction of this muscle pulls the palatine bone backward, thereby depressing the upper jaw, as well as, adducting the mandible by elevating the anterior portion of mandible that leads to closing the beak. Physically, the naso-frontal hinge determines the ability of the gliding movement of the palatine bone beside its shape and position. The skull of kestrel have immovable naso-frontal hinge; this leads to the mechanical force which is produced during the contraction of the pterygoid muscle closing the mandible quickly to produce a strong bit force; this result agree with those mentioned by Mahmoud et al. (2017).

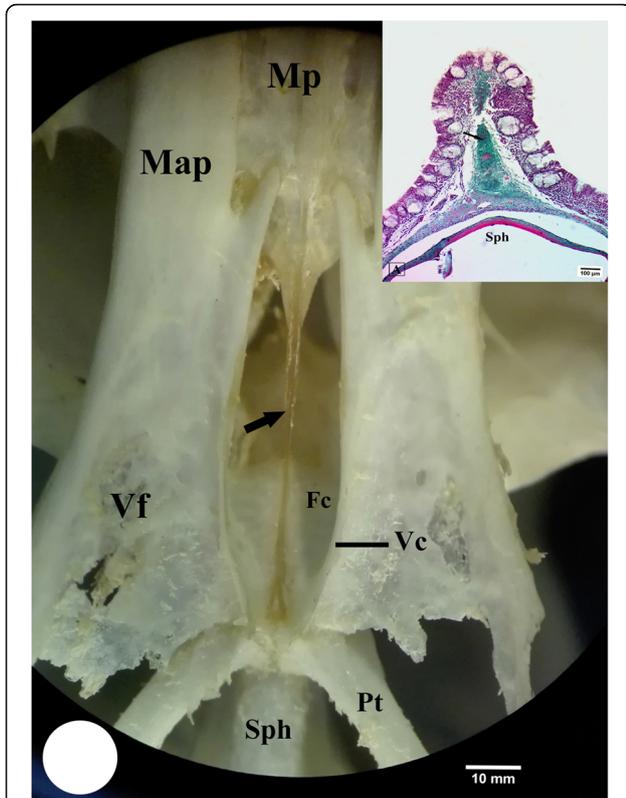


Fig. 9 High magnification of ventral surface of skull of hoopoe shows the maxillary process of the palatine bone (Map), maxillopalatine process (MP), vomer bone (arrow) is absent and replaced by a longitudinal ribbon of collagenous connective tissue, choana fossa (Fc), ventral crest (Vc), ventral fossa (Vf), Pterygoid (Pt), and parasphenoid (Sph). Upper right, photomicrograph of a transverse section of roof of hoopoe shows the collagenous connective tissue. (Masson's Trichrome)

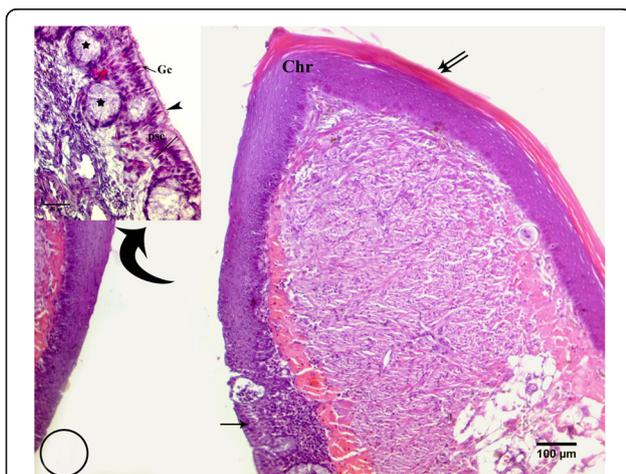


Fig. 10 Photomicrograph of a transverse section of kestrel shows the epithelium roof is keratinized (double arrows) which covers the choanal ridges (Chr), then extends dorsally and changes gradually into pseudostratified ciliated columnar epithelium (arrow). Upper left shows pseudostratified columnar epithelium (Psc) with cilia (head arrow), goblet cell (Gc), and simple alveolar gland (star). (H& E)

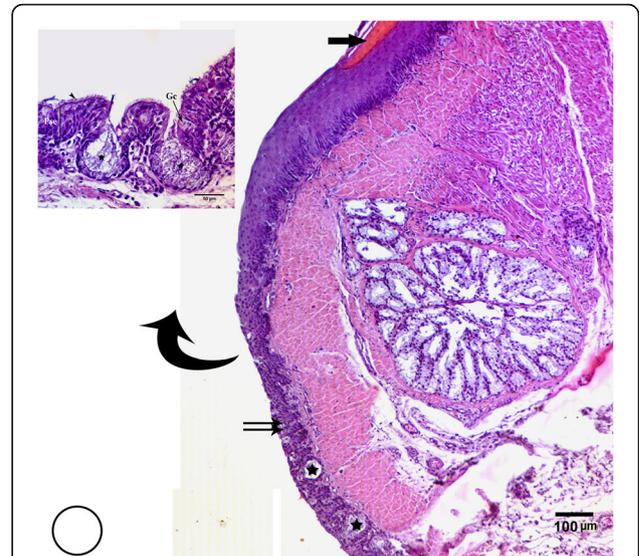


Fig. 11 Photomicrograph of a transverse section of common moorhen shows the epithelium roof is keratinized (arrow) then extends dorsally and changes gradually into pseudostratified ciliated columnar epithelium (double arrows) with simple alveolar gland (star). Upper left shows pseudostratified columnar epithelium (Psc) with cilia (head arrow), goblet cell (Gc) and simple alveolar gland (star). (H& E)

Meanwhile, in hoopoe and the common moorhen, the movable naso-frontal hinge gives flexibility for depression of the upper jaw by pulling the palatine bone during the contraction of the pterygoid muscle. During depression of upper jaw in the common moorhen, the force transferred to curve the anterior portion of the palatine bone “maxillary process of the palatine bone”. This force enables bird to widen the choana. Morphologically, widening of choana

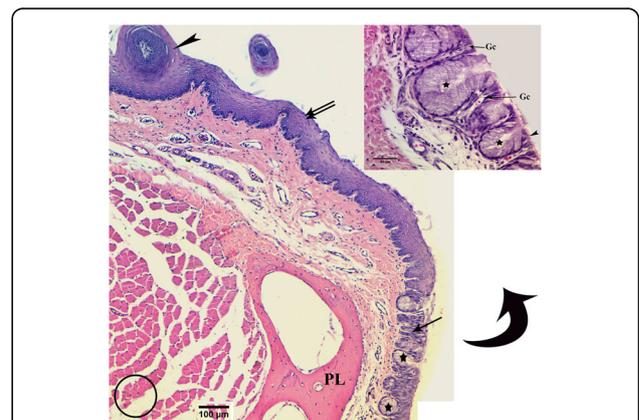
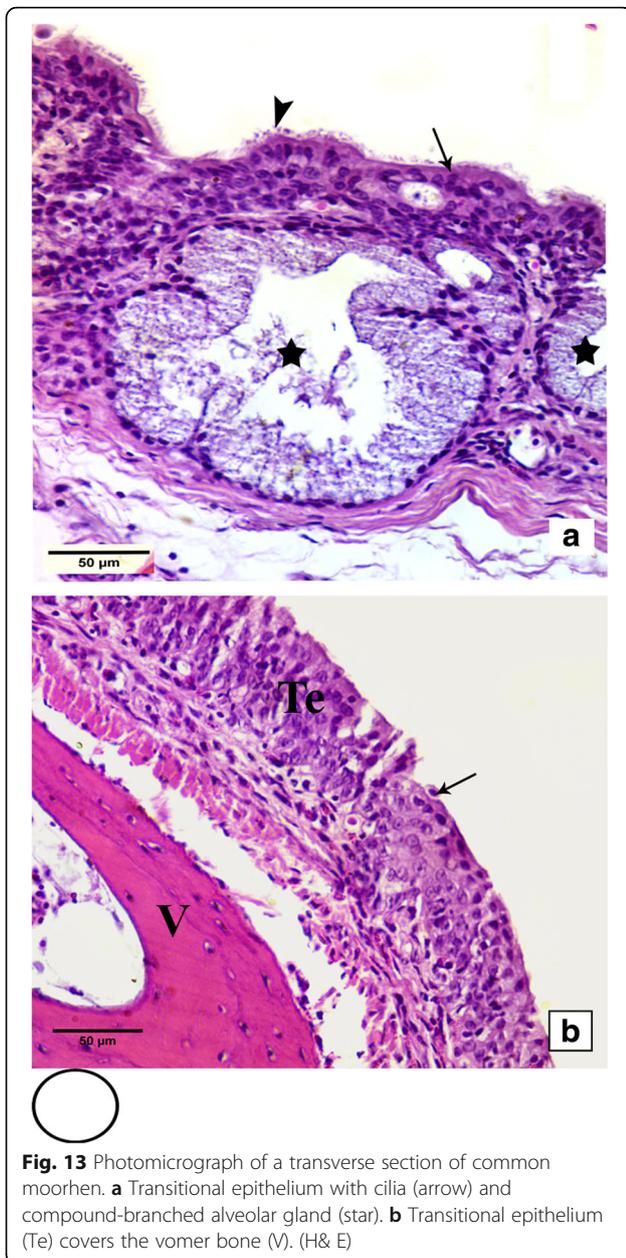
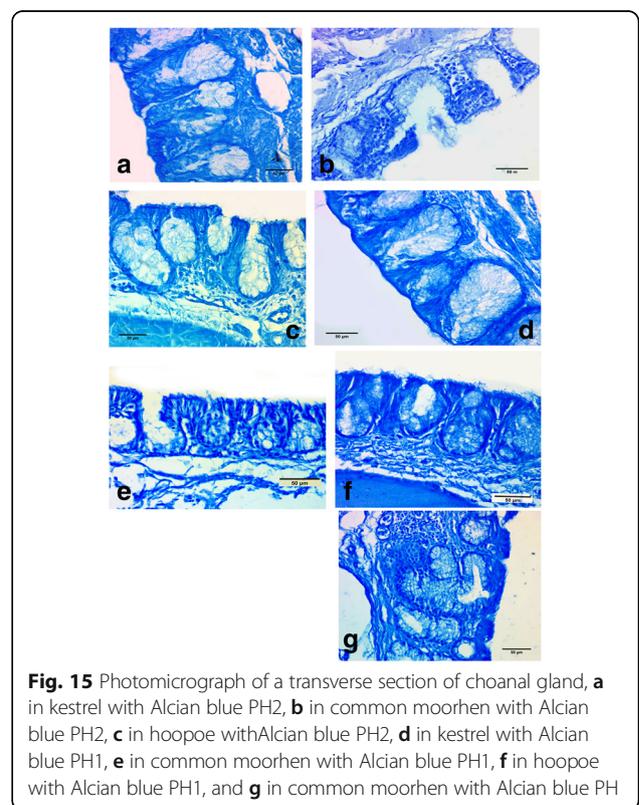
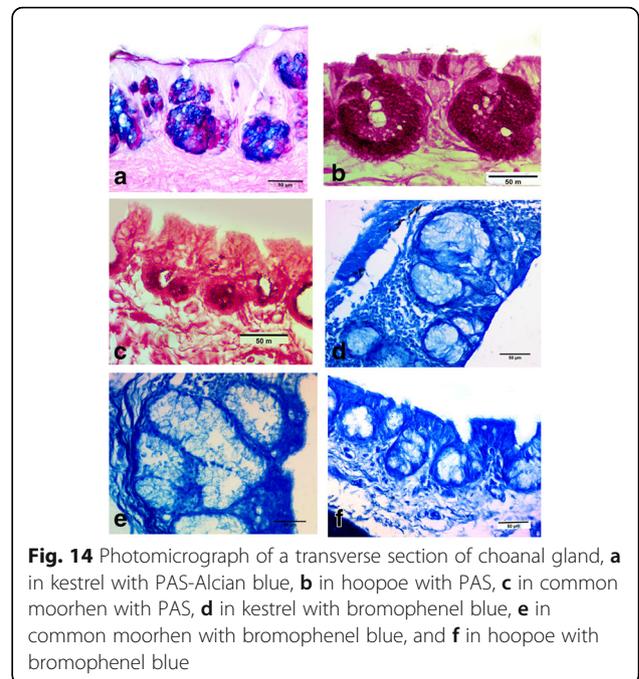


Fig. 12 Photomicrograph of a transverse section of hoopoe shows the epithelium roof is non-keratinized (double arrows), appears only to cover the papillae (head arrow), then changes gradually into pseudostratified ciliated columnar epithelium (arrow) with simple alveolar gland (star). Upper right shows goblet cells (Gc) within pseudostratified ciliated columnar epithelium (head arrow) and simple alveolar gland (star). (H& E)



may lead to increase air-flow that drain to the buccal cavity during closing of the mouth after catching prey or may be related to the uptake of large food items. In the hoopoe, the anatomical structure of the palatine bone maxillary process of the palatine bone is none allowable to change the diameter of choana. In fact, the hoopoe catches small insects and worms in no need to change the diameter of choana like that of kestrel which feeds on small items cutting before by their beak.

However, the morphological analysis of choana of these bird species suggests that the ability of movement of upper jaw relative to skull (cranial kinesis) affects the type



of epithelium that lining the choana. The choana of kestrel and hoopoe is lined by pseudostratified ciliated columnar epithelium. This type of epithelium usually placed within the nasal passages of birds (Bang & Wenzel, 1995) and some part of respiratory system of other animals (Junqueira & Carneiro, 1980) formed the mucosa of the olfactory and respiratory tracts. The presence of pseudostratified ciliated columnar epithelium within the choana in all studied bird species may help in increasing the efficiency of smell in these bird species. In addition, in the common moorhen, there is another type of epithelium beside the pseudostratified ciliated columnar epithelium, transitional epithelium type which lining the dorso-medial surface of choana. This surface of choana is more exposed to the mechanical forces during the movement of upper jaw explaining the presence of this type of epithelium in this region. The transitional epithelium has stretching ability during exposure to any pressure, if it is external (food items) or internal (mechanical performance of the feeding apparatus) pressure.

Moreover, the epithelium of choana in the three studied bird species provides with simple alveolar glands and numerous goblet cells which lack in most bird species (Bang & Wenzel, 1995). In kestrel and hoopoe, the secretion products of glands contain neutral and sulfated mucin, while in the common moorhen, secretion is neutral and carboxylate mucopolysaccharides. The natural secretion of choanal gland of these bird species confirms that these glands have no role in the digestion of food items. Moreover, these birds feed on meat; thereby, the digestion process occurs by secretion of proventriculus portion of the alimentary tract of the bird (McLelland, 1979), so their secretions of choanal gland in these bird species may help in lubrication of ingested food for ease of swelling process and provide an effective barrier against enzymatic acidic elements in contact with the buccal mucosal surface. In addition, we suggested that the choanal glands may share in detection the odoriferous molecules through dissolving in it as an olfactory stimulus.

Conclusions

The choana of the three studied bird species appears adaptation to the olfaction process but also affects the movement of skeletal elements of the skull during the feeding process. We suggest that the different epithelium which appears within the choana and the natural of their gland secretions may be specialized for different functions. Thus, it is clear that we still have much to know about the structure and function of the choana in birds.

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Availability of data and materials

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Authors' contributions

FM, AG, and NS designed and performed this work. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The authors declare that this work is carried out within an appropriate ethical framework.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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