

LIPIDS IN THE LOCOMOTOR MUSCLES OF BIRDS

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Fat content in locomotor muscles is an important source of energy, especially during sustained activity (George and Jyoti, 1957). The amount of such fat varies with different species, but whether this depends upon the use made of these muscles or other factors is uncertain. George and Naik (1960) reported values for the pectoralis major of birds ranging from 2.18 to 6.35 per cent in 18 species.

Hoping to throw more light on this question, we have conducted the present investigation. A comparative study of the weights of the locomotor muscles gave us the opportunity to determine the fat or lipid content of the muscles in a large number of species of birds. Our study included muscles of the lower extremities as well as the pectoralis. We have determined muscle lipids in 104 species representing 42 families.

ACKNOWLEDGMENTS

This work was supported by a grant from the Comly-Coleman Fund of Ohio State University. We are indebted to Dr. Carl Johnson, director of the Gorgas Memorial Laboratory, Panamá, for the facilities of the Juan Mina Field Station. We also wish to thank Mr. Pablo Brackney for the use of facilities at the finca "Palo Santo" near the village of El Volcán.

METHODS

All specimens were kept in plastic waterproof bags to prevent drying until they reached the field station. Approximately one gram samples of the muscle free from any macroscopic fat deposits were weighed accurately on a sensitive torsion balance. The muscle was cut into small pieces and dropped into redistilled ethyl alcohol and kept there until the time for analysis. Lipids (these include fats and a small quantity of other compounds soluble in the solvents used) were determined by grinding the muscle to a pulp with sand and then extracting thoroughly with a boiling 3 to 1 alcohol-ether mixture as outlined by Bloor (1943). After removal of the solvent, the residue was extracted with boiling petroleum ether. The ether was removed and the residue, determined gravimetrically, reported as total lipid.

All birds except the Japanese Quail, Indigo Bunting and Field Sparrow were collected in Panamá in December and January near sea level and in February and March at 4300 feet above sea level. The Japanese Quail were raised in the laboratory, whereas the other two species were collected in Ohio in June.

RESULTS

Our results (see table 1) have been grouped by families since species of the same family are likely to have similar habits of activity. Taxonomic arrangement is according to Eisenmann (1955). We shall consider the pectoralis first because that is the most important muscle for locomotion.

PECTORALIS MUSCLE

Many birds show a high lipid content of the pectoralis superficialis (p. major). These are: Least Grebe, Olivaceous Cormorant, Cattle Egret, Boat-billed Heron, parrots, Barn Owl, Lesser Nighthawk, hummingbirds, Amazon and Green kingfishers, White-ruffed Manakin, Gray-breasted Martin, Red-legged Honeycreeper, Shining Honeycreeper and Slate-throated Redstart.

The lipid content of this muscle was very low in a few species. These are: Hook-billed Kite, Barred Forest Falcon, Chestnut-winged Chachalaca, Black and White Owl

TABLE 1
PER CENT OF LIPIDS IN LOCOMOTOR MUSCLES OF BIRDS

Tinamidae	
<i>Crypturellus soui</i> (Little Tinamou):	pectoralis, 4.27, 4.56; thigh, 1.25.
Podicipedidae	
<i>Podiceps dominicus</i> (Least Grebe):	pectoralis, 5.12.
Phalacrocoracidae	
<i>Phalacrocorax olivaceus</i> (Olivaceous Cormorant):	pectoralis, 5.30, 6.72; thigh, 4.08, 4.87.
Anhingidae	
<i>Anhinga anhinga</i> (Anhinga):	pectoralis, 3.53.
Ardeidae	
<i>Casmerodius albus</i> (Common Egret):	pectoralis, 3.78; thigh, 2.52.
<i>Leucophox thula</i> (Snowy Egret):	pectoralis, 4.21; thigh, 3.21.
<i>Bubulcus ibis</i> (Cattle Egret):	pectoralis, 4.99, 6.17, 7.33; thigh, 4.88.
<i>Tigrisoma lineatum</i> (Banded Tiger-heron):	pectoralis, 3.05.
<i>Ixobrychus exilis</i> (Least Bittern):	pectoralis, 2.91; thigh, 2.92.
Cochleariidae	
<i>Cochlearius cochlearius</i> (Boat-billed Heron):	pectoralis, 5.28.
Anatidae	
<i>Anas discors</i> (Blue-winged Teal):	pectoralis, 4.78.
<i>Aythya affinis</i> (Lesser Scaup):	pectoralis, 3.15, 4.45; thigh, 2.22, 3.12.
Accipitridae	
<i>Chondrohierax uncinatus</i> (Hook-billed Kite):	pectoralis, 1.04, 2.39, 2.73; thigh, 1.10.
<i>Buteo platypterus</i> (Broad-winged Hawk):	pectoralis, 3.22; thigh, 2.98.
Falconidae	
<i>Micrastur ruficollis</i> (Barred Forest Falcon):	pectoralis, 2.83; thigh, 2.21.
Cracidae	
<i>Ortalis garrula</i> (Chestnut-winged Chachalaca):	pectoralis, 1.94, 2.00, 2.04; thigh, 2.25.
Phasianidae	
<i>Odontophorus guttatus</i> (Spotted Wood Quail):	pectoralis, 1.96, 3.87.
<i>Coturnix coturnix</i> (Japanese Quail):	pectoralis, (11) 3.23±0.19 (S.E.); thigh, (10) 2.30±0.15.
Rallidae	
<i>Aramides cajanea</i> (Gray-necked Wood Rail):	pectoralis, 2.52, 2.70, 4.62; thigh, 2.23, 2.34, 3.68.
<i>Laterallus albigularis</i> (White-throated Crake):	pectoralis, 2.68, 2.76, 2.94, 3.53; thigh, 2.82, 3.16, 4.25.
Heliornithidae	
<i>Heliornis fulica</i> (Sungrebe):	pectoralis, 2.83.
Jacanidae	
<i>Jacana spinosa</i> (American Jacana):	pectoralis, 2.99, 3.60, 4.07, 4.51, 4.95; thigh, 1.52, 2.68, 3.28.
Columbidae	
<i>Columba speciosa</i> (Scaled Pigeon):	pectoralis, 3.90, 4.14, 4.76; thigh, 2.22, 3.15, 4.08.
<i>Columba albalinea</i> (White-naped Pigeon):	pectoralis, 4.47, 5.10, 5.11; supracoracoideus, 2.40; thigh, 2.72, 3.60, 5.34.
<i>Columba subvinacea</i> (Ruddy Pigeon):	pectoralis, 3.30; thigh, 3.00.
<i>Columbigallina talpacoti</i> (Ruddy Ground Dove):	pectoralis, 2.99, 3.08, 3.31, 3.56.
<i>Claravis pretiosa</i> (Blue Ground Dove):	pectoralis, 2.23, 3.50, 3.64, 4.23.
<i>Leptotila verreauxi</i> (White-tipped Dove):	pectoralis, 2.62.
<i>Leptotila cassinii</i> (Gray-chested Dove):	pectoralis, 1.81, 2.80; thigh, 5.81, 6.45.
<i>Leptotila rufinucha</i> (Rufous-naped Dove):	pectoralis, 2.33; thigh, 1.73.
<i>Geotrygon chiriquensis</i> (Rufous-breasted Quail Dove):	pectoralis, 2.48, 2.50.
Psittacidae	
<i>Brotogeris jugularis</i> (Orange-chinned Parakeet):	pectoralis, 4.81, 5.03, 5.27.
<i>Pionopsitta haematotis</i> (Brown-hooded Parrot):	pectoralis, 5.00, 5.57, 5.72; thigh, 3.35, 3.73, 4.10.
<i>Amazona autumnalis</i> (Red-lored Parrot):	pectoralis, 4.90.

Cuculidae

Crotophaga ani (Smooth-billed Ani) : pectoralis, 3.27, 3.85.

Tytonidae

Tyto alba (Barn Owl) : pectoralis, 5.40; thigh, 1.93.

Strigidae

Otus choliba (Tropical Screech Owl) : pectoralis, 2.76.

Ciccaba nigrolineata (Black and White Owl) : pectoralis, 2.10; thigh, 1.80.

Rhinoptynx clamator (Striped Owl) : pectoralis, 3.10.

Nyctibiidae

Nyctibius griseus (Common Potoo) : pectoralis, 2.56, 3.86.

Caprimulgidae

Chordeiles acutipennis (Lesser Nighthawk) : pectoralis, 6.94.

Nyctidromus albicollis (Parauque) : pectoralis, 3.78, 3.86.

Trochilidae

Campylopterus hemileucurus (Violet Sabrewing) : pectoralis, 4.50, 4.66, 5.06, 5.18, 5.23, 5.32; heart 4.20, 5.66.

Phaeochroa cuvierii (Scaly-breasted Hummingbird) : pectoralis and supracoracoideus, 5.24, 5.31.

Damophila julie (Violet-bellied Hummingbird) : pectoralis and supracoracoideus, 5.05, 5.39, 5.62.

Amazilia tzacatl (Rufous-tailed Hummingbird) : pectoralis and supracoracoideus, 4.72.

Lampornis castaneiventris (White-throated Mountain Gem) : pectoralis and supracoracoideus, 5.05.

Trogonidae

Pharomachrus mocinno (Quetzal) : pectoralis, 3.55, 3.93.

Trogon strigilatus (White-tailed Trogon) : pectoralis, 2.99, 3.40; thigh, 5.32, 7.12.

Trogon rufus (Black-throated Trogon) : pectoralis, 3.77.

Trogon violaceus (Violaceous Trogon) : pectoralis, 3.56.

Alcedinidae

Ceryle torquata (Ringed Kingfisher) : pectoralis, 3.72; thigh 4.08.

Chloroceryle amazona (Amazon Kingfisher) : pectoralis, 4.49, 4.76, 5.32.

Chloroceryle americana (Green Kingfisher) : pectoralis, 4.15, 4.42, 5.27.

Momotidae

Momotus momota conexus (Blue-crowned Motmot) : pectoralis, 2.04.

Momotus momota lessonii : pectoralis, 3.91.

Capitonidae

Eubucco bourcierii (Red-headed Barbet) : pectoralis, 3.23.

Semnornis frantzii (Prong-billed Barbet) : pectoralis, 2.91; thigh, 3.40, 3.80.

Ramphastidae

Pteroglossus torquatus (Collared Araçari) : pectoralis, 2.92.

Pteroglossus frantzii (Fiery-billed Araçari) : pectoralis, 3.15; thigh, 3.25.

Ramphastos swainsonii (Chestnut-mandibled Toucan) : pectoralis, 2.78; thigh, 1.93.

Picidae

Picumnus olivaceus (Olivaceous Piculet) : pectoralis, 3.84, 3.86.

Piculus rubiginosus (Golden-olive Woodpecker) : pectoralis, 4.14; thigh, 3.11.

Dryocopus lineatus (Lineated Woodpecker) : pectoralis, 3.54, 3.63; thigh, 3.15.

Centurus rubricapillus (Red-crowned Woodpecker) : pectoralis, 3.09, 4.07; thigh, 5.85, 6.32.

Centurus pucherani (Black-cheeked Woodpecker) : pectoralis, 3.42, 4.10; thigh, 4.39, 4.73.

Phloeocastus melanoleucos (Crimson-crested Woodpecker) : pectoralis, 3.22, 3.60; thigh, 2.20, 3.39.

Dendrocolaptidae

Xiphorhynchus guttatus (Buff-throated Woodhewer) : pectoralis, 2.46; thigh, 5.09.

Lepidocolaptes affinis (Spot-crowned Woodhewer) : pectoralis, 2.78, 2.80.

Furnariidae

Synallaxis brachyura (Slaty Spinetail) : pectoralis, 3.40.

Anabacerthia striaticollis (Scaly-throated Foliage-gleaner) : pectoralis, 4.20.

Formicariidae

- Cymbilaimus lineatus* (Fasciated Antshrike) : pectoralis, 2.56.
Thamnophilus doliatus (Barred Antshrike) : pectoralis, 2.81.
Dysithamnus mentalis (Plain Antvireo) : pectoralis, 3.40.
Cercomacra tyrannina (Dusky Antbird) : pectoralis, 3.99.

Pipridae

- Corapipo leucorrhoa* (White-ruffed Manakin) : pectoralis, 5.11.
Manacus vitellinus (Golden-crowned Manakin) : pectoralis, 4.32.

Cotingidae

- Tityra semifasciata* (Masked Tityra) : pectoralis, 4.45.
Querula purpurata (Purple-throated Fruitcrow) : pectoralis, 3.69.

Tyrannidae

- Miodynastes maculatus* (Streaked Flycatcher) : pectoralis, 2.89, 3.01; thigh, 3.45.
Megarhynchus pitangua (Boat-billed Flycatcher) : pectoralis, 3.42; thigh, 2.80.
Rhynchocyclus brevirostris (Eye-ringed Flatbill) : pectoralis, 2.72, 2.75.
Lophotriccus pileatus (Scale-crested Pygmy Tyrant) : pectoralis, 3.75.
Elaenia frantzii (Mountain Elaenia) : pectoralis, 4.04.
Myiopagis viridicata (Greenish Elaenia) : pectoralis, 3.71.

Hirundinidae

- Progne chalybea* (Gray-breasted Martin) : pectoralis, 5.50, 6.00, 6.31.

Troglodytidae

- Thryothorus modestus* (Plain Wren) : pectoralis, 3.27.

Turdidae

- Turdus plebejus* (Mountain Robin) : pectoralis, 3.18; thigh 2.24.
Hylocichla ustulata (Olive-backed Thrush) : pectoralis, 3.81.

Coerebidae

- Cyanerpes cyaneus* (Red-legged Honeycreeper) ; pectoralis, 4.56.
Cyanerpes lucidus (Shining Honeycreeper) : pectoralis, 4.90, 5.46, 5.70, 6.24.

Parulidae

- Myioborus miniatus* (Slate-throated Redstart) : pectoralis, 4.89.

Icteridae

- Zarhynchus wagleri* (Chestnut-headed Oropendola) : pectoralis, 3.18, 3.89; thigh, 2.24, 3.44.

Thraupidae

- Tangara larvata* (Golden-masked Tanager) : pectoralis, 3.60, 3.81.
Tangara gyrola (Bay-headed Tanager) : pectoralis, 3.55.
Thraupis virens (Blue-gray Tanager) : pectoralis, 3.64.
Piranga rubra (Summer Tanager) : pectoralis, 3.70.
Chlorospingus ophthalmicus (Common Bush Tanager) : pectoralis, 3.00, 3.88.

Fringillidae

- Saltator albicollis* (Streaked Saltator) : pectoralis, 3.20.
Pheucticus ludovicianus (Rose-breasted Grosbeak) : pectoralis, 3.99, 4.28.
Passerina cyanea (Indigo Bunting) : pectoralis, 3.85; thigh, 3.83; heart, 1.31.
Arremonops conirostris (Green-backed Sparrow) : pectoralis, 2.25.
Spizella pusilla (Field Sparrow) : pectoralis, 2.44.

and Blue-crowned Motmot. The lipid values of the others lay between these high and low groups.

Usually lipid content in individuals of the same species agreed fairly well. Occasionally one specimen would be very low. In the family Ardeidae, there is considerable range in lipid values of the pectoralis (2.91 to 7.33 per cent), that for the Cattle Egret being extremely high. Likewise in the Columbidae the range is great (1.81 to 5.11 per cent). In the Caprimulgidae, the lipid content in the Lesser Nighthawk was much higher than that in the Parauque. All species of the Trochilidae possessed high lipid contents in the

combined pectoralis and supracoracoideus muscles (combination necessary to obtain enough tissue for analysis). The lipid content of the pectoralis was higher in *Momotus momota lessonii* than in *Momotus momota conexus*. The values in the different Picidae were not far apart, while in the Tyrannidae the range was somewhat greater. Pectoralis lipids checked closely for the different species of Thraupidae but not so closely for members of the Fringillidae.

In connection with pectoral lipid determination in the hummingbird, we made lipid determinations of the heart in two specimens of *Campylopterus hemileucurus*. We found it to be almost as high in the heart as in the pectoralis, or even higher. The values in each individual were: bird A—heart lipid, 4.20 per cent, pectoral lipid, 4.50 per cent; bird B—heart lipid, 5.66 per cent, pectoral lipid, 4.66 per cent.

THIGH MUSCLE

Lipids of the thigh were determined in a much smaller number of species than those in which values for lipids were obtained for the pectoralis. The values were often different from those for the pectoralis. They were high in the Olivaceous Cormorant, Cattle Egret, White-naped Pigeon, Gray-chested Dove, White-tailed Trogon, Ringed Kingfisher, Red-crowned Woodpecker, Black-cheeked Woodpecker, and Buff-throated Woodhewer. They were low in the Little Tinamou, the Hook-billed Kite, the Rufous-naped Dove, the Barn Owl and the Black and White Owl. Although only scattered determinations were made, thigh lipids were most often equal to or less than pectoral lipids. They were less in the Little Tinamou, the Olivaceous Cormorant, the Common Egret, the Snowy Egret, Cattle Egret, the Lesser Scaup, the Hook-billed Kite, the Barred Forest Falcon, the Japanese Quail, the American Jacana, the Rufous-naped Dove, the Brown-hooded Parrot, the Barn Owl, the Chestnut-mandibled Toucan, the Golden-olive Woodpecker, the Lineated Woodpecker, the Boat-billed Flycatcher and the Mountain Robin. They were greater in the Gray-chested Dove, the White-tailed Trogon, the Prong-billed Barbet, the Red-crowned Woodpecker, the Black-cheeked Woodpecker, the Buff-throated Woodhewer, the Streaked Flycatcher and the Yellow-billed Cacique. Some of these comparisons were made between different individuals, but in many instances the comparative data came from the same individual.

DISCUSSION

In this preliminary survey of representative members of several families, it is evident that the amount of lipid in the muscles of locomotion varies considerably. It may be similar in members of the same family or occasionally quite divergent. Within the species the values tend to be close for the various individuals but here again there are exceptions. Usually the amount of lipid is high in muscles accustomed to sustained activity. But it may also be high in species not noted for prolonged exercise as for example the pectoralis in the Little Tinamou and the Barn Owl. Why the lipid concentration in the thigh of the White-tailed Trogon and the Ringed Kingfisher is high is difficult to understand on the basis of use.

What are the possible factors involved in lipid concentration in these muscles? Fats absorbed from the alimentary canal or produced from other food stuffs are stored in depots of various parts of the body, some being found in the liver where it is processed, and some in the muscles themselves.

The fat in the muscle can be utilized there, since George and Scaria (1956) found high lipase activity in the pectoralis. Evidence for its use was demonstrated by George and Jyoti (1955) by stimulating the pectoralis and leg muscles electrically until fatigued, or by forcing pigeons to fly in a large hall, or by starving pigeons for one week. They

observed that the muscle fibers lost their fat globules but that their utilization during starvation was secondary. In other words, muscle fiber fat was used primarily for muscle work. Later George and Jyoti (1957) reported that when the pectoral muscle was electrically stimulated, of the total energy expended, 71 per cent in the pigeon and 61 per cent in the kite and fowl were derived from fat. The breast muscle in the kite was fatigued more quickly.

George and Naik (1960) published lipid values for the pectoralis in two birds which differed markedly from ours. For the Cattle Egret they obtained a mean of 3.90 per cent for 4 specimens (maximum, 4.14 per cent) whereas our values for the same species were 6.20 per cent for 3 specimens (maximum, 7.33 per cent). In the Barn Owl they obtained 3.69 per cent for one specimen whereas our value was 5.40 per cent for a single specimen. It is difficult to account for these discrepancies. Their method differed from ours in that our final extraction contained only the substances soluble in boiling petroleum ether. Our values should have been lower than theirs since some substances were eliminated by the last extraction. Difference in diet might be a factor. However, there is no evidence for this.

In a preliminary experiment we took eight mature Japanese Quail hatched at the same time, 48 days before. All birds were fed "Game Bird Growena" for 30 days, four of them receiving the same type of feed to which 10 per cent fat had been added. At the end of the period, lipid determinations were made on the pectoralis and thigh muscles. There was no significant difference between the values in the fat fed and the control birds. Perhaps a larger group of birds would show a difference.

It is noteworthy that the lipid content of the heart in the hummingbird is similar to that of pectoralis plus supracoracoideus. The heart in this species must meet increased demands several hours a day. The pectoralis is required to do the same. The heart also must beat throughout the life of the individual.

The importance of the presence of lipid or fat in skeletal muscle has not been fully appreciated. It represents a reserve which is more readily available for immediate use than that in the more remote fat depots. It is a constant constituent of locomotor muscles. Birds that use their wings in power flight for long periods possess high or fairly high lipid content in the pectoralis muscles. Although some species that are not very active also show high pectoral lipid content, the important fact is that the very active birds usually have a high lipid reserve.

SUMMARY

The lipid content of the pectoralis was determined in 104 species of birds representing 42 families. All but three species were collected in Panamá.

Most species showed a high lipid content of the pectoralis, only a few showed a low content. Different individuals of the same species usually agreed fairly well. Differences between species in the same family were sometimes of a considerable range. This was true for Ardeidae, Columbidae, Caprimulgidae, and Momotidae. Pectoralis lipid corresponded closely in the different species of Picidae and Thraupidae. The lipid content of the heart in a hummingbird was almost as high or higher than that in the pectoralis and supracoracoideus combined.

The lipids of the thigh muscles were sometimes different from those in the pectoralis. They were high in some and low in others. More often they were equal to or less than pectoral lipids.

Usually the lipid concentration is high in muscles acting to sustain activity, but it may also be high in species not noted for prolonged activity.

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