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Early View

Original Research Article

Comparative Morphology and Morphometry of Wing Patagia in *Gallus gallus domesticus* and *Numida meleagris*: Functional Implications

Key words

avian flight biomechanics; chicken; guinea fowl; *ligamentum propatagiale*; metapatagium; propatagium

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Abstract: This study aimed to test the hypothesis that *Numida meleagris* (guinea fowl), as a species retaining greater flight capability than *Gallus gallus domesticus* (domestic chicken), exhibits structurally reinforced wing patagia reflecting functional adaptations to more demanding biomechanical requirements. A total of 15 guinea fowls (8 males, 7 females) and 14 domestic chickens (7 males, 7 females), aged 6–7 months and maintained under identical husbandry and dietary conditions, were examined through gross anatomical dissection and morphometric analysis. Measurements were recorded using a digital caliper at two standardized wing positions: resting (90° elbow angle) and fully extended (135° elbow angle). These positions were selected to capture the functional range of the propatagium during the downstroke and upstroke phases of the wingbeat cycle. Results indicated that neither species possessed muscular or ligamentous support for the *patagium cervicale* or *patagium alulae*. In the metapatagium, both *m. serratus superficialis pars metapatagialis* and *m. latissimus dorsi pars metapatagialis* supported this region in chickens, whereas only the former was present in guinea fowls. The propatagium of guinea fowls exhibited significantly denser connective tissue fibers, which obscured the margins of the *ligamentum limitans cubiti*. Morphometric analysis revealed that the *ligamentum propatagiale* was significantly shorter in guinea fowls ($P < 0.001$), yet remained proportionally consistent with long-bone lengths across wing positions in both species. The insertion thickness of the *ligamentum propatagiale* was significantly greater in guinea fowls ($P = 0.05$ at 90°; $P = 0.001$ at 135°). Collectively, these findings suggest that the reinforced propatagial architecture of *N. meleagris* represents a functional adaptation to sustain higher mechanical loads during active flight, offering new comparative insights into musculoskeletal diversity and evolutionary plasticity within Galliformes.

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Introduction

Wings represent the primary apparatus for avian flight, comprising a complex and functionally integrated arrangement of feathers, bones, muscles, nerves, and specialized patagial integumentary folds. The synergistic coordination of kinematics and aerodynamics during wing flapping is critical for sustained flight; consequently, any structural impairment affecting specific wing components can lead to detrimental biomechanical and aerodynamic outcomes (1). Within the Galliformes — an order encompassing both strong fliers and predominantly terrestrial species — the wing has undergone considerable evolutionary diversification, making this taxon particularly suitable for comparative functional morphology studies.

The patagium (pl. *patagia*), commonly referred to as the flight membrane, is a specialized anatomical structure formed by a double-layered fold of integument that contributes both to powered flight and to gliding in various avian species. The wing patagia (*patagia alae*) are organized into five functionally integrated subunits: the *parapatagium*, *propatagium*, *metapatagium*, *postpatagium*, and *patagium alulae* (2, 3, 4) (Figure 1).

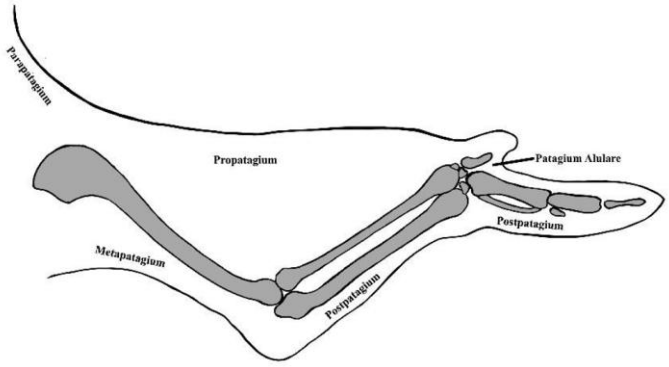

Figure 1: Schematic illustration of patagial regions on the avian wing

Among these, the propatagium is the most extensively studied due to its central role in generating aerodynamic lift by defining the leading edge of the wing and maintaining appropriate camber throughout the wingbeat cycle (1, 4).

The *parapatagium* is a cutaneous fold extending from the cervical base to the cranial margin of the propatagium, typically supported in strongly flying birds by the *m. cucullaris pars patagialis*. The *propatagium* occupies the cranial angle between the humerus and the antebrachium and is primarily supported by two ligaments — the *ligamentum propatagiale* and the *ligamentum limitans cubiti* — as well as by the propatagial slips of *m. cucullaris capitis*, *m. pectoralis*, *m. biceps brachii*, and *m. deltoideus* (2, 3, 5). The *metapatagium* fills the caudal angle between the trunk and the proximal humerus, providing structural support for the humeral feather tract and axillary remiges, with stabilization from *m. serratus pars metapatagialis* and, in certain species, *m. latissimus dorsi pars metapatagialis* (6). The *postpatagium* and *patagium alulae* complete the wing membrane, anchoring the primary and secondary remiges and the alular digit, respectively.

Despite the wealth of descriptive literature on patagial anatomy in wild birds and raptors (2, 4, 5, 7, 8), comparative morphological and morphometric data for domestic poultry species remain scarce. The domestic chicken (*Gallus gallus domesticus*) is a ground-dwelling species with markedly reduced flight capability resulting from selective breeding, whereas the guinea fowl (*Numida meleagris*) is a gamebird that retains appreciable flight ability. These two species thus represent a functionally divergent pair within Galliformes that share comparable body mass ranges in their juvenile-to-adult transitional phase, making them ideal subjects for isolating the structural correlates of flight performance independent of phylogenetic distance and husbandry conditions. We hypothesized that the greater flight demands of *N. meleagris* would be reflected in a more robust propatagial architecture — specifically in greater ligament thickness and denser connective tissue organization — compared to *G. g. domesticus*. The present study therefore aimed to provide a detailed comparative morphological and morphometric analysis of the five patagial subunits in these two galliform species to test this hypothesis and to contribute baseline data for future biomechanical modelling and clinical investigations

Material and methods

A total of 15 guinea fowls (*Numida meleagris*; 8 males, 7 females) and 14 domestic chickens (*Gallus gallus domesticus*; 7 males, 7 females) were utilized. All individuals were healthy adults aged 6–7 months at the time of sampling. Birds were obtained from a single commercial supplier to minimize variation attributable to different rearing histories. Prior to the study, all animals were housed in identical conditions under a 16:8 h light–dark cycle at 20–22 °C with free access to a commercial layer-type pelleted diet and water ad libitum. The body condition of each animal was assessed by a licensed veterinarian prior to euthanasia; animals showing signs of injury, parasitism, or systemic disease were excluded. The study protocol was reviewed and approved by the Animal Experiments Local Ethics Committee of Aydin Adnan Menderes University (Approval No: 64583101/2020/083). All procedures complied with national legislation on animal experimentation. Anatomical nomenclature throughout this study follows the *Nomina Anatomica Avium* 2nd Edition(3).

Anatomical and Dissection Procedures

Prior to euthanasia by decapitation, the live body weight of each bird was recorded using a precision balance (±0.1 g), and standard somatic measurements (body length, chest diameter, wingspan) were obtained with a flexible measuring tape. Dissections were initiated immediately after euthanasia on fresh cadavers to prevent artefactual tissue shrinkage or hardening. Each wing was examined systematically, proceeding from superficial skin layers to the deep ligamentous and muscular elements. Morphological features of each patagial subunit and its associated supporting structures were documented in situ before transection. Highresolution digital photographs (minimum 12 megapixels) were taken at each dissection stage to document morphological findings. All dissections were performed by the same investigator (E.O.Y.) to minimize inter-observer variability.

Morphometric Parameters

All morphometric measurements were obtained with a digital caliper (accuracy ± 0.01 mm) at two standardized wing positions: 90° elbow angle (resting position, simulating the folded wing during perching) and 135° elbow angle (fully extended position, approximating the downstroke phase of flight). Both angles were set accurately using a goniometer fixed to the elbow joint. Each measurement was repeated three times and the mean value was recorded.

Body and wing measurements — body length (BL), chest diameter (CD), and wingspan (WS) — were determined in accordance with FAO Animal Production and Health Guidelines, No. 11, 2012 (9). Individual wing length (WL) at both positions was measured following the methodology described by Brown et al. (4).

The length of the humerus (HL; from tuberculum dorsale to the distal extremity) and the length of the skeleton antebrachii (AL; from the proximal olecranon to the distal extremity) were also recorded.

For the *ligamentum propatagiale*, the following parameters were measured at both wing angles: length (LPL), origo thickness (LPOT), mid-point thickness (LPMT), and insertion thickness (LPIT). For the *ligamentum limitans cubiti*, length (LLCL), origo thickness (LLCOT), and insertion thickness (LLCIT) were recorded. Due to the absence of distinct borders in the *ligamentum limitans cubiti* of *N. meleagris* — attributable to the denser connective tissue matrix obscuring its margins — reliable morphometric measurements of this ligament could not be obtained in guinea fowls, and comparative data are therefore presented for *G. g. domesticus* only. This limitation is explicitly acknowledged as a methodological constraint of the present study.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics (version 21.0). Normality of data distribution was assessed with the Shapiro–Wilk test. Bilateral symmetry between right and left wings was evaluated using the Paired-Samples t-test for normally distributed variables and the Wilcoxon signed-rank test for non-parametric data. Mean values of right and left measurements were subsequently used for all index calculations and inter-species comparisons. Inter-species and inter-sex comparisons were performed using the Independent-Samples t-test for normally distributed variables and the Mann–Whitney U test for non-parametric variables. The threshold for statistical significance was set at $P \leq 0.05$. Effect sizes are reported as Cohen's *d* for parametric comparisons and as rank-biserial correlation (*r*) for non-parametric ones, to supplement P-values and provide an indication of biological magnitude. Given the exploratory and descriptive nature of this study and the limited number of a priori comparisons, no correction for multiple comparisons was applied; however, findings with $P < 0.01$ are explicitly distinguished from those with $P < 0.05$ to promote transparency. All data are presented as mean ± standard deviation (SD)

Results

General Body Measurements

Body measurements for all groups are summarized in Table 1. Male *G. g. domesticus* exhibited disproportionately greater body weight (3517.14 ± 317.20 g) compared to all other groups, which likely reflects the strong sexual dimorphism characteristic of this breed. In contrast, body measurements for both sexes of *N. meleagris* were more similar to those of female chickens, suggesting a more sexually monomorphic body plan consistent with the behavioral ecology of the species.

Parapatagium and Patagium Alulae

The *parapatagium* (*patagium cervicale*) was identified bilaterally in both species as a thin cutaneous fold. On the right side, the fold was occupied by the crop (*ingluvies*). No macroscopic muscular or ligamentous elements were associated with this structure in either species, indicating that it is passively tensioned in these ground-adapted galliforms and is unlikely to contribute actively to flight control. Similarly, the *patagium alulae* formed a simple triangular membrane between the alular digit phalanges and the carpometacarpal bone, firmly connected to the covering fascia, with no intrinsic muscular support identified in either species. These findings are consistent with the general consensus that such structures are functionally vestigial or reduced in heavy-bodied, predominantly terrestrial birds (1).

Table 1: Body and wing measurements of *Gallus gallus domesticus* and *Numida meleagris*

	Gallus gallus domesticus		***Numida meleagris***	
	Male ♂ (n=7)	**Female ♀ (n=7)**	**Male ♂ (n=8)**	**Female ♀ (n=7)**
BW (g)	3517.14 ± 317.20	1654.71 ± 275.42	1290.88 ± 127.16	1258.57 ± 162.22
BL (cm)	52.5 ± 2.18	41.71 ± 2.02	43.13 ± 1.89	44.07 ± 2.42
CD (cm)	38.57 ± 1.46	33.5 ± 1.87	29.19 ± 1.25	29.36 ± 2.43
WS (cm)	52.29 ± 3.75	40.21 ± 1.52	38.00 ± 0.96	38.14 ± 1.52
WL90 (cm)	13.43 ± 1.24	10.71 ± 0.49	10.75 ± 0.60	10.79 ± 0.49
WL135 (cm)	16.86 ± 0.80	13.43 ± 0.73	13.38 ± 0.83	13.64 ± 0.90
HL (cm)	9.10 ± 0.42	7.61 ± 0.34	7.61 ± 0.08	7.66 ± 0.07
AL (cm)	10.24 ± 0.32	8.62 ± 0.32	8.14 ± 0.13	8.14 ± 0.07

Note: Data are presented as mean ± SD. BW: body weight; BL: body length; CD: chest diameter; WS: wingspan; WL90/WL135: wing length at 90° and 135°; HL: humerus length; AL: antebrachii length

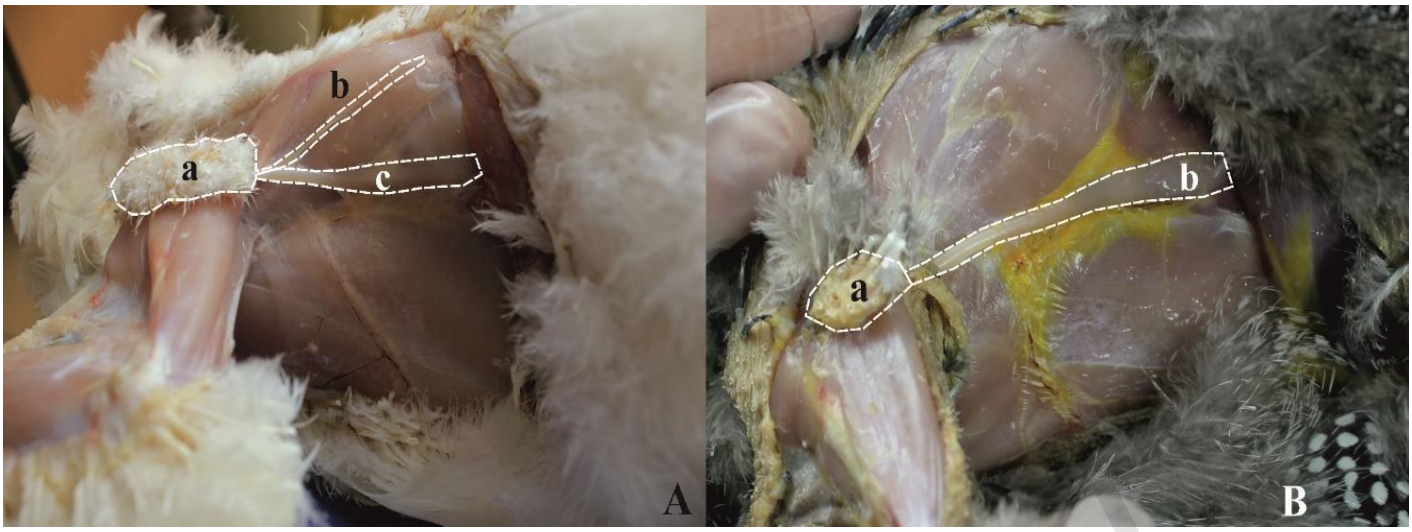

Figure 2: Lateral view of muscles supporting the metapatagium in *Gallus gallus domesticus* (A) and *Numida meleagris* (B). a: Humeral feather tract region; b: M. latissimus dorsi pars metapatagialis (absent in B); c: M. serratus superficialis pars metapatagialis

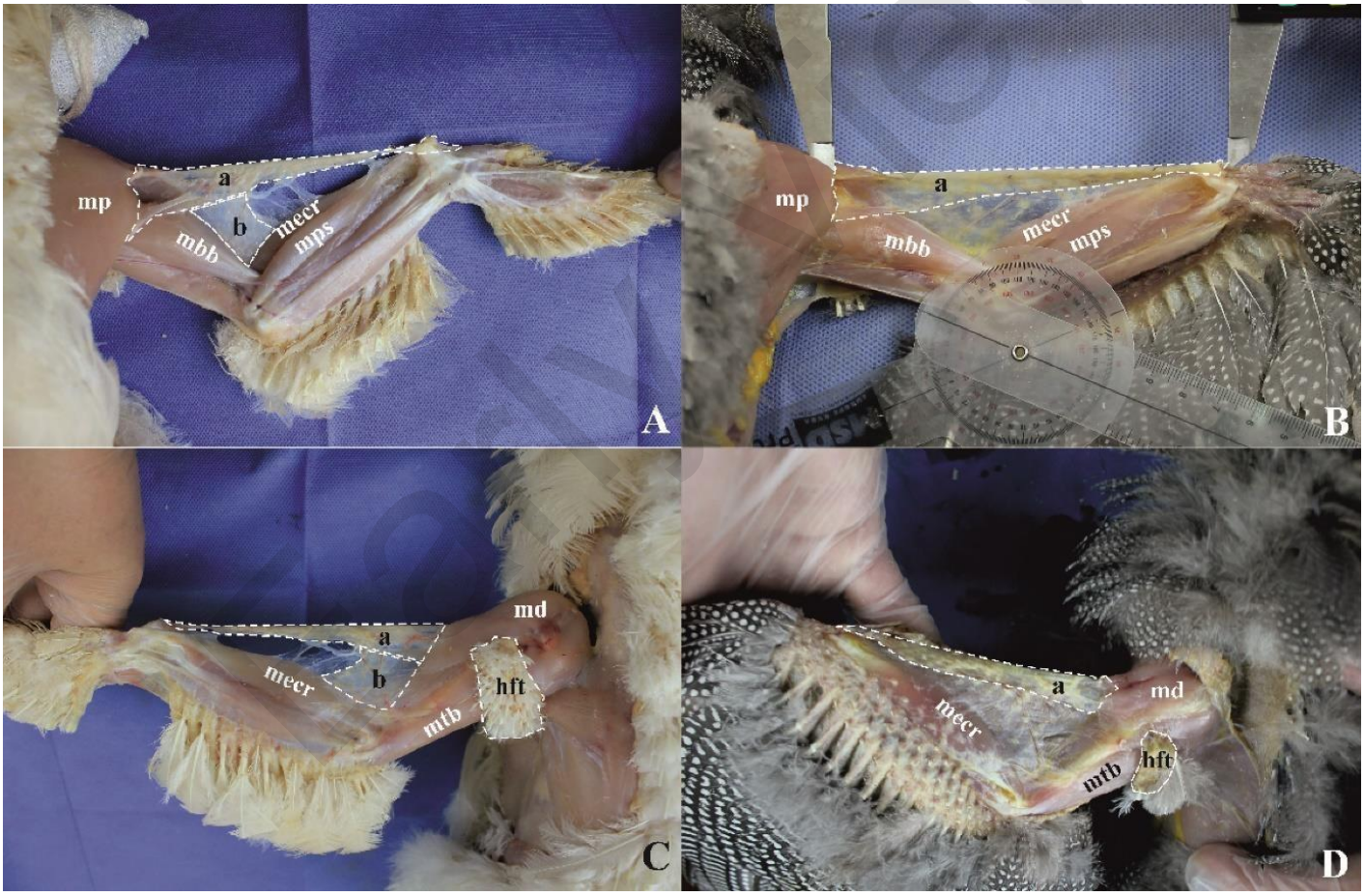

Figure 3: Dissected propatagium with skin layers removed in *Gallus gallus domesticus* (A: ventral view; C: dorsal view) and *Numida meleagris* (B: ventral view; D: dorsal view). a: lig. propatagialis; b: lig. limitans cubiti; mbb: m. biceps brachii; md: m. deltoideus; mecr: m. extensor carpi radialis; mp: m. pectoralis; mps: m. pronator superficialis; mtb: m. triceps brachii; hft: humeral feather tract region. Note the absence of distinct borders of the lig. limitans cubiti in *N. meleagris* (B, D) compared to the clearly delineated structure in *G. g. domesticus* (A, C)

Table 2: Interspecific comparison of *ligamentum propatagiale* measurements at resting (90°) and fully extended (135°) wing positions. Bold P-values indicate statistical significance

Measurement (mm)	*Gallus gallus domesticus* (n=14)	*Numida meleagris* (n=15)	P
LPL 90°	100.09 ± 9.56	86.47 ± 1.08	**< 0.001**
LPOT 90°	12.71 ± 1.41	12.04 ± 0.99	0.163
LPMT 90°	10.04 ± 0.88	10.18 ± 0.49	0.607
LPIT 90°	2.68 ± 0.46	2.72 ± 0.21	**0.050**
LPL 135°	125.71 ± 10.07	108.48 ± 1.97	**< 0.001**
LPOT 135°	9.97 ± 1.64	10.04 ± 0.73	0.527
LPMT 135°	7.44 ± 0.90	7.81 ± 0.37	0.222
LPIT 135°	2.44 ± 0.53	3.15 ± 0.17	**0.001**

Note: Data are presented as mean ± SD. Bold P-values indicate statistical significance. LPL: length; LPOT: origo thickness; LPMT: mid-point thickness; LPIT: insertion thickness of the ligamentum propatagiale

Table 3: Sex-based comparison of *ligamentum propatagiale* measurements in both species

	Gallus gallus domesticus			*Numida meleagris*		
Meas. (mm)	Male ♂ (n=7)	Female ♀ (n=7)	P	Male ♂ (n=8)	Female ♀ (n=7)	P
LPL 90°	107.9 ± 6.8	92.27 ± 3.10	**< 0.001**	86.44 ± 1.21	86.50 ± 1.00	0.922
LPOT 90°	13.35 ± 1.41	12.08 ± 1.17	0.920	12.27 ± 1.01	11.78 ± 0.96	0.355
LPMT 90°	10.04 ± 1.15	10.04 ± 0.61	0.988	10.12 ± 0.64	10.24 ± 0.30	0.357
LPIT 90°	2.94 ± 0.51	2.41 ± 0.20	**0.025**	2.74 ± 0.18	2.70 ± 0.26	0.452
LPL 135°	134.53 ± 4.65	116.89 ± 4.04	**< 0.001**	108.34 ± 1.76	108.64 ± 2.33	0.780
LPOT 135°	10.89 ± 1.25	9.04 ± 1.50	**0.035**	10.24 ± 0.77	9.80 ± 0.65	0.254
LPMT 135°	7.78 ± 1.01	7.10 ± 0.69	0.173	7.76 ± 0.32	7.87 ± 0.43	0.298
LPIT 135°	2.87 ± 0.41	2.02 ± 0.16	0.173	3.20 ± 0.04	3.08 ± 0.23	0.223

Note: Data are presented as mean ± SD. Bold P-values indicate statistical significance. LPL: length; LPOT: origo thickness; LPMT: mid-point thickness; LPIT: insertion thickness of the ligamentum propatagiale

Table 4: Bilateral symmetry analysis of *ligamentum propatagiale* measurements in both species

	Gallus gallus domesticus			*Numida meleagris*		
Meas. (mm)	Right (n=14)	Left (n=14)	P	Right (n=15)	Left (n=15)	P
LPL 90°	100.43 ± 9.59	99.74 ± 9.56	**0.011**	86.52 ± 1.08	86.42 ± 1.12	0.413
LPOT 90°	12.49 ± 1.32	12.93 ± 1.56	**0.027**	12.02 ± 1.02	12.05 ± 0.97	0.710
LPMT 90°	10.11 ± 0.76	9.97 ± 1.18	0.574	10.32 ± 0.56	10.03 ± 0.56	0.061
LPIT 90°	2.61 ± 0.49	2.75 ± 0.61	0.433	2.74 ± 0.24	2.71 ± 0.21	0.490
LPL 135°	125.89 ± 9.97	125.54 ± 10.19	0.255	108.52 ± 1.95	108.44 ± 2.01	0.303
LPOT 135°	9.87 ± 1.69	10.06 ± 1.63	0.222	10.05 ± 0.78	10.02 ± 0.73	0.787
LPMT 135°	7.46 ± 0.84	7.42 ± 1.09	0.869	7.84 ± 0.49	7.78 ± 0.35	0.621
LPIT 135°	2.44 ± 0.52	2.44 ± 0.61	0.995	3.16 ± 0.16	3.13 ± 0.18	0.170

Note: Data are presented as mean ± SD. Bold P-values indicate. LPL: length; LPOT: origo thickness; LPMT: mid-point thickness; LPIT: insertion thickness of the ligamentum propatagiale

Table 5: Sex-based comparison of *ligamentum limitans cubiti* measurements in *Gallus gallus domesticus*

Measurement (mm)	Male ♂ (n=7)	Female ♀ (n=7)	P
LLCL 90°	33.83 ± 3.49	23.30 ± 1.34	**< 0.001**
LLCOT 90°	12.09 ± 0.96	9.56 ± 1.20	**0.001**
LLCIT 90°	18.61 ± 2.60	16.87 ± 2.05	0.190
LLCL 135°	40.47 ± 5.41	27.62 ± 3.39	**< 0.001**
LLCOT 135°	11.42 ± 2.40	9.89 ± 1.31	0.225
LLCIT 135°	24.22 ± 4.97	17.88 ± 2.53	**0.011**

Note: Data are presented as mean ± SD. Bold P-values indicate. LLCL: ligamentum limitans cubiti length LLCOT: origo thickness; LLCIT: insertion thickness. Measurements were not obtainable in *Numida meleagris* owing to the absence of distinct ligament borders

Table 6: Bilateral symmetry analysis of *ligamentum limitans cubiti* measurements in *Gallus gallus domesticus*

Measurement (mm)	Right (n=14)	Left (n=14)	P
LLCL 90°	28.50 ± 6.09	28.62 ± 6.03	0.730
LLCOT 90°	10.92 ± 1.87	10.72 ± 1.60	0.861
LLCIT 90°	17.91 ± 2.47	17.57 ± 2.51	0.281
LLCL 135°	34.05 ± 7.92	34.05 ± 8.03	0.993
LLCOT 135°	10.79 ± 2.11	10.52 ± 2.28	0.331
LLCIT 135°	21.22 ± 5.06	20.88 ± 5.02	0.157

Table 7: Comparative summary of muscular support for the propatagium across avian species. Present study results are included for direct comparison

Reference	*m. cucullaris capitis pars propatagialis*	*m. pectoralis pars propatagialis*	*m. biceps brachii pars propatagialis*	*m. deltoideus pars propatagialis*	Species
Baumel et al. (1993) (3)	✓	✓	✓	✓	*Psittacine, Picids, Passerines*
Brown et al. (1994) (4)	✓	✓		✓	*Bubo virginianus*
Hudson & Lanzillotti (1964) (10)		✓	✓	✓	*Galliformes*
McGowan (1985) (14)		✓	✓		*Gallirallus australis*
Zhang & Yang (2013) (15)		✓	✓		*Chrysolophus pictus*
Canova et al. (2015) (5)		✓		✓	*Pernis apivorus, Buteo buteo*
Present study		✓	✓	✓	*G. g. domesticus, N. meleagris*

Table 8: Comparative summary of muscular support for the metapatagium across avian species. Present study results are included for direct comparison

Reference	*m. latissimus dorsi pars metapatagialis*	*m. serratus superficialis pars metapatagialis*	Species
McGowan (1985) (14)	✓		*Gallirallus australis*
Razmadze et al. (2018) (8)		✓	*Psittacus erithacus*
Brown et al. (1994) (4)	✓	✓	*Bubo virginianus*
Zhang & Yang (2013) (15)	✓	✓	*Chrysolophus pictus*
Canova et al. (2015) (5)	✓	✓	*Buteo buteo, Pernis apivorus*
Present study — *G. g. domesticus*	✓	✓	*Gallus gallus domesticus*
Present study — *N. meleagris*		✓	*Numida meleagris*

Metapatagium

A dermal fold corresponding to the metapatagium was present in both species, extending from the trunk to the caudoproximal humerus and filling the angle between the body wall and the proximal third of the bone. In *G. g. domesticus*, both *m. serratus superficialis pars metapatagialis* and *m. latissimus dorsi pars metapatagialis* were identified as supporting structures of the metapatagium and provided posterior reinforcement to the humeral feather tract (Figure 2A). In *N. meleagris*, *m. latissimus dorsi pars metapatagialis* was absent, leaving *m. serratus superficialis pars metapatagialis* as the sole muscular support (Figure 2B). The *ligamentum metapatagiale* was not observed in either species. A comparative summary of metapatagial muscle distribution across avian species is provided in Table 8.

Propatagium and Ligamentum Propatagiale

The propatagium was present in both species as a well-defined triangular skin fold situated between the cranial wing margin and the fasciae of *m. triceps brachii* and *m. extensor carpi radialis*. Qualitatively, the connective tissue within the propatagial fold was markedly denser and more compact in *N. meleagris* compared to *G. g. domesticus*, in which the fold exhibited a relatively loose fibrous matrix. This increased fiber density in the guinea fowl obscured the distinct lateral borders of the *ligamentum limitans cubiti*, rendering it visible as a continuous connective membrane rather than a clearly delineated ligamentous band (Figure 3B, D). In chickens, the *ligamentum limitans cubiti* originated from both *m. deltoideus pars propatagialis* and the *ligamentum propatagiale*, forming a wide fascia extending caudally to the proximal antebrachium (Figure 3A, C).

In both species, the *ligamentum propatagiale* constituted the main tensioning element along the cranial border of the propatagium, originating from the propatagial slips of *m. deltoideus*, *m. pectoralis*, and *m. biceps brachii*, before narrowing distally to insert on the carpal and alular bones. A fibrocartilaginous structure — consistent with the sesamoid-like ossicle previously reported by Brown et al.,Hudson and Lanzillotti and Smith et al. (4, 10, 11) — was consistently observed at the point where the ligament crossed the distal radius in both species, suggesting a conserved mechanism for reducing frictional stress at this anatomical fulcrum.

Quantitative results for the ligamentum propatagiale are presented in Tables 2–4. Interspecific comparison revealed that the absolute length of the ligament (LPL) was significantly greater in *G. g. domesticus* than in *N. meleagris* at both wing positions ($P < 0.001$; Table 2). When LPL was normalized to humerus and antebrachii length, however, no significant interspecific difference was detected (data not shown), indicating that the relative geometry of the propatagial leading edge is evolutionarily conserved between these galliform species despite differences in absolute body size. Regarding thickness, origo (LPOT) and mid-point (LPMT) measurements did not differ significantly between species at either wing position; however, insertion thickness (LPIT) was significantly greater in *N. meleagris* at both 90° ($P = 0.050$) and 135° ($P = 0.001$), with a moderate-to-large effect size (Cohen's $d > 0.7$) at the fully extended position. This finding is functionally relevant, as greater distal thickness implies a reinforced attachment capable of withstanding higher tensile forces during the rapid wing extension phase of the downstroke.

Intraspecific sex-based comparisons (Table 3) revealed that male *G. g. domesticus* exhibited significantly longer ligaments and greater thickness at specific regions than females (LPL: $P < 0.001$; LPIT at 90°: $P = 0.025$; LPOT at 135°: $P = 0.035$). No statistically significant sexual dimorphism was detected in *N. meleagris*, consistent with the reduced morphological dimorphism

typically observed in this species. Bilateral asymmetry analysis (Table 4) revealed a minor but statistically significant difference in LPL between right and left wings in *G. g. domesticus* at 90° (P = 0.011); no asymmetry was detected in *N. meleagris*. The biological relevance of this slight asymmetry in chickens is uncertain given the small magnitude of the difference and warrants further investigation.

Ligamentum Limitans Cubiti

Sex-based comparisons for the *ligamentum limitans cubiti* in *G. g. domesticus* (Table 5) demonstrated that males exhibited significantly longer and thicker ligaments than females at both wing positions (LLCL at 90° and 135°: P < 0.001; LLCOT at 90°: P = 0.001; LLCIT at 135°: P = 0.011). No significant bilateral asymmetry was detected in either measurement (Table 6). As noted above, the absence of distinct ligament borders in *N. meleagris* precluded morphometric assessment of this structure in guinea fowls; this is an acknowledged limitation that should be addressed in future studies using histological sectioning or imaging techniques.

Postpatagium

The postpatagium appeared as a narrow cutaneous fold extending from the elbow (*articulatio cubiti*) to the wrist (*articulatio manus*) along the caudal margin of the wing in both species. It was firmly adherent to the underlying muscular fascia of the antebrachium and manus, anchoring both primary and secondary remiges. No interspecific differences in gross morphology were noted for this structure.

Discussion

The present study provides a comparative morphological and morphometric analysis of wing patagia in two galliform species that diverge substantially in their flight capabilities, thereby addressing a gap in the existing literature on poultry functional anatomy. Our central finding — that *N. meleagris* exhibits a significantly thicker distal insertion of the *ligamentum propatagiale* and a markedly denser propatagial connective tissue matrix compared to *G. g. domesticus* — is consistent with our a priori hypothesis that the more flight-capable guinea fowl has evolved structurally reinforced patagial elements to sustain greater biomechanical demands.

The *ligamentum propatagiale* and *ligamentum limitans cubiti* were identified as the primary tensors of the propatagium in both species, in agreement with the foundational descriptions of Baumel et al. (3) and Brown (2). The functional significance of the propatagium for aerodynamic lift production is well established: it synchronizes elbow and carpal movements, maintains the camber of the wing's leading edge, and — working in concert with the primary remiges — contributes substantially to total lift generation (1, 4). The significantly greater insertion thickness of the *ligamentum propatagiale* in *N. meleagris* at both wing positions (P = 0.050 at 90°; P = 0.001 at 135°) implies a reinforced distal attachment capable of withstanding higher tensile forces during the rapid extension phase of the downstroke. According to Beaufrère (1), any structural alteration at the leading edge of the wing — including increased ligamentous cross-sectional area — will directly influence the aerodynamic efficiency of lift generation. The reinforced distal attachment in *N. meleagris* may therefore represent a structural adaptation to the higher mechanical demands imposed during more frequent and forceful wing strokes, consistent with this species' capacity for burst flight and sustained low-altitude flight to evade predators (12).

The absence of a significant interspecific difference in normalized ligament length (LPL indexed to bone lengths) is noteworthy. Although the absolute LPL was significantly shorter in *N. meleagris*, this difference disappeared when controlled for skeletal proportions, suggesting that the relative geometry of the propatagial leading edge is maintained at a conserved ratio across these galliform species. This proportional consistency is consistent with the view that the topological relationships of patagial structures are phylogenetically constrained within the Galliformes (2), even as absolute dimensions and material properties diverge in response to flight demands. Future studies incorporating geometric morphometrics or finite-element modelling could test whether this conservation extends to the distribution of stress along the ligament during the wingbeat cycle.

The increased density of connective tissue fibers in the propatagium of *N. meleagris* — sufficient to obscure the margins of the *ligamentum limitans cubiti* — merits further investigation at the histological level. Dense regular connective tissue in load-bearing ligaments typically reflects elevated collagen fiber packing and cross-linking, properties associated with higher stiffness and tensile strength (13). The functional consequence of this denser matrix in guinea fowls may be a stiffer propatagial fold that maintains a more consistent wing camber during high-speed flight maneuvers, at the potential cost of reduced passive compliance. In contrast, the looser connective tissue matrix of *G. g. domesticus* may confer greater passive compliance suitable for brief, low-speed escape flights but would be mechanically inadequate for sustained flight. Histological sectioning and collagen fibril density analysis are warranted in future studies to confirm these hypotheses.

The muscular architecture supporting the propatagium (Table 7) showed notable inter-specific variation that aligns with patterns documented in the broader avian literature. Both species shared *m. pectoralis*, *m. biceps brachii*, and *m. deltoideus* as propatagial tensors — a configuration consistent with the findings of Hudson and Lanzillotti (10) for Galliformes — but differed in the absence of *m. cucullaris capitis pars propatagialis* in both species. This pattern differs from the configuration described by Baumel et al. (3) for psittacines, picids, and passerines, where all four muscles contribute, suggesting that the muscular redundancy of the propatagial tensioning system is reduced in galliforms compared to stronger-flying nongalliform birds. As noted by Brown et al. (4), variations in accessory muscular slips enable muscle-controlled variation in wing camber during rapid adjustments in flight trajectory, and the relatively

simplified muscular support in galliforms may limit their capacity for fine aerodynamic control compared to raptors or passerines.

The metapatagial muscular differences between species (Table 8) provide additional evidence of functional divergence. The presence of both *m. serratus superficialis pars metapatagialis* and *m. latissimus dorsi pars metapatagialis* in *G. g. domesticus*, but only the former in *N. meleagris*, is an unexpected finding, as one might predict the more flight-capable species to retain greater muscular complexity. While classic literature (6) considers both muscles to be typical features of the avian metapatagium, our results indicate that their cooccurrence is not universal across Galliformes, consistent with the phylogenetically variable patterns compiled in Table 8. The absence of *m. latissimus dorsi pars metapatagialis* in *N. meleagris* may be functionally compensated by increased fascial tension from the enlarged *m. serratus superficialis* component, or may reflect a different tensioning strategy for the humeral feather tract during the upstroke. Electromyographic studies would be required to evaluate the functional equivalence of these alternative configurations.

The present study has several limitations that should be acknowledged. The sample sizes, while within the range of those employed in comparative avian anatomy studies, are modest and limit statistical power for detecting small-to-medium effect sizes in secondary comparisons. The study design is cross-sectional, and the observed morphological differences may reflect developmental plasticity, genetic divergence, or a combination of both. The inability to measure the *ligamentum limitans cubiti* in *N. meleagris* by gross morphometry is a methodological limitation; future studies should incorporate histological sectioning, microcomputed tomography, or ultrasound imaging to characterize this structure quantitatively. Finally, while we controlled for age and husbandry conditions, we did not quantify physical activity levels or flight frequency, which could independently influence ligament morphology. Despite these limitations, the present study provides the first systematic comparative morphometric dataset for the wing patagia of these two galliform species and establishes a baseline for future experimental and biomechanical investigations.

Conclusion

This study demonstrates that two domestically reared galliform species with contrasting flight capabilities exhibit substantial and functionally meaningful differences in their wing patagial architecture. The significantly greater insertion thickness of the *ligamentum propatagiale* and the markedly denser connective tissue matrix of the propatagium in *N. meleagris* support the hypothesis that the structural reinforcement of the wing's leading edge is associated with greater flight demand, even within a domestically managed setting. The differential muscular support of the metapatagium further illustrates that musculoskeletal diversity within the Galliformes is more extensive than previously recognized. These findings contribute to the broader understanding of avian functional morphology, provide a comparative anatomical baseline for clinical evaluation of wing disorders in these species, and open avenues for future biomechanical modelling of wing kinematics in galliform birds. We recommend that subsequent studies incorporate histological analysis, kinematic recording, and larger, phylogenetically diverse samples to further elucidate the evolutionary and functional significance of patagial variation in birds.

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