Anatomical study of the musculus deltoideus *and* musculus flexor carpi ulnaris *in 3 species of wild birds*

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Summary
Given the limited information regarding the anatomy of the thoracic limb in European avian species, we decided to investigate the related muscles in the grey heron (*Ardea cinerea*), in the eurasian buzzard (*Buteo buteo*), and in the common kestrel (*Falco tinnunculus*). Therefore we performed a stratigraphic dissection of the wing in 3 subjects. The *pars major* and *minor* of the *musculus deltoideus*, despite being roughly in line with those reported by other authors in other species, displayed unique features. Concerning the *pars propatagialis* of the *musculus deltoideus*, from what was observed in the grey heron, we believe this structure can contribute to maintain the propatagial tension. In this way vibrations of this structure, which could cause diminished lift, are avoided. Moreover the peculiarity evidenced in the distal insertion of the common kestrel could influence the control of the pronation-supination of the wing during hovering. With respect to the *musculus flexor carpi ulnaris*, we believe the presence of a sesamoid-like structure at the base tendon, found in the grey heron and in the eurasian buzzard, may help complete the articular surfaces of the elbow. This study shows interesting data on species not previously examined and provides a possible functional correlation between the peculiarity observed and the kind of flight of each species.

Studio anatomico dei muscoli deltoide e flessore ulnare del carpo in tre specie di uccelli selvatici

Parole chiave
Airone cenerino,
Ala,
Anatomia,
Animali selvatici,
Ardea cinerea,
Buteo buteo,
Falco tinnunculus,
Gheppio,
Miologia,
Poiana eurasiatica,
Uccelli,
Volo.

Riassunto
Alla luce delle scarse informazioni circa l'anatomia dell'arto toracico nelle specie aviari presenti sul territorio europeo si è ritenuto opportuno indagare tali strutture nell'airone cenerino (*Ardea cinerea*), nella poiana eurasiatica (*Buteo buteo*) e nel gheppio comune (*Falco tinnunculus*). A tal fine si è realizzata una dissezione stratigrafica dell'arto toracico nelle suddette specie. Le parti maggiore e minore del muscolo deltoide si sono dimostrate grosso modo in linea con quanto precedentemente riscontrato da altri autori in altre specie. Per quanto concerne la parte propatagiale di questo muscolo, in base a quanto osservato nell'airone cenerino, riteniamo che essa possa contribuire al mantenimento della tensione del propatagio evitando vibrazioni a questo livello che provocherebbero cadutea di portanza. Le peculiarità emerse a carico del livello dell'inserzione distale di questa parte nel gheppio comune potrebbero avere un ruolo nella prono-supinazione dell'ala durante l'*hovering*. Parallelamente, la presenza di una struttura simil-sesamoidea a livello della parte prossimale del tendine del muscolo flessore ulnare del carpo nella poiana eurasiatica e nell'airone cenerino, potrebbe contribuire a completare la superficie articolare dell'articolazione del gomito. Questo studio evidenzia interessanti dati in specie non precedentemente esaminate e fornisce una possibile interpretazione funzionale delle peculiarità osservate in relazione al tipo di volo delle specie esaminate.

Introduction

The thoracic limb in birds differs considerably from that of mammals due to the high level of specialization of the locomotor system typical of this class. Several studies (Baumel *et al.* 1993, George and Berger 1966, King and Mclelland 1985) have focused on the anatomical analysis of the wing in order to correlate anatomical details with the characteristics of flight in different species. Due to the limited information about the anatomy of the thoracic limb in European avian species, we decided to investigate the related muscles in 3 bird species of notably differing flight characteristics and distributed throughout Italy. They are the grey heron (*Ardea cinerea*), the eurasian buzzard (*Buteo buteo*), and the common kestrel (*Falco tinnunculus*). The grey heron is a regular Autumn and Spring migrant and also dispersive (Brichetti and Fracasso 2003). Its flight action is slow, with pronounced flaps of noticeably bowed wings, but when, for example, descending to nest site or confined feeding area, markedly agile, side-slipping, and parachuting downwards, often with head and legs extended (Cramp 2004).

The eurasian buzzard is a migrant wintering but is also sedentary in Italy (Brichetti and Fracasso 2003). During soaring, it maintains the wings flattish and slightly lifted, often with the wrist kinked. It displays flight with stoop and loops in descending and undulating flight alternating with high and slow wing beats. These birds sit mostly hidden on low perches when hunting while they are frequently seen on the wing, covering huge areas while looking for hunting grounds (Forsman 2003).

The common kestrel is a migrant wintering but also sedentary in Italy. (Brichetti and Fracasso 2003). Its flapping flight consists of a series of wing-beats interrupted by frequent glides and the wing action is looser than in other falcons. When hunting, it quarters at moderate height above the ground, stooping every now and then to hover against the wind with fluttering wing-beats and fanned tail (Forsman 2003). This paper presents data on the gross anatomy of the *musculus deltoideus* and *musculus flexor carpi ulnaris* in the above species observed during a wider investigation on the wing musculature.

Materials and methods

For each species we examined 3 deceased subjects obtained from the Centro di Recupero degli Animali Selvatici della Lega Italiana Protezione Uccelli (LIPU) of Padova (Italy) and from the Ufficio Faunistico del Servizio Foreste e Fauna of the Guardia Forestale of the Provincia Autonoma of Trento (Italy). The carcasses, were stored at -20°C by the relative agencies and then were transferred and maintained in our cold storage (at -20°C) until the moment of the dissection. Chicks, juvenile subjects, and animals that had suspected or evident injuries to the thoracic limb were excluded from the study. The remaining birds were then bilaterally dissected from shoulder to hand, effecting a progressive exposition of the muscle layers. Anatomical nomenclature is from *Nomina Anatomica Avium* (Baumel *et al.* 1993) unless otherwise stated. Pictures were taken utilizing a Fuji camera. Images were then digitally elaborated using Adobe Photoshop CS4.

Results

Musculus deltoideus

Each of the species examined showed a *musculus deltoideus* composed of 3 parts: *pars propatagialis*, *pars major*, and *pars minor* (Figure 1A).

Grey heron (Ardea cinerea)

Pars propatagialis was formed by cranial (*caput craniale*) and caudal (*caput caudale*) parts that converged immediately after the origin thus forming a single muscular belly. The *c. craniale* originated from the *extremitas omalis* of the *clavicula* and of the *coracoideum*, while the *c. caudale* originated from the *extremitas omalis* of the *clavicula* and the *extremitas cranialis* of the *scapula*. The common belly continues with 2 tendons. The cranial tendon joined the *p. propatagialis* of the *musculus pectoralis* while the caudal tendon crossed caudolaterally the propatagial region to the elbow joint. The caudal tendon, in proximity of its distal attachment, split into cranial and caudal portions. The cranial component ended on the *musculus extensor carpi radialis* (Figure 1B). The caudal component was, instead, attached onto the *musculus extensor carpi ulnaris* and onto a fascial sheet surrounding the calami of the secondary feathers. *Pars major* arose from the distal extremity of the *coracoideum*, from the *collum* and the first part of the *scapula* and from the shoulder joint. A very short fibromuscular sheet (scapular anchor) commenced from the caudal margin of the proximal insertion. It ended on the *corpus scapulae*, slightly more cranial to the proximal tendon of the *musculus scapulotriceps* (Figure 1C). The belly of the muscle extended to the *humerus*, passing caudally to the dorsal tubercle of the *humerus*. It was inserted on the caudal aspect between the *crista deltopectoralis* and the 3/5 of this bone. *Pars minor*, which was located under the *p. propatagialis*, arose from the caudal edge of the *canalis triosseus* and was strictly connected to the tendon of the *musculus supracoracoideus*.

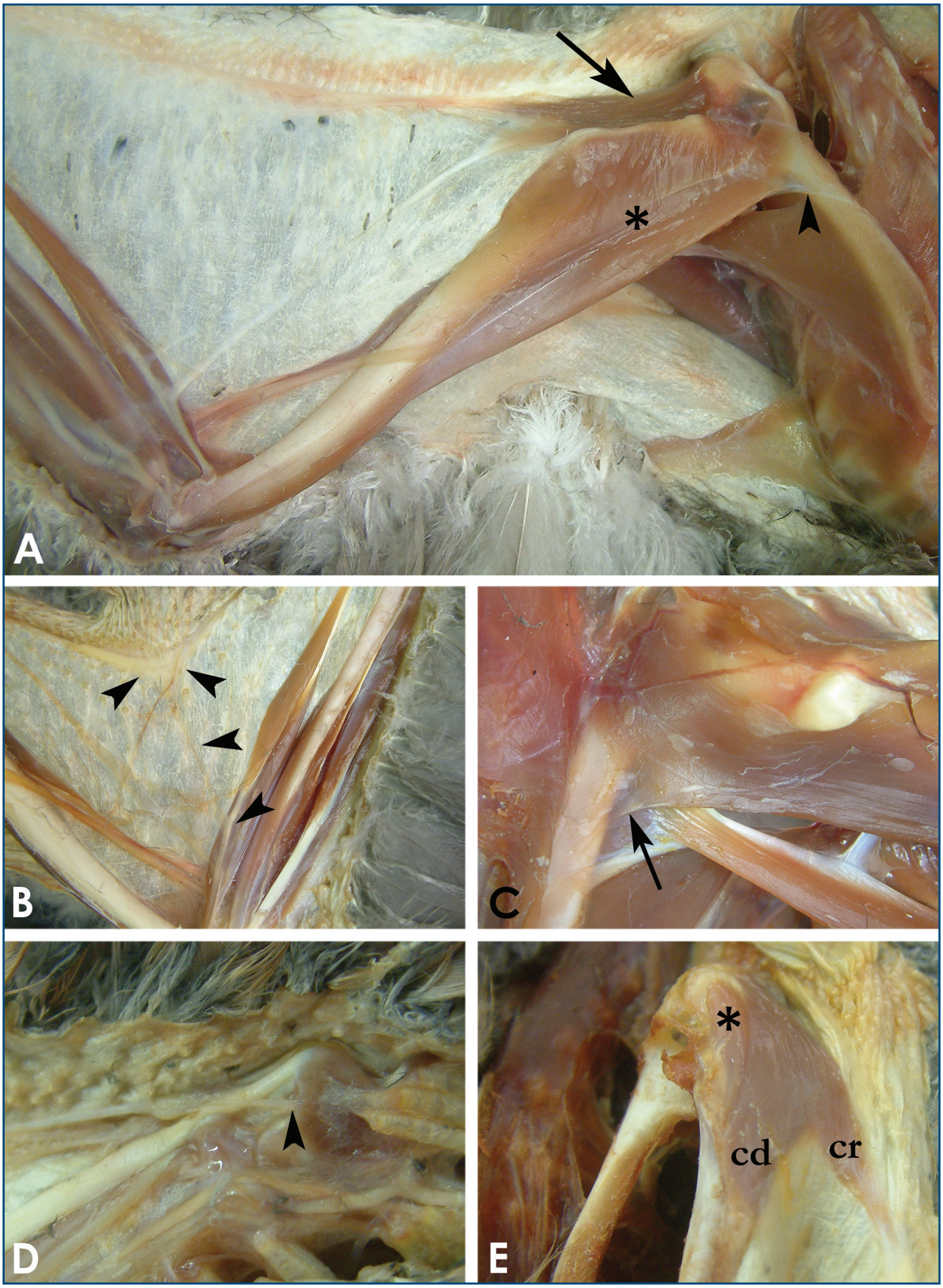

Figure 1. ***A.*** Musculus deltoideus *of a eurasian buzzard - dorsal view of the left wing. Pars propatagialis* (arrow); *pars major* (asterisk); scapular anchor (arrowhead). ***B.*** *Dorsal view of the right wing.* Propatagial fold in a grey heron. Additional fibrous band arising from the *ligamentum propatagialis* (arrowheads). ***C.*** *Detailed dorsal view of the right shoulder in the grey heron.* The arrow points to the fibromuscular scapular anchor. ***D.*** *Dorsal view of the right wrist in the common kestrel.* The arrowhead points to the dorsal insertion of the *ligamentum propatagialis*. ***E.*** Musculus deltoideus *of a common kestrel (right shoulder). Pars minor* (asterisk) and *pars propatagialis*: cranial (cr) and caudal (cd) heads. Picture was taken in Ozzano dell'Emilia, Bologna, IT on March 2012 to illustrate the dissection.

It terminated on the ventral aspect of the *crista deltopectoralis*. The muscle belly, near its proximal insertion, gave rise to a thin tendon which joined the tendon of the caudal part of the *p. propatagialis*.

*Eurasian buzzard (*Buteo buteo*)*

Pars propatagialis emanated with fleshy fibers from the *coracoideum* in the acrocoraco-humeral ligament's area of insertion. It also emerged at the level of the *extremitas omalis* of the *clavicula* and the *crista deltopectoralis*. It was composed of cranial (*c. craniale*) and caudal (*c. caudale*) parts. The common belly of the two parts extended up to the middle of the *crista deltopectoralis* (Figure 1A). At this level the cranial part gave rise to a long tendon which joined the tendon of the *pars propatagialis* of the *m. pectoralis* so as to form the *ligamentum propatagialis*. This latter ligament rested on the cranial edge of the propatagium until reaching the wrist. Near its end, the *lig. propatagialis* split into 2 branches. The caudal branch ended on the ventral aspect of the *os carpi radiale*. It was barely caudal to cranial branch. Regarding the *c. caudale* of *p. propatagialis*, its muscle belly, after passing the middle of the *crista deltopectoralis*, gave rise to a tendon. This structure extended caudolaterally across the propatagium. At the last third of the *humerus* the tendon divided. The cranial part inserted on the proximal tendon of the *m. extensor carpi radialis*. The caudal part inserted onto the caudal edge of the forearm surrounding the quills of the secondary feathers and their coverts. *Pars major* of the *m. deltoideus* was composed of fleshy fibers lying on the dorsoproximal part of the *humerus* and intimately connected with *p. minor* (Figure 1A). It was composed of 2 elements. The cranial element arose from the cranial end of the *clavicula* and the *extremitas cranialis* of the *scapula*. The caudal member originated from the *extremitas omalis* of the *clavicula* and from the *extremitas cranialis* of the *scapula*. Over the *humerus* the 2 parts merged into a single belly occupying the proximal third of the body of the bone (Figure 1A). From the ventral aspect of the caudal branch arose a short flat tendon inserted on the dorsocaudal edge of the *canalis triosseus*. *Pars minor* was less developed than *p. major*. It arose from the *coracoideum* near the *processus acrocoracoideum* and from the dorsocranial edge of the *canalis triosseus*. The origin of this part covered the distal tendon of the *m. supracoraoideus*. It ended on the ventral side of the *crista deltopectoralis* of the *humerus*.

*Common kestrel (*Falco tinnunculus*)*

In this species the conformation of the *p. propatagialis* corresponded to the one of the eurasian buzzard with the single exception of the distal insertion of the *lig. propatagialis*. In fact, the caudal branch ended on the ventral aspect of the distal extremity of the *radius*, while the cranial branch split into 2 sections which extended to the opposite side of the wrist joint. One of the sections remained on the ventral aspect, passing the distal extremity of the *radius*. At this level it showed a sesamoid-like oval structure of a few millimeters length. The tendon continued on the cranial margin of the *os carpi radiale* and on the ventral side of the base of the alula. It inserted on the *processus extensorius* and fanned out at the proximal part of the carpal joint, merging with the ventral aponeurosis. The second branch, much thinner compared to the other, extended on the dorsal side of the wrist joint, lying over the terminal tendon of the *m. extensor carpi radialis*. It terminated at the base of the *p. extensorius* of the *os metacarpale alulare*, intimately associated with the corresponding covert feathers (Figure 1D). *Pars major* (Figure 1A) was the most developed. It consisted of 2 asymmetrical muscular bellies. The cranial head (*c. craniale*) extended from the proximal extremity of the *humerus* to the third proximal of the cranial aspect of the same bone. The caudal part (*c. caudale*) arose from the *collum scapulae* and the first quarter of the dorsal edge and lateral side of that bone. On the caudal edge of the *scapula*, near the proximal insertion of the caudal part, there was the insertion of the scapular anchor. The origin of this thin fibrous structure lays between the insertion of the *mm. scapulohumeralis caudalis* and *subscapularis*. On the ventral part of the belly there was a thin bundle of fibrous fibers connecting to the *m. scapulotriceps*. These 2 muscles were in strict relation to each other because of a fibrous fascia enveloping the two bellies at their scapular insertions. Then the belly extended laterally occupying the cranial half of the cranial aspect of the *humerus*, intimately associated to the belly of the *musculus omerotriceps*. *Pars minor* of the *m. deltoideus* (Figure 1E) is weakly developed. It arose from *tuberculum dorsale* at the level of the *extremitas proximalis humeri*. It was inserted at the base of the *crista deltopectoralis*, partially covering the distal tendon of *m. supracoracoideus*.

Musculus flexor carpi ulnaris

*Grey heron (*Ardea cinerea*)*

In all the subjects examined the *m. flexor carpi ulnaris* was the most caudal and the best developed muscle among the ventral side of the forearm (Figure 2A). It originated from a tendon at *processus flexorius* of the *humerus*. A sesamoid-like structure was present in the proximal part of the tendon (Figure 2B). Next to the origin the belly split into 2 parts. The cranial portion was bipinnate and extended from the proximal to the middle third of the ulna. At this

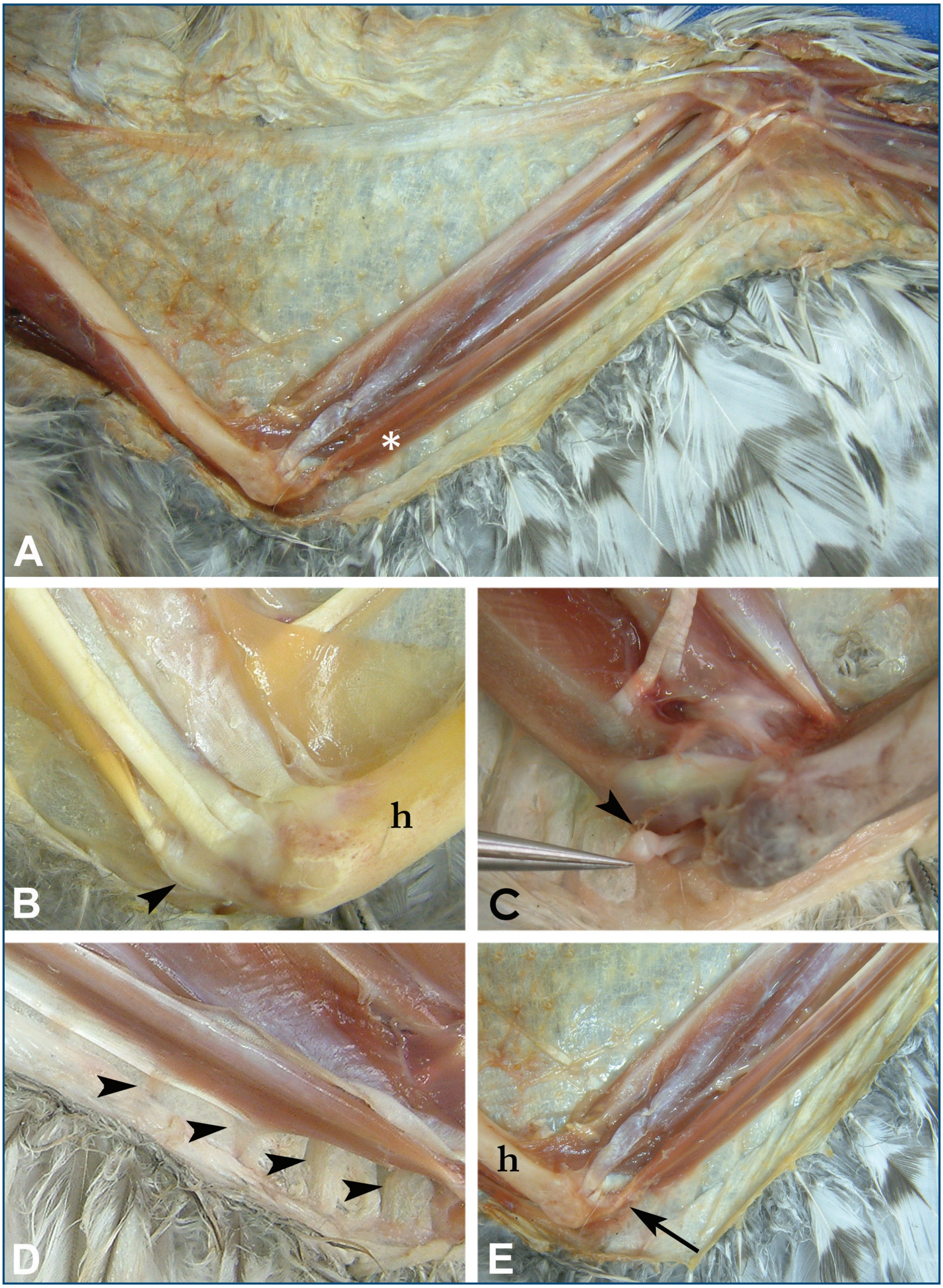

Figure 2. *Different ventral views of the* musculus flexor carpi ulnaris. **A.** Right wing of a eurasian buzzard. The insertions of this muscle are similar throughout the species examined. The asterisk shows the position of the belly. **B.** Right elbow of a grey heron. The arrowhead points to a sesamoid-like structure in the proximal tendon of the *musculus flexor carpi ulnaris*; h = *humerus*. **C.** Right elbow of a eurasian buzzard. The arrowhead points to a sesamoid-like structure in the proximal tendon of the muscle; h = *humerus*. **D.** Right antebrachium of a common kestrel. Origin of *musculus flexor carpi ulnaris*. Fibromuscular fibers (arrowheads) stemming from the *pars remigalis* directed to the calami of the secondary feathers. **E.** Left elbow of the common kestrel. Proximal tendon (arrow); h = *humerus*. Picture was taken in Ozzano dell'Emilia, Bologna, IT on March 2012 to illustrate the dissection.

level the belly gave rise to a wide, flat tendon which ended on the processus muscularis of the *os carpi ulnare*. Next to the main belly there was a thinner part (*pars remigalis*) composed of fleshy fibers extending to slightly less than the middle of the body of the ulna. This part continued distally giving rise to a long tendon. This latter element ended on the ventral aspect of the calami of the secondary and primary feathers. The tendon of the caudal part, close to the wrist, gave rise to a fibrous slip which met the terminal tendon of the cranial part. They inserted together on the ulnar carpal bone.

*Eurasian buzzard (***Buteo buteo***)*

The *m. flexor carpi ulnaris* was the most developed muscle of the ventral part of the antebrachium in the eurasian buzzard (*Buteo buteo*). It was composed of cranial and caudal parts. The source of the muscle corresponded to that for the grey heron. The proximal tendon is intimately associated with the terminal tendon of the *m. scapolotriceps* and the humero-scapular pulley. This latter tendon is well developed in this species. It was possible to recognize a humeral (*pars humeralis*) and an ulnar part (*pars ulnaris*) of the structure. Just distally to the origin of the ulnar part, there was a sesamoid-like structure in the tendon. It was oval, a few millimeters long and apparently fibro-tendinous (Figure 2C). The fleshy belly of the *m. flexor carpi ulnaris* arose close to the proximal insertion. The cranial part was bipinnate, composed of 2 bellies converging to a central tendon. The above mentioned heads were flattened and ran together until the initial part of the body of the ulna. At this point the superficial head, more developed, continued along this bone. At the middle third of the ulna it gave rise to a strong tendon which ran to the wrist. There it passed under a fibrous band derived from the ventral aponeurosis. It ended on the proximal extremity of the *os carpi ulnare*. The deep slender head, lay on the postpatagial skin continuing and giving rise to a tendon terminating on the calami of the first secondary feathers. Near the proximal insertion the main tendon gave rise to the slender tendon of the *p. remigialis*. This latter tendon continued with a fleshy belly along the antebrachium and terminates joining the tendon of the main head before their insertion on the ulnar carpal bone. It also sent many thin but strong fibromuscular slips to every calamus of the secondary feathers (Figure 2D).

*Common kestrel (***Falco tinnunculus***)*

In the common kestrel the *m. flexor carpi ulnaris* could be subdivided in 3 heads. The cranial head was the most superficial and laid on the ulna. The caudal head was in relation with the ulna and the the postpatagial skin, while the *p. remigalis* was intimately associated with the calami of the secondary feathers. All 3 of the heads emanated out of a common tendon from the *processus flexorius* of the *humerus*. (Figure 2E). The muscular belly developed as soon as the muscle passed the humero-ulnar joint. A central fibrous slip separated the belly into 2 attached symmetrical heads (Figure 2A). These heads divided at 1/4 of the body of the ulna. The *p. remigalis* came forth from the proximal tendon immediately after its origin. It was entirely composed of fibrous fibers and continued distally associated to the postpatagial skin and the quills of the secondary feathers. It also sent a strong fibrous slip to every calamus. In the middle of the postpatagial region, the *p. remigalis* was intimately associated to the caudal edge of the caudal head. At the level of the distal fourth of the ulna, the *p. remigalis* parted and continued to the most distal calami of the secondary feathers where it ended joining the distal tendon of the cranial head. The 3 heads of this muscle were inserted by a common tendon on the caudoventral angle of the *os carpi ulnari*, under the insertion of the ventral aponeurosis.

Discussion

Musculus deltoideus

According to previous work (Baumel *et al.* 1993, George and Berger 1996, McKitrick 1985, Meyers 1992a, Rosser 1980, Vanden Berge 1970), the *m. deltoideus* is the most cranial muscle of the shoulder. Baumel and colleagues (Baumel *et al.* 1993) also stated that it is comprised of 3 parts: *p. propatagialis*, *p. major*, and *p. minor*. In the eurasian buzzard and in the common kestrel, the proximal part of *p. propatagialis* was in conformity with that described in other species (Baumel *et al.* 1993, George and Berger 1996, Hudson and Lanzillotti 1955, Meyers 1992a). Contrarily, in the grey heron, despite many similarities to what was seen in the black-crowned night heron (*Nycticorax nycticorax*) as reported by Berge (Berge 1970), we observed some particularities not previously described in the *Ciconiiformes*. Firstly, it is possible to see a thickening in the middle of the *lig. propratagialis* giving off a fibrous band which crosses the propatagium and ends on the *m. extensor carpi radialis*. We believe that this feature can contribute to maintain the propatagial tension during gliding and flapping flight. During gliding it can contribute to avoid vibrations of the propatagium, which could cause diminished lift. During flapping flight, and especially in case of take off or parachuting downwards on landing, it could also reinforce the propatagium, providing additional strength. Another interesting feature is that the belly of this part of muscle seems to be composed of cranial and caudal heads. Contrary to what was reported by Berge (Berge 1970), no sesamoid was observed at this level. We also observed differences on the termination of the *lig. propatagialis*. In fact, in the grey heron and in the eurasian buzzard the ligament ends with 2 parts inserting only on the ventral aspect of the wrist. Interestingly, in the common kestrel, there is an additional fibrous slip, not previously described, inserting on the dorsal aspect of the wrist joint. In agreement with Meyers (Meyers 1992a), it is plausible to assume that in the 3 species mentioned above, the *lig. propatagialis* may mantain the tension of the cranial edge of the wing. Furthermore, it may take part in the flexion and extension of the hand. Additionally in the common kestrel, it may play a role in the pronation-supination of the hand. Contrary to what was reported in extant literature (Baumel *et al.* 1993, George and Berger 1996, Hudson and Lanzillotti 1955, McKitrick 1985, Meyers 1992a, Rosser 1980), in other species *p. major* is composed of a single muscular belly. Instead, the description provided by Berge (Berge 1970) for the black-crowned night heron and the distinctions found in the *Ardeidae* correspond to those observed in the present study for the grey heron. In this species we have found a fibromuscular structure referable to the scapular anchor. The muscular belly of this species also demonstrates another attribute, as it remains considerably caudal to the tuberculum dorsale of the *humerus*. According to Meyers (Meyers 1992a), the *p. major* of *m. deltoideus* is an abductor of the brachium. In spite of the absence of the cranial part and due to its humeral insertion considerably caudal, we believe it less likely to be an elevator of the *humerus*. In contrast to what is described in *Ciconiiformes* by Berge (Berge 1970), *p. minor* in the grey heron is an extremely short single belly composed of fleshy fibers. *Pars minor* is in a position to elevate the *humerus* but it seems to be too thin to be effective in this movement. According to what reported by Meyers in the american kestrel (Meyers 1992a, Meyers 1992b) this aspect could have a postural role.

Musculus flexor carpi ulnaris

Musculus flexor carpi ulnaris has, in all 3 examined species, the same origin and termination. In the grey heron and in the eurasian buzzard the proximal tendon shows a sesamoid-like structure which is absent in the common kestrel. The greatest differences regard the development of the 3 parts composing this muscle. *Pars cranialis* and *p. remigalis* in the grey heron are distinctly separate and with similar development. They occupy the proximal middle of the body of the ulna. In the eurasian buzzard, the 2 heads stay together up until the caudal part of the distal third of the same bone. In the common kestrel, the cranial belly has an equivalent extension of the one of the grey heron, while the *p. remigalis* continues almost up to the distal extremity of the bone. In the examined species the extension of the muscle differs and so does its relationship with the complex consisting of *ligamentum humerocarpale* and *musculus flexor digitorum superficialis*. In the grey heron the ligament and the muscle are wrapped by both the fascia of the antebrachium and a fibrous band. Contrarily, in the eurasian buzzard both the medial aspect of these structures are intimately associated. This association takes place through a thick fibrous band which issues from the *lig. humerocarpale* and continues until reaching the calami of the secondary feathers. The 2 structures in the common kestrel remain merged by their edges only at the level of the caudal margin of the ulna. According to Meyers (Meyers 1996), in the species examined it would seem plausible that this muscle works as a flexor of the carpus and of the hand. The terminal tendon may also have the function to limit the movements of the ulna during flexion and extension of the elbow.

Conclusions

This study provided interesting data on species not previously examined. In particular, *p. major* and *p. minor* of the *m. deltoideus*, despite being roughly in line with those reported in other species (Baumel *et al.* 1993, George and Berger 1996, McKitrick 1985, Meyers 1992a, Rosser 1980, Vanden Berge 1970) displayed unique features. Regarding the *p. propatagialis* of the *m. deltoideus* observed in the grey heron, we believe that it can contribute to maintain the propatagial tension. In this way vibrations of this structure, which could cause diminished lift, are avoided. The peculiarity seen in the distal insertion of the common kestrel could instead influence the control of the pronation-supination of the hand during hovering. Relative to the *m. flexor carpi ulnaris*, we believe the presence of a sesamoid-like structure at the base tendon, found in the grey heron and in the eurasian buzzard, may have the purpose to complete the articular surfaces of the elbow. In this manner the dislocation of this joint is avoided and this insertion is reinforced rendering it more resistant to tensile stresses. On the contrary, the american kestrel, which possess a smaller wing producing lower friction, may not need such resistance to mechanical stresses at the elbow.

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