EXCLUSIVELY "RED" FLIGHT MUSCLE: METABOLIC SPECIALIZATION AND SPECIFIC FLIGHT PHYSIOLOGY

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ABSTRACT

The main flight muscle of certain bats and finches is composed exclusively of red fibres. These fibres, unlike the fibres of most mixed muscles, possess distinct capacity for glycolytic (anaerobic) as well as lipoxidative (aerobic) types of metabolism. The metabolic duality of this highly active muscle seems to be related to its contractile physiology.

INTRODUCTION

THE flight muscles of most birds and bats, unlike other vertebrate skeletal muscles, are adapted for contractions at a high frequency for prolonged periods, resulting in their specialized histophysiological and biochemical organization. Of the two main types of fibres in these muscles[1], the smaller red fibres are rich in myoglobin, mitochondrial substance, certain lipolytic and oxidative enzymes (lipoxidative), and function largely aerobically-metabolizing lipids as their chief energy fuel. The larger white fibres are poor in myoglobin, mitochondrial content, lipoxidative enzymes, rich in glycolytic enzymes, and function largely anaerobically-using glycogen as their major energy substrate. The red fibres perform slow and sustained contractions, while the white fibres are capable of relatively faster/short-lasting contractions. Certain birds and bats have been described as having only red fibres in their major flight muscle[1]. The metabolism of these red muscles has been closely identified with that of the usual red fibres of other muscles, as mentioned above. However, during our recent studies[2] on the exclusively red breast muscle of certain microchiropteran bats and weaver finches, we observed significant metabolic differences between the fibres of this muscle and the red fibres of the mixed muscles (having both red and white fibre types). Our observations are at variance with the usual metabolic speciation of the red fibres as predominantly fat-utilizing, aerobic components of muscle metabolism. We report results that suggest the distinct metabolic capacity of the pure red flight muscles to meet their energy requirements through both glycolytic and lipoxidative metabolic channels, quite unlike the fibres of other skeletal muscles. A possible correlation of such metabolic duality in these muscles with the specific flight physiology of the animals has been attempted.

MATERIALS AND METHODS

The main flight muscle (m. pectoralis major) of certain microchiropteran bats (*Pipistrellus* sp.) and weaver finches (*Ploceus philippinus*) was used in the present study. Cryostat-cut 10 μ sections of the fresh frozen muscle were processed for the histochemical demonstration of succinic dehydrogenase (SDH), lactic dehydrogenase (LDH), α-glycerophosphate dehydrogenase (α-GPDH), phosphorylase, lipids, glycogen[3], and lipase[4].

OBSERVATIONS AND DISCUSSION

Cytologically, the fibres of the pectoralis muscle could readily be identified as the usual red ones[2] on the basis of their mitochondrial density—apparent in the preparation for SDH activity (Fig. 1 A)—and high myoglobin content, imparting an intense red colour to the muscle. Histochemical preparations revealed the presence of both glycolytic (Fig. 1 C, D) and lipoxidative (Fig. 1 A, B) metabolic components, and also that of lipids, glycogen and LDH activity[2], uniformly in all the muscle fibres. Due to this histochemical uniformity it was not possible to differentiate the muscle fibres into specifically glycolytic and lipoxidative types, that are observed in mixed skeletal muscles.

Higher level of glycogen has been reported in the red than in white fibres of certain mammalian and avian skeletal muscles[5,6]. Hexokinase activity has also been reported[7] to be higher in red than in white muscle. Besides these, *in vitro* studies on the carbohydrate metabolism in predominantly red muscles have revealed their glycolytic capacity[8-10]. Yet, there seems to have been no attempt to investigate critically the glycolytic capacity of totally red skeletal muscles. In the house sparrow pectoralis, presence of glycogen and phosphorylase activity has been described in the fibres of the superficial region, while the fibres of the deeper region were found to be predominantly of oxidative type[11]. This, in a morphologically homogeneous red muscle both glycolytic and lipoxidative activities were demonstrated (though in different regions)—in direct relation to the specific mode of flight of the animal. Closely parallel to this are our observations. Though there is no distinction of fibres (and of their regional distribution) into glycolytic and lipoxidative populations, both types of metabolic components were present uniformly in all the fibres of bat (Fig. 1) and finch pectoralis. These fibres also showed uniform myosin-adenosine triphosphatase (m-ATPase) activity throughout the

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muscle[2], reflecting their identical pattern of contractility, since the m-ATPase activity of the muscle fibres is directly related to the speed of their contraction[12]. We have also observed that the intensity of the glycolytic activity in the fibres of the 'red' pectoralis of bats and finches is almost as high as in the white fibres of the typical skeletal muscle[2].

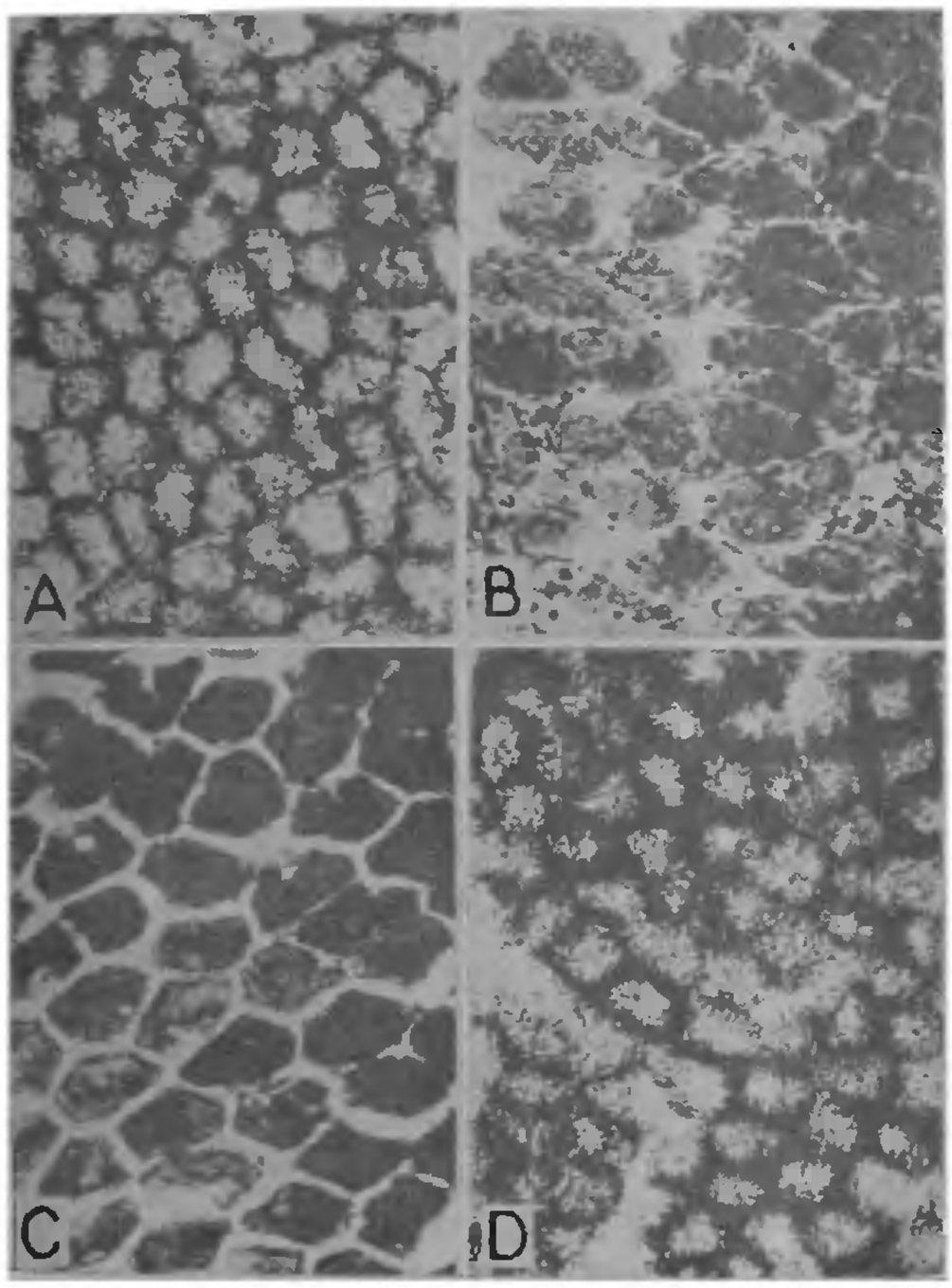

FIG. 1. Histochemical demonstration of the enzymic components of glycolytic and lipoxidative metabolism in the major flight muscle (m. pectoralis major) of the microchiropteran bat. Both lipoxidative and glycolytic enzymes are shown to have uniform activity in all the fibres, which are all of one type. (A), succinic dehydrogenase activity; (B), (C), (D), activity of lipase, phosphorylase, and *a*-glycerophosphate dehydrogenase respectively, × 200.

Slow and fast contractions, in the pectoralis of most birds and bats, are the individual functions of red and white fibres—using mainly lipids and glycogen respectively. Thus, it seems only appropriate to elicit from our observations that the occurrence of both glycolytic and lipoxidative metabolic components uniformly in all the individual fibres of the 'red' pectoralis of the small microchiropteran bats and weaver finches (probably also in other birds having similar pectoralis) is an essential parallel of their capacity to perform both slow and fast contractions during flight. Physiological studies, using electromyographic recordings of the pectoralis muscle (composed exclusively of red fibres) of certain birds, have revealed the capacity of such 'red' fibres to perform both slow and fast contractions during flight[13-15]. We suggest that a physiological shift from a fast to slow contraction (or *vice versa*) during flight is accompanied by a metabolic shift at cellular level—of which these 'red' fibres are quite capable since they possess both glycolytic and lipoxidative metabolic systems. Similar metabolic shift has been reported in dogs —where longer periods of muscular exercise showed gradual shift from carbohydrate to fat utilization[16]. It is likely that in the exclusively red pectoralis of bats and finches, energy derived from glycolysis is used during the short bursts of flight (requiring instant energy), while that from lipoxidative activity is utilized for relatively sustained flight. This interpretation however can be substantiated only by comparing the metabolic profile of the muscle at rest, as in the present study, with that of the muscle immediately after flight.

This, to our knowledge, is the first suggestion of the possible operation of both glycolytic and lipoxidative metabolic cycles within the same individual fibres of the exclusively red pectoralis of the active fliers. Evidently, a pure red muscle also possesses the metabolic equipment that is normally, and almost exclusively, characteristic of the white fibres of mixed skeletal muscles, suggesting thereby a local metabolic specialization of the muscle fibres in response to the specific flight physiology of the animals.

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