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COMPARATIVE MORPHOMETRICS OF THE QUADRATE BONE OF BIRDS OF THE ORDERS APODIFORMES, PASSERIFORMES, STRIGIFORMES, COLUMBIFORMES AND NYCTIBIIFORMES

MORFOMETRIA COMPARATIVA DO OSSO QUADRADO DE AVES DAS ORDENS APODIFORMES, PASSERIFORMES, STRIGIFORMES, COLUMBIFORMES E NYCTIBIIFORMES

Luana Célia Stunitz da Silva[1], Nelson Dias Lucas[1], Gabriela Follador Silva Oliveira[1], Franciny Caroline Cordeiro[1]

1. Departamento de Medicina Veterinária da Universidade Federal do Paraná (UFPR) – Setor Palotina.
*Autor correspondente: luanastunitz@ufpr.br

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RESUMO

Devido à importância na cinética dos movimentos cranianos das aves, o osso quadrado foi descrito nesse trabalho a partir de 12 indivíduos de oito espécies diferentes, das ordens Apodiformes, Passeriformes, Strigiformes, Columbiformes e Nyctibiiformes. Após dissecação e maceração procedeu-se com a mensuração das distâncias entre os três processos presentes nesses ossos e as particularidades das espécies foram analisadas. Em todas as espécies observaram-se três processos (ótico, orbicular e mandibular) surgindo a partir do corpo do osso quadrado. Para *Serinus conaria* e *Megascops choliba* observou-se que o processo ótico encontrava-se desenvolvido. O processo orbital mostrou-se evidente em *Columbina talpacoti, Serinus canaria e Pitangus sulfuratus*. E foi constatado a existência de três côndilos (lateral, caudal e medial) no processo mandibular em todos os espécimes analisados, os quais estavam pobremente visíveis, exceto para o espécime de *Megascops choliba*. Assim, a partir das análises obtidas nota-se semelhança nas estruturas anatômicas encontradas nas espécies aviárias analisadas mesmo estas pertencendo a Ordens distintas. E embora o trabalho contemple, em alguns casos, somente um exemplar das espécies o conhecimento anatômico apresentado possui valor intrínseco de consulta à comunidade científica, pois fornece informações a respeito das características fisiológicas do osso quadrado o qual é essencial na craniocinese das aves.

Palavras-chave: Anatomia Animal, Osteologia, Crânio, Aves, Filogenética.

ABSTRACT

In view of its importance for the kinetics of cranial movements in birds, this study describes the quadrate bone of 12 individuals of eight different species, of the orders Apodiformes, Passeriformes, Strigiformes, Columbiformes and Nyctibiiformes. After dissection and maceration, the distances between the three processes occurring in these bones were measured and the peculiarities of the species analyzed. All species showed three processes arising from the quadrate body, namely: otic, orbicular and mandibular. The otic process was developed in *Serinus canaria* and *Megascops choliba*. The orbital process was evident in *Columbina talpacoti*, *Serinus canaria* and *Pitangus sulphuratus*. The mandibular process of all analyzed specimens showed three condyles (lateral, caudal and medial), which were poorly visible, except in the *Megascops choliba* specimen. Therefore, the analyses reveal a similarity in the anatomical structures found in the evaluated avian species, even though they belong to different orders. Although the study investigates only one specimen in some species, the presented anatomical knowledge holds intrinsic value of consultation to the scientific community, as it provides information on the physiological characteristics of the quadrate bone, an essential element of the cranial kinesis of birds.

Keyword: Animal Anatomy, Osteology, Skull, Birds, Phylogenetics

INTRODUCTION

Approximately 10,488 avian species have been described around the globe. In this regard, Brazil is home to one of the greatest biodiversity of such vertebrates, with 1,919 species described so far, which are divided into 26 orders and 96 families (MENEZES et al., 2004; IBAMA/CEMAVE, 2005; CBRO, 2015).

Birds are widely distributed worldwide, inhabiting diverse ecosystems (POUGH and JANIS, 2003). Among the Brazilian biomes, the Atlantic Forest is the richest in birdlife diversity, harboring 1020 species, of which 188 are endemic (CBRO, 2015).

This great morphological diversity constitutes an excellent and precious source of characters, which can also be used for the construction of phylogenetic trees. In this respect, the description of the skull of birds is known to possibly be an even safer source in cladistic analysis if new characters and anatomical evidence of homologies are described and documented (GUZZI et al., 2015; LIVEZEY and ZUSI, 2001).

The quadrate, which forms the skull of birds, is the center of all movements in the region precisely because it is highly mobile, assuming great importance in the articulation between the skull and the jaw (FEDUCCIA, 1986; BÜHLER, 1981; BOCK, 1964). In this way, birds are able to move the mandibular bone or a part of it relative to the head—a property termed cranial kinesis (GUZZI et al., 2015). According to Feduccia (1986), the quadrate has morphological complexity in all birds, as it serves not only for jaw suspension, but also to form a pivotal axis that helps the kinetic mechanism of the jaw, culminating in the axis that generates all cranial kinetic movements (PASCOTTO, 2006; FISHER, 1955). It has a triangular shape and articulates with the pterygoid, rostral squamosal and quadratojugal bones (BAUMEL, 1993; FEDUCCIA, 1986).

The quadrate has a central part called the quadrate body (*corpus quadrati*), from which three processes are classically projected: the otic process (*processus oticus*), the mandibular process (*processus mandibularis*) and the orbital process (*processus orbitalis*) (MARCELIANO et al., 2007; ANDRELA and DONATELLI, 1995; BAUMEL, 1993; NICKEL et al., 1977).

Two capitula are also observed on the otic process: the squamosal capitulum (*capitulum squamosum*), which articulates medially relative to the base of the suprameatic process; and the otic capitulum (*capitulum oticum*), which articulates with the dorsal wall of the tympanic cavity and is more developed than the first. A small groove (sulcus) is present between these capitula (ANDRELA and DONATELLI, 1995; BAUMEL, 1993).

The mandibular process, which is located in the ventral portion of the quadrate body and articulates with the jaw of birds, normally has three condyles: lateral, medial and caudal (*condylus lateralis*, *medialis* and *caudalis*) (ANDRELA and DONATELLI, 1995).

In this scenario, this study proposes to describe the quadrate of eight different avian species, belonging to the orders Apodiformes, Passeriformes, Strigiformes, Columbiformes and Nyctibiiformes.

MATERIAL AND METHODS

Twelve individuals of eight different species of birds were used, as follows: one specimen of *Chaetura meridionalis* (Sick's swift); two *Pitangus sulphuratus* (great kiskadee); one *Serinus canaria* (Atlantic canary); one *Athene cunicularia* (burrowing owl); one *Megascops choliba* (tropical screech owl); one *Columbina talpacoti* (ruddy ground dove); two *Tyrannus savana* (fork-tailed flycatcher); and three specimens of *Nyctibius griseus* (common potoo), which died due to natural causes and were donated to the Laboratory of Animal Anatomy at the Federal University of Paraná (UFPR) - Palotina Unit.

The birds were previously frozen for later dissection without fixing the material. After thawing, organic tissues of the head were dissected and the atlanto-occipital region was disarticulated in all animals, which was followed by heated maceration for a short time. Afterwards, the pieces were immersed in a 10% hydrogen peroxide solution for about 10 min and the material was dried in the sun. To complete the process, the quadrates of both antimers of each specimen were removed using tweezers and delicate scissors.

Measurements were taken on the collected quadrates using a 0.01-mm precision digital caliper (Starret®*) and based on the descriptions contained in "*Nomina anatomica avium*", published by the International Committee on Avian Anatomical Nomenclature (BAUMEL, 1993). The measurements, which were performed by a single examiner, were as follows: length between the mandibular (PrMq) and otic (PrOq) processes; length between the mandibular (PrMq) and orbital (PrORq) processes; and length between the otic (PrOq) and orbital (PrORq) processes of the quadrate bone (Figure 1). All obtained values were described in millimeters and their averages and standard deviations were calculated.

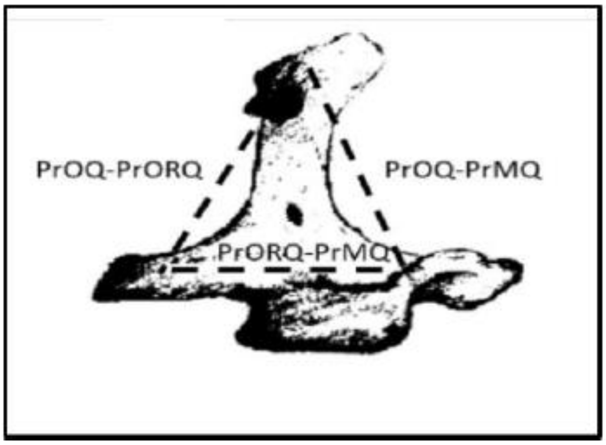

Figure 1. Medial view of the quadrate bone in birds. PrOq-PrMq: Length between the otic and the mandibular processes of the quadrate; PrORQ-PrMQ: Length between the orbital and the mandibular processes of the quadrate; PrOq-PrORq: Length between the otic and the orbital processes of the quadrate. Source: illustration by Heloisa Fontana Rocha.

* 150-mm digital caliper, EC799 series, 0.01 mm, Starrett®, São Paulo-SP, Brazil.

RESULTS AND DISCUSSION

Several bony landmarks were identified in the evaluated quadrates, e.g. condyles, processes, capitula and pneumatic foramina, which are represented schematically in Figure 2. Box 1 describes the values found in all measurements performed on the animals.

Overall, the longest distance in the evaluated species was between PrOq and PrORq. As an example, in *Chaetura meridionalis*, the distance between PrMq and PrOq was in an intermediate position, while the shortest distance was identified between PrMq and PrORq. Among the analyzed raptors, the distance between the otic and the orbital processes of the quadrate (PrOq-PrORq) in *Athene cunicularia* was greater than that observed in *Megascops choliba* (Figure 3E). Considering specifically the measurements taken on *Megascops choliba* (tropical screech owl), all values were below that described in the same species by Wagner et al. (2017).

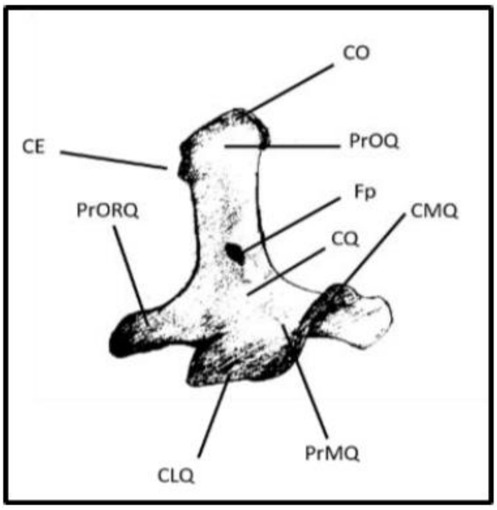

Figure 2. Medial view of the right quadrate bone of *Athene cunicularia* (burrowing owl), showing the orbit process of the quadrate (PrORQ), the mandibular process of the quadrate (PrMQ), the lateral condyle of the quadrate (CLQ), the medial condyle of the quadrate (CMQ), the otic process of the quadrate (PrOQ), the squamosal capitulum (CE), the otic capitulum (CO), the pneumatic foramen (Fp) and the quadrate corpuscle (CQ). Source: illustration by Heloisa Fontana Rocha.

Box 1. Identification of the studied avian species with the description of sex (M: male; F: female; I: indeterminate) and measurements of distances on the quadrate bone, in millimeters (mm). PrOq-PrMq: Length between the otic and the mandibular processes of the quadrate; PrORQ-PrMQ: Length between the orbital and the mandibular processes of the quadrate; PrOq-PrORq: Length between the otic and the orbital processes of the quadrate.

No.	Species	Common name	Sex	PrMq-PrORq	Mean/ SD	PrMq-PrOq	Mean/ SD	PrOq-PrORq	Mean/ SD
01	*Chaetura meridionalis*	Sick's swift	M	2.78	-	3.54	-	4.37	-
02	*Pitangus sulphuratus*	Great kiskadee	M	4.38	4.31 (±0.11)	4.78	4.17 (±0.87)	4.66	4,52 (±0.21)
03	*Pitangus sulphuratus*	Great kiskadee	I	4.23		3.55		4.37	
04	*Serinus canaria*	Atlantic canary	M	2.35	-	3.81	-	4.3	-
05	*Athene cunicularia*	Burrowing owl	I	5.36	-	11	-	10.7	-
06	*Megascops choliba*	Tropical screech owl	I	4.82	-	5.43	-	5.93	-
07	*Columbina talpacoti*	Ruddy ground dove	F	2.54	-	5.14	-	4.01	-
08	*Tyrannus savana*	Fork-tailed flycatcher	M	2.77	2.7 (±0.1)	2.43	2.5 (±0.1)	3.24	3,2 (±0.1)
09	*Tyrannus savana*	Fork-tailed flycatcher	M	2.65		2.55		3.11	
10	*Nyctibius griseus*	Common potoo	M	5.06	5.1 (±0.04)	8.77	8.4 (±0.4)	5.71	6,5 (±0.9)
11	*Nyctibius griseus*	Common potoo	M	5.13		8.08		7.48	
12	*Nyctibius griseus*	Common potoo	M	5.10		8.28		6.33	
MEAN				3.93	-	5.61	-	5.35	-
STANDARD DEVIATION				±1.20	-	±2.77	-	±2.12	-

In all species evaluated in this study, three processes were observed (otic, orbicular and mandibular) arising from the quadrate body, in agreement with the literature (BAUMEL, 1993; COSTA and DONATELLI, 2009) (Figures 3A-F). However, in addition to these, the existence of a fourth process has been reported: the so-called pterygoid process, described by Marceliano et al. (1997) in birds of the family Psophiidae (trumpeters) and in some parrot species, such as *Amazona aestiva* and *Diopsittaca nobilis* (SOUZA et al., 2018). Being less developed than the others, this process is located rostro-medially from the quadrate body and articulates the caudal bifurcation of the pterygoid bone, which was not evidenced in the present study.

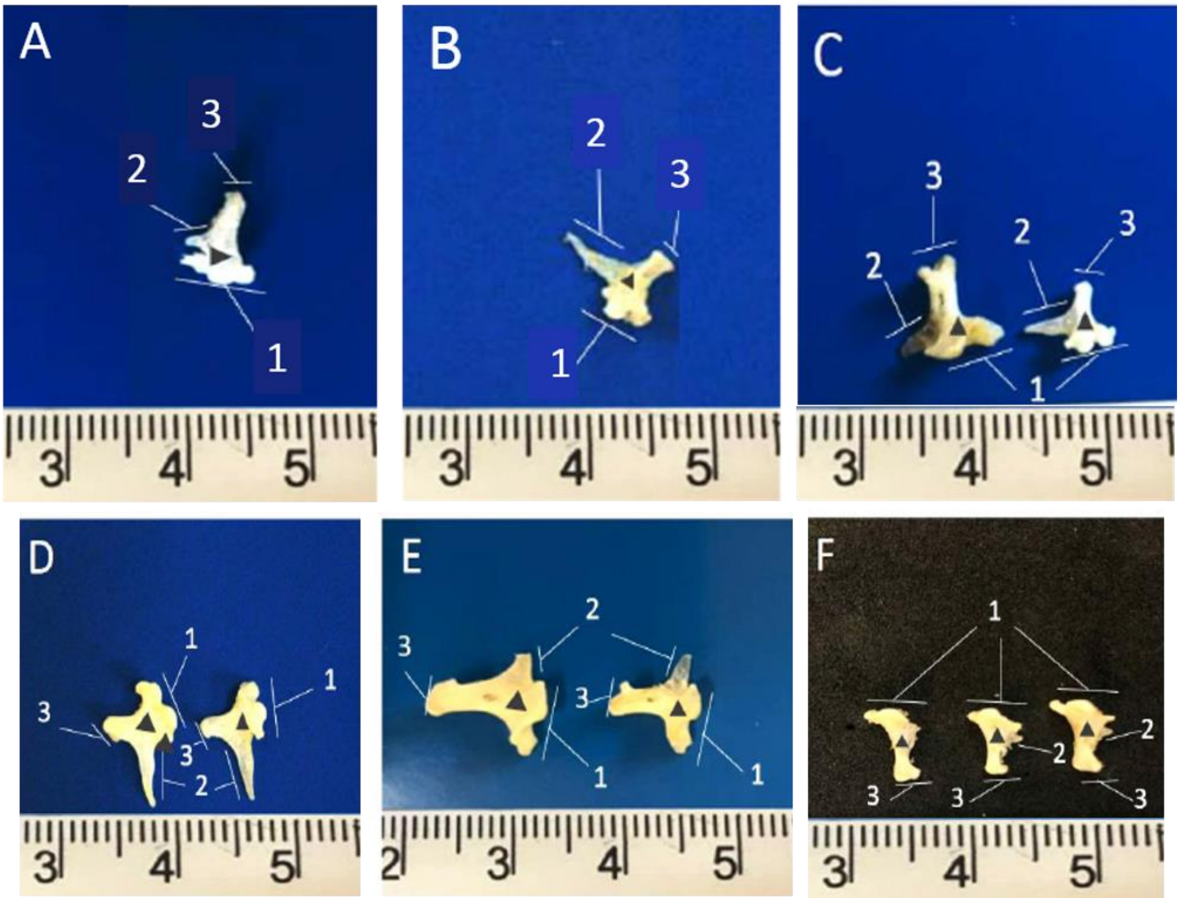

Figure 3. Photographs of the quadrate bone of the analyzed specimens. A- Medial view of the left quadrate of *Chaetura meridionalis*. B- Medial view of the right quadrate of *Serinus canaria*. C- Medial view of the right quadrate of *Megascops choliba* on the left, and quadrate of *Pitangus sulphuratus* on the right. D- Medial view of the right quadrate of *Pitangus sulphuratus*. E- Medial view of the right quadrate of *Athene cunicularia* on the left, and *Megascops choliba* on the right; F- Medial view of the right quadrate of three specimens of *Nyctibius griseus*. (1) Mandibular process, (2) orbital process, (3) otic process and (▲) the quadrate corpuscle. Source: personal archive.

An otic process on the quadrate of birds has the function of being the point of origin of the deep pseudotemporal muscle and region for insertion of muscles with the function of jaw suspension (BÜHLER, 1981). In addition, according to BURTON (1984), in some groups of birds, this otic process could avoid excessive elevation of the maxilla. However, further studies on the possible functions of this bony landmark are still needed to confirm the propositions of said researcher. The otic process in the Atlantic canary (*Serinus canaria*) analyzed in this study (Figure 3B) was found to be developed, as also seen in the tropical screech owls (Figures 3C and 3E). These findings disagree with the descriptions of Costa and Donatelli (2009), who observed that caprimulgiform birds showed a vestigial orbital process.

The presence of a clear pneumatic foramen and a defined quadrate corpuscle were observed in *Megascops choliba*, *Athene cunicularia* and in one specimen of the species *Tyrannus savana* (no. 12). In the two *Pitangus sulphuratus* individuals, the pneumatic foramina were discrete and narrow. In contrast, in the other species, e.g., Sick's swift (*Chaetura meridionalis*) and common potoo (*Nyctibius griseus*), this foramen was not identified, as the quadrates became very porous due to the technique used, which culminated in a loss of definition of some structures and bony landmarks. This consequence had already been described by Rodrigues (2010), who reported the techniques of bone maceration in the scope of Anatomy Laboratories.

The orbital process showed to be well-developed in *Columba livia* (common pigeon) (GENNIP, 1986), as seen in the analyzed specimen of ruddy ground dove, a bird phylogenetically close to the first. This was also reported in the passerine *Coryphospingus pileatus* (grey pileated finch) (LIMA et al., 2019), which the present study corroborates in the analysis of some species of passerines, such as the Atlantic canary and the great kiskadee (Figures 3B to D).

In the evaluated swift, the condyle of the orbital process was more projected than in the other species (Figure 3A), disagreeing with the reports of Donatelli (1997), who described that the distal portion in the passerine species *Xiphorhynchus guttatus* (buff-throated woodcreeper) and *Dendrocolaptes certhia* (Amazonian barred woodcreeper) was convex and flat, resembling “an ax head”.

Three condyles (lateral, caudal and medial) were identified in the mandibular process of the specimens of all avian species analyzed. These were poorly visible, except for the *Megascops choliba* specimen (Figures 3C and E). Conversely, Lima et al. (2009) found only one condyle in the mandibular process of the quadrate in the evaluated species of grey pileated finch (*Coryphospingus pileatus*). Likewise, Pode and Donatelli (2001) reported that the mandibular process in birds of the family Cucunidae and in some Falconiformes species such as *Milvago chimango* and *Milvago chimachima* (GUZZI et al., 2015) had four condyles: lateral, medial, caudal and pterygoid (*condylus lateralis, medialis, caudalis* and *pterygoideus*). In birds of the family Cucunidae, the lateral and medial condyles had practically the same development; however, the medial condyle tapered ventrally and the lateral condyle had a rounded appearance (POSSO and DONATELLI, 2001).

The caudal condyle of the mandibular process seen in several species, such as the specimens of fork-tailed flycatcher and common potoo (Figure 3F), was not found in the Bucconidae species evaluated by Ladeira and Höfling (2007). These authors did not observe an evident distinction between the lateral and caudal condyles of the mandibular process, causing the caudal condyle to be considered an extension of the lateral condyle, as also described in some Falconiformes such as *Milvago chimango, Milvago chimachima* (GUZZI et al., 2015) and *Micrastur semitorquatus* (SILVA et al., 2012).

In birds of the families *Phoeniculidae*, *Upupidae* and *Leptosomidae,* the caudal condyle is fused laterally to the lateral condyle (PASCOTTO et al., 2006). This is very different from findings in birds of the family Psophiidae (trumpeters), whose both lateral and caudal condyles of the mandibular process had similar development; the medial condyle being proportionally more developed, in this case (MARCELIANO et al., 1997).

Studies have described the existence of an intercondylar groove on the quadrate between the lateral and medial condyles of the mandibular process in *Columbina squammata* (scaled dove) (ANDRELA and DONATELLI, 1995) and in birds of the family Psophiidae (trumpeters) (MARCELIANO et al., 1997). In the present study, however, this bony landmark was not present in the evaluated specimens.

CONCLUSIONS

The presented analyses reveal a similarity in the anatomical structures found in the evaluated avian species, even though they belong to different orders. Although this study examined only one specimen of some species, the presented anatomical knowledge holds intrinsic value of consultation to the scientific community, as it provides information on the physiological characteristics of the quadrate, an essential element of cranial kinesis in birds.

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