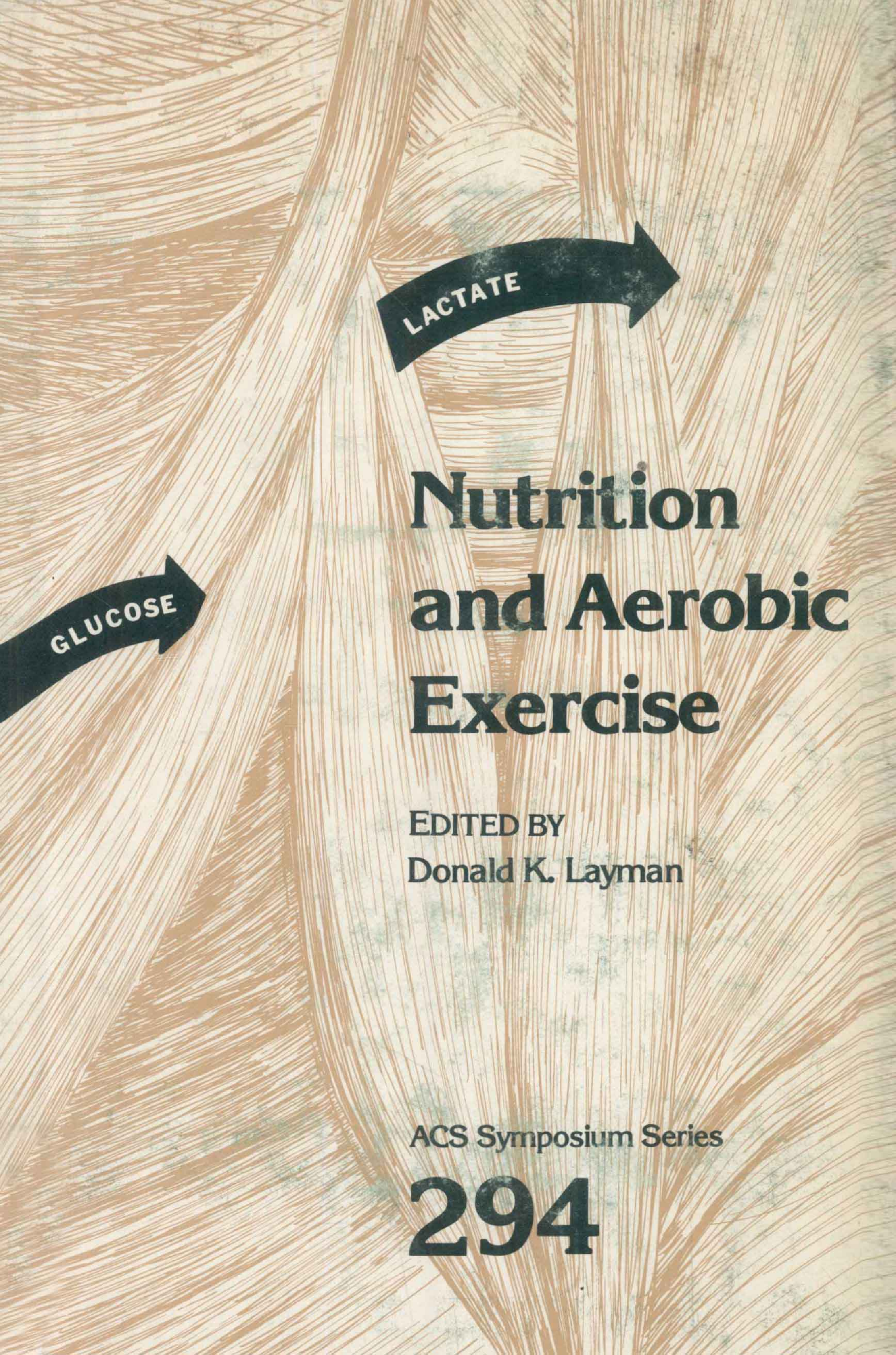

Nutrition and Aerobic Exercise

EDITED BY
Donald K. Layman

ACS Symposium Series

294

ACS SYMPOSIUM SERIES 294

Nutrition and Aerobic Exercise

Donald K. Layman, EDITOR
University of Illinois at Urbana–Champaign

American Chemical Society, Washington, D.C. 1986

Library of Congress Cataloging in Publication Data

Nutrition and aerobic exercise.
(ACS symposium series, ISSN 0097-6156; 294)

Developed from a symposium held Apr. 10, 1984, in St. Louis, entitled "The Influence of Aerobic Exercise on Energy Metabolism and Nutrient Requirements", sponsored by the Division of Agricultural and Food Chemistry of the American Chemical Society, the Quaker Oats Company, and the Dart-Kraft Company.

Includes bibliographies and index.

Contents: Nutrition and exercise/ Donald K. Layman—Biochemical adaptations in skeletal muscle induced by exercise training/ Ronald L. Terjung and David A. Hood—Influence of aerobic exercise on fuel utilization/ Michael N. Goodman—[etc.]

1. Nutrition—Congresses. 2. Exercise—Physiological aspects—Congresses.

I. Layman, Donald K., 1950- . II. American Chemical Society. Division of Agricultural and Food Chemistry. III. Quaker Oats Company. IV. Dart & Kraft. V. Series.

QP141.A1N86155 1986 612'.3 85-26872
ISBN 0-8412-0949-9

PRINTED IN THE UNITED STATES OF AMERICA

ACS Symposium Series

M. Joan Comstock, *Series Editor*

FOREWORD

The ACS SYMPOSIUM SERIES was founded in 1974 to provide a medium for publishing symposia quickly in book form. The format of the Series parallels that of the continuing ADVANCES IN CHEMISTRY SERIES except that, in order to save time, the papers are not typeset but are reproduced as they are submitted by the authors in camera-ready form. Papers are reviewed under the supervision of the Editors with the assistance of the Series Advisory Board and are selected to maintain the integrity of the symposia; however, verbatim reproductions of previously published papers are not accepted. Both reviews and reports of research are acceptable, because symposia may embrace both types of presentation.

PREFACE

THE POTENTIAL HEALTH BENEFITS of a combined program of nutrition and exercise have increasingly been recognized during the past decade. World-class athletes have long known the importance of controlling caloric intake to maintain desired body weight and that a poor diet will diminish performance. However, as the general public becomes more conscious of health and fitness, routine aerobic exercise is becoming a focal point of daily health maintenance for large numbers of people. This trend raises new questions about the impact of exercise on nutritional requirements. This book addresses the principal questions concerning the interaction of nutrition and aerobic exercise training. Each chapter reviews the basic topics and examines new findings and important questions remaining to be solved.

The book is written for an audience that has a basic understanding of physiology and intermediary metabolism. However, it assumes little or no background in nutrition or exercise physiology. It is intended to provide an easily read insight into the current knowledge about nutrition and exercise, and it should appeal to both the specialist and nonspecialist.

This book originated from a symposium entitled "The Influence of Aerobic Exercise on Energy Metabolism and Nutrient Requirements" and was sponsored by the Division of Agricultural and Food Chemistry of the American Chemical Society, the Quaker Oats Company, and the Dart-Kraft Company. I would like to especially thank John Whitaker, David Hurt, and Robert Bursey as the representatives of the respective sponsors.

DONALD K. LAYMAN
University of Illinois
Urbana, IL 61801

September 19, 1985

CONTENTS

1

Nutrition and Exercise: An Overview

Donald K. Layman

Department of Foods and Nutrition, Division of Nutritional Sciences, University of Illinois, Urbana, IL 61801

Across the United States, interest has increased in physical fitness, exercise, and nutrition. Almost one-half of adult Americans state that they exercise regularly (1). Activities include walking, running, swimming, biking, racketball, tennis, aerobic dancing, and many others. The renewed interest in exercise appears to be due, in large part, to the association of exercise with health. Most health organizations, including the American Heart Association, the American Diabetes Association, the American Dietetic Association, and the American Medical Association, advocate exercise for maintenance of health and to reduce the risk of the onset of the adult diseases of obesity, hypertension, heart disease, and diabetes (2-4).

Likewise, health-related changes have occurred in the American diet. The Dietary Goals for the United States developed in 1977 by the Senate Select Committee on Nutrition (5) recommended that adults reduce their calorie intake, reduce total fat, saturated fat, and cholesterol, avoid excessive salt intake, and increase consumption of complex carbohydrates and fiber. These recommendations have resulted in trends toward lower consumption of animal products plus use of low fat products and increased consumption of fruits and vegetables. Consumers are selecting less sugar and saturated fat (6). During the past 3 years, use of poultry and fish has increased about 16%, while use of beef and eggs has decreased 16% (7). This increased consciousness of the general public to nutrition has also led to a proliferation of miracle diets, quick weight loss schemes, and vitamin supplements. Surveys indicate that the majority of Americans take vitamin supplements (6) and many have tried a fad weight loss diet (8).

The response of the American public to utilize diet and exercise for maintenance of health has increased the need for more definitive scientific information about the interactions of exercise with dietary needs. This book reviews some of the physiological and metabolic changes that occur during exercise training and examines the impact of routine exercise on nutritional requirements.

0097-6156/86/0294-0001$06.00/0

Physiological and Metabolic Responses to Exercise

The influence of physical activity on nutritional requirements and health is not the same for all activities. For the purposes of this book, exercise will be classified as either anaerobic or aerobic activities. These terms provide descriptive information about both the level of exertion and the duration of the activity and are useful in relating activities to nutritional needs. Anaerobic exercise includes activities such as weightlifting and sprinting, and involves maximum exertion for periods of time less than 1 or 2 minutes. Aerobic activities are performed for periods usually in excess of 15 minutes at less than maximum speed or strength. Aerobic exercise requires greater endurance and includes activities such as distance running, swimming, biking, and walking.

Some of the responses by the body to anaerobic exercise are visually obvious. Greater strength, speed, and muscle development are reasons that athletes emphasize anaerobic training. However, research has shown that these results are not easily predicted, and even the effects on the amount of muscle mass are not entirely clear (9). The effects of these short-duration exercises on cardiopulmonary function and on nutritional requirements are minimal.

Aerobic exercise involves endurance training. As the body performs activities for extended periods, physiological and cellular adaptations occur (10-12). These adaptations focus on the ability of the body to supply oxygen to the muscle cells, the capacity of the cells to utilize oxygen, and a shift in the fuel source to greater use of fatty acids. The magnitude of these changes defines aerobic capacity and endurance.

Aerobic training produces numerous physiological changes, including changes in heart rate and oxygen uptake. There is a decrease in the resting heart rate and the heart rate at any specific work load. However, cardiac output is maintained because stroke volume is increased. Changes also occur within the muscle cells that allow for increased oxygen uptake from the circulating blood. Thus, aerobic exercise training increases stroke volume, the efficiency of oxygen uptake by muscles (A-V O2), VO2 max and reduces the heart rate during submaximal exercise (10,13-14).

At the cellular level, aerobic exercise training increases the oxidative capacity of the tissues (11), and produces numerous changes in the function of the muscle cells. Changes in specific skeletal muscle cells and the effects of exercise intensity, duration, and frequency are discussed in Chapter 2. Mitochondria increase in size and number which allows for increased oxygen use in fuel conversion to energy for muscular contraction. Training also produces a shift in the primary source of fuel for exercise from carbohydrates to fatty acids. Since fatty acids are the principal form of fuel storage in the body, this shift is critical in allowing for prolonged activity. Use of carbohydrates and lipids during aerobic exercise is examined in Chapter 3.

Influence of Aerobic Exercise on Nutritional Needs

Interest in the relationship of nutrition and exercise arises from many sources. Athletes and coaches often seek an extra edge from specific foods or supplements. Wrestlers, dancers, and gymnasts frequently attempt to control food intake to modify body weight; and, as stated above, large numbers of people are now looking to the combination of improved nutrition and exercise for maintenance of health. Thus, the topics of "Nutrition and Exercise" produce a wide variety of questions from a diverse audience with different needs and goals. Questions most frequently asked include:

Is exercise important for weight control?
Is increased protein essential for muscle building or strength?
Does exercise reduce the risk of heart disease?
Should athletes take vitamin supplements?
Are salt tablets or electrolyte drinks essential for exercise during hot weather?
Is exercise important for a diabetic?
Does aerobic exercise create an increased need for iron?
Does exercise prevent osteoporosis?

This book addresses these issues and examines the current research in these areas.

To evaluate nutrition requirements, the reader needs a basic understanding of nutrients and the parameters that affect their needs. Nutrients are chemical substances needed to maintain life which are supplied to the body in food or drinks. The nutrients include vitamins, minerals, carbohydrates, fats, proteins, and water. These classifications of nutrients encompass approximately 45 different chemicals that are involved in every function or structure of the body. While some of these functions that are directly influenced by exercise will be discussed in the subsequent chapters, a complete listing of these functions is beyond the scope of this book. For a more thorough review of nutrient functions, the reader is referred to any one of a number of excellent nutrition references (5-6,15-16).

To assess the impact of exercise on the needs for specific nutrients, nutrient functions must be evaluated. At a generalized level, the functions of nutrients are (a) growth or maintenance of the structures of the body (one can consider either macro-structures like muscles and bones, or micro-structures like cell membranes and enzymes), (b) fuels for the energy to run the body processes, (c) fluids and regulation of body fluids, and (d) protection from toxic substances including toxic chemicals, carcinogens, and antigens. The effects of exercise on nutritional requirements can be assessed against the likelihood of substantial changes in one or more of these functions.

As the effects of exercise on the body are examined, clearly the primary effects are on body fluids and fuels. Movement of the body requires additional fuels and the process of conversion of these fuels into energy produces heat which must be dissipated, in large part, by evaporation of sweat from the skin.

Water is the most critical of the effects of exercise on nutritional requirements. As discussed in Chapter 8, exercise produces increased body heat and increased water losses. If this results in dehydration, it will decrease performance and can produce nausea, irregularities in heart beat, heat stroke, and death. Associated with water losses, there are losses of salts or electrolytes. However, water loss is clearly the most limiting factor for work capacity as defined in a position paper by the American College of Sports Medicine (17).

After supplying an adequate amount of water, the next most important dietary issue is adequate energy. Physical activity is the major variable of energy expenditure and the only component under voluntary control. The other components are basal metabolism (the energy expended to maintain the vital body processes while at rest) and Specific Dynamic Action (the energy utilized during the digestion, absorption, and assimilation of nutrients after a meal). These two components expend about 1000-2000 kilocalories of energy per day, depending on the size of the body and composition of meals. However, food intakes range from 2000 to 6000 kcals per day, depending on the level of activity. Sedentary adults need about 2000-2500 kcal/day, while athletes consume approximately 3000-4000 kcal/day (18). The primary factors determining the energy expenditure of exercise are the weight of the body and the distance traveled. While it is true that there is less energy expended at walking speeds versus running due to greater efficiencies in movement, over a fairly wide range of running speeds energy expenditure is essentially independent of speed for a given distance (19-20).

Fuels for the body are limited to carbohydrates, fats, and proteins. In the American diet, these fuels are consumed in a ratio of approximately 46:42:12 with the recommended ratio being closer to 53:35:12 (5). Thus in a nongrowing adult, these ratios provide estimates of the fuel use for daily activities. The primary fuels for exercise are carbohydrates and fats. Chapter 3 examines utilization of specific fuels during aerobic exercise. As the amount of daily exercise increases, there is an increased energy expenditure and hence increased need for energy nutrients usually reflected in increased food consumption, decreased body fat, or both (see Chapter 9).

Protein has long been a dominant feature at the training table for athletes who believe that high intakes of protein are essential for muscle development and strength. However, research indicates that little or no additional protein is required for maximum muscle growth. Interestingly, recent studies suggest that aerobic exercise may have larger effects on protein metabolism than anaerobic training (21). The effects of both anaerobic and aerobic exercise on the nutritional needs for protein are reviewed in Chapter 4.

As discussed above, aerobic exercise produces numerous physiologic and metabolic changes in the body. Many of these changes are believed to be beneficial for prevention of heart disease. The effects on cardiopulmonary function were mentioned earlier and are clearly beneficial, as are the changes in body composition described in Chapter 9. Further, aerobic exercise appears to have positive effects on blood cholesterol and other lipids. These effects of exercise on the metabolism of lipids and the important transport particles called lipoproteins are discussed in Chapter 5.

Athletes have long sought to maximize performance by use of special nutrients. "Ergogenic Aids" have been promoted to increase endurance, strength, or performance. Ergogenic aids including vitamins, minerals, and other substances are suggested to "supply" or "produce" more energy. Besides pure vitamin and mineral supplements, other aids include honey, wheat germ oil, gelatin, glucose, and vitamin E. With the exception of possible psychological benefits, any other suggested benefits are without sound scientific documentation (22). As with most misleading advertising, the premise begins with a basic fact and then plays to the desires of the consumer. For example, conventional wisdom holds that the requirements of many of the B-vitamins are dependent on the amount of energy or number of calories used by the body. For thiamin, riboflavin, niacin, pantothenic acid, and biotin, the needs could increase proportional to energy expenditure. Thus the athlete burning twice the energy of the non-athlete was assumed to have approximately twice the B-vitamin needs. While the "logic" that exercise increases B-vitamin needs is reasonable, only riboflavin has been specifically studied. Chapter 6 summarizes these findings and indicates that while riboflavin needs are increased, the increase is small and the associated increased food consumption should be adequate to meet these needs without supplementation.

The effects of exercise on the dietary needs for minerals have not been extensively studied. Of particular interest is the impact of exercise on the minerals iron and calcium which are examined in Chapter 7. Iron is an essential component of hemoglobin which is responsible for transport of oxygen within red blood cells in the blood. Thus, iron deficiency (anemia) will decrease oxygen carrying capacity of the blood and hence lower aerobic capacity. This problem appears to be most important for women who frequently have marginal iron intakes (5).

Calcium needs and metabolism have become an important nutrition issue due to the increased prevalence of osteoporosis. Osteoporosis is a disease of fragility of major bones such as the pelvis, femur, and spine caused by an age-related loss of bone minerals. As discussed in Chapter 7, calcium intake and physical activity may favorably affect the calcium content of bones and delay the onset of osteoporosis.

These issues and associated topics are discussed in more detail in the following chapters. Each of the individual authors has provided background information and research data in an effort to review and evaluate the important issues. Finally, each author has provided a summary statement defining the nutrient needs during an aerobic exercise program.

Literature Cited

1. U.S. Department of Health, Education, and Welfare. (1979) Healthy people. The Surgeon General's report on health promotion and disease prevention. DHEW (PHS) Publ. No. 79-55071.

2. American Heart Association. (December, 1981) Statement on Exercise. Springfield, IL.

3. American Dietetic Association. (1980) Nutrition and physical fitness. J. Am. Diet. Assoc. 76, 437.

4. Castelli, W. P. (1979) Exercise and high-density lipoproteins (editorial). J. Am. Med. Assoc. 242, 2217.

5. Guthrie, H. A. (1983) Introductory Nutrition. 5th edition. C. V. Mosby Co., St. Louis.

6. Hamilton, E. M., Whitney, E. N. & Sizer, F. S. (1985) In: Nutrition: Concepts and Controversies. West Publishing Co., St. Paul.

7. American Institute for Cancer Research. (Summer, 1985) Trends in Food Consumption. In: AICR Newsletter. Falls Church, VA.

8. Stern, J. S. (1983) Diet and Exercise. In: Obesity (Greenwood, M.R.C., ed.), pp. 65-84, Churchill Livingstone, New York.

9. Clark, D. H. (1973) Adaptations in strength and muscular endurance resulting from exercise. Exer. Sport Sci. Rev. 1, 73-102.

10. McArdle, W. D., Katch, F. I. & Katch, V. L. (1981) Exercise Physiology: Energy, Nutrition, and Performance. Lea & Febiger, Philadelphia.

11. Holloszy, J. O. & Booth, F. W. (1976) Biochemical adaptations to endurance exercise in muscle. Ann. Rev. Physiol. 38, 273-291.

12. Pollock, M. L. (1973) The quantification of endurance training programs. Exer. Sport Sci. Rev. 1, 155-188.

13. Saltin, B. (1973) Metabolic fundamentals in exercise. Med. Sci. Sports 5, 137-146.

14. Keul, J. (1973) The relationship between circulation and metabolism during exercise. Med. Sci. Sports 5, 209-219.

15. Briggs, G. M. & Calloway, D. H. (1979) Nutrition and Physical Fitness. 10th edition. W. B. Saunders Co., Philadelphia.

16. Pike, R. L. & Brown, M. L. (1984) Nutrition: An integrated approach. 3rd edition. John Wiley & Sons, New York.

17. American College of Sports Medicine. (1975) Position Paper. Med. Sci. Sports 7:7.

18. Buskirk, E. R. (1981) Some nutritional considerations in the conditioning of athletes. Ann. Rev. Nutr. 1, 319-350.

19. Fellingham, G. W., Roundy, E. S., Fisher, A. G. & Bryce, G. R. (1978) Caloric cost of walking and running. Med. Sci. Sports 10, 132-136.

20. Howley, E. T. & Glover, M. E. (1974) The caloric cost of running and walking one mile for men and women. Med. Sci. Sports 6, 235-237.

21. Lemon, P.W.R. & Nagle, F. J. (1981) Effects of exercise on protein and amino acid metabolism. Med. Sci. Sports 13, 141-149.

22. Williams, M. H. (1985) Ergogenic foods. In: Nutritional Aspects of Human Physical and Athletic Performance. 2nd edition, pp. 296-321, Charles C. Thomas, Springfield, IL.

RECEIVED September 6, 1985

2

Biochemical Adaptations in Skeletal Muscle Induced by Exercise Training

Ronald L. Terjung and David A. Hood

Department of Physiology, Upstate Medical Center, State University of New York, Syracuse, NY 13210

Exercise performance seems to be greatly affected by the chronic level of physical activity experienced by the animal or individual. For example, differences in the capacity for prolonged exercise seem obvious between wild and domesticated animals. This is probably due, in part, to inherent biochemical differences between the muscles of active and less active species (1). Muscles of wild animals appear darker than those of their domesticated counterparts (2). Further, variations in activity patterns due to seasonal change (3) or hibernation (4), are associated with differences in the enzymes related to oxidative metabolism. Thus, in a general sense physical activity seems to be associated with biochemical changes that enhance the muscle's capacity for aerobic metabolism.

Muscle Adaptations

The specific biochemical changes induced by increased physical activity are well characterized from laboratory studies and have been the subject of a number of excellent reviews (5-9). The fundamental change found in skeletal muscle after exercise training is an enhanced capacity for energy provision via aerobic metabolism. There is an increase in mitochondrial protein content and cristae component enzymes associated with the electron transport. In a thorough study, Holloszy (10) found that an exercise program of prolonged treadmill running increased the mitochondrial content of laboratory rats by approximately 100%. Similar training responses are found in a wide variety of other animals including man (9,11). Subsequent morphological studies have shown that the mitochondria of trained muscles appear to be more abundant (12) and larger (13). Thus, the cross-section of the trained muscle appears more densely packed with mitochondria. Mitochondria isolated from muscles of trained animals exhibit the same dependence on ADP to stimulate and increase respiration, and are as efficient in the coupling of ATP production to oxygen consumption as muscle obtained from sedentary animals (10). Thus, the increased mitochondrial content represents a true increase in the potential for aerobic ATP generation within the muscle. In addition to the greater electron transport capacity, there is also a coordinated increase in the enzymes of support

0097-6156/86/0294-0008$06.00/0

systems necessary to supply the reducing equivalents for the electron transport and ATP synthesis. Thus, the capacities for carbohydrate oxidation (14), fatty acid oxidation (15,16), ketone body oxidation (17), tricarboxylic acid cycle enzymes (18), and mitochondrial shuttle pathways (19) are increased by endurance training. In addition, the content of myoglobin, which is thought to facilitate oxygen transfer within the cell (20,21), increases in the trained muscle (2,22). Thus, there is a coordinated increase in the capacity of the trained muscle for ATP provision via oxidative metabolism. These changes contribute to the darker appearing muscles of the trained animals. The primary metabolic significance of the enhanced aerobic capacity is probably related to the control of energy metabolism and a shift in substrate source from carbohydrate to fat in the muscles during submaximal exercise (6,8,23).

Specificity of Adaptations

The biochemical adaptations to exercise training are very specific to the working muscles. For example, an increase is found in the hindlimb muscle of treadmill run rats, but not in liver (24) or the less active abdominal muscles of the same animals (22). Further, when a unique training program that exercises only one limb on a cycle ergometer is employed, the adaptation is induced in the exercised leg, but not the untrained contralateral leg (13,25). Thus, the training adaptation is not a generalized response within the individual. This indicates that the stimulus responsible for bringing about the biochemical change is specific to the working muscle and related to the demands placed upon the muscle by the exercise effort.

Factors that determine the magnitude of the training effect are fairly complex, due in part to the ordered pattern of motor unit recruitment found during normal locomotion and/or a specific work task. The type and intensity of the exercise effort largely determine which motor units will be utilized to perform the work (26). Each motor unit within a muscle is composed of a single nerve axon and the muscle fibers that it innervates. While all fibers within a given motor unit have the same properties, it is now recognized that at least three different skeletal muscle fiber types (and thus motor units) exist in mammals. They differ considerably in their contractile characteristics, in their inherent biochemical capabilities, and probably in their response to training. Thus, it is important to consider the impact of the different types of skeletal muscle motor units.

Muscle Fiber Types

Mammalian skeletal muscle can be separated into two distinct fiber populations, based on relative contraction characteristics, and are referred to as slow-twitch (Type I) or fast-twitch (Type II) fibers. The slow-twitch fiber type exhibits a relatively low shortening velocity (27), a low rate of tension development (27), a low myosin ATPase activity (28) and a low rate of calcium sequestration by the sarcoplasmic reticulum (29). The converse is true for the fast-twitch fibers. Since contraction velocity highly correlates with myosin ATPase activity (30), it is possible to easily identify, within a muscle cross-section, fast and slow-twitch fibers by the intensity of staining of the myosin ATPase using histochemical procedures (31). The slow-twitch fibers are characteristically red in appearance, indicative of a relatively high mitochondrial content (14), exhibit a high blood flow (32,33), and have a low glycogenolytic capacity (e.g., phosphorylase activity) (7,34). The fast-twitch fibers uniformly possess a relatively high glycogenolytic capacity (7,34), but can be subdivided by their contrasting capacities for oxidative metabolism. In fact, the greatest difference in mitochondrial content for most non-primate mammalian muscle is found between the fast-twitch red and the fast-twitch white fiber types (14,35). In humans, the mitochondrial content of slow-twitch red fibers is typically greater than that of the fast-twitch red fibers (7,35). Similarly, measurements of blood flows to sections of muscle, which are primarily composed of a single fiber type, exhibit large differences consistent with the expected demands of oxygen supply based on mitochondrial content (32,33). Thus, mammalian skeletal muscle is typically comprised of three biochemically and functionally distinct fiber types: slow-twitch red, fast-twitch red and fast-twitch white. These fiber types are also commonly referred to as Type I, Type IIa, and Type llb, respectively (7).

Contraction performance of these different fiber types is predictable from a knowledge of their biochemical and blood flow differences. For example, the slow-twitch red fiber type can contract for long periods of time without a loss in tension development (36). Although the relatively high functional aerobic capacity must be important for sustained performance (37), it is also known that the slow-twitch fiber type requires less energy to maintain tension (38). Therefore, this fiber type seems well-suited for prolonged sustained activity such as that required for postural support. The fast-twitch red muscle fiber is fairly fatigue resistant and capable of repeated powerful contractions before tension development declines significantly (36). Although this fiber type has a high capacity for lactate production (39,40), its performance during prolonged contraction periods is made possible by its relatively high functional aerobic capacity (40). In contrast, the fast-twitch white muscle fiber exhibits a rapid loss of tension development and is capable of powerful contractions for only a brief period of time (36). A high rate of glycogenolysis, resulting in a high lactate content and cellular acidosis, would be found during intense contraction conditions in this fiber type (41).

The slow-twitch muscle fibers are relatively small in diameter and belong to motor units that are typically the first to be recruited during any motor task. Thus, during simple muscle activity required for postural support of standing, the slow-twitch motor units are very active and, in some cases, function near their maximal force output (42). The fast-twitch red fibers belong to larger motor units (26) and are recruited for muscle actions that are more forceful (42). Their recruitment increases, for example, when running at increasing speeds on a treadmill (42). Finally, the fast-twitch white fibers belong to large powerful motor units and are recruited during very intense exercise (43,44) or during extremely forceful movements such as jumping (42). The relatively infrequent and specialized utilization of the fast-twitch white motor units is especially purposeful, since these intense exercise