Corey H. Evans
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Exercise Testing for Primary Care and Sports Medicine Physicians

Springer

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This book is dedicated to Myrvin H. Ellestad, MD, and Victor F. Froelicher, MD. Their work and textbooks in the field of exercise and exercise testing are truly the bibles in this field and have helped countless physicians. We appreciate their guidance, friendship, and support over the years and their encouragement of exercise testing among primary care physicians.

Foreword

This book by Corey H. Evans, Russell D. White, and coauthors is a gem. There was a time when exercise testing was largely limited to cardiologists, but no more. Exercise testing, which provides information on fitness, the risk of coronary disease, and all around vitality, is now being performed in the offices of primary care physicians across the United States.

Although there is a significant risk in some populations, a careful doctor who takes the trouble to become knowledgeable in exercise physiology and the pathophysiology of coronary artery disease can use exercise testing to improve his ability to give excellent, preventive medicine.

Over the years I have read many books on this subject, and even contributed to some, and this one rates right up there with the best. Like many multiauthored books there is some repetition, but this is not all bad. A careful study of the various chapters will provide a depth of knowledge that will come in good stead when problems arise.

I can especially recommend the chapter on exercise physiology. When the reader has mastered the material presented in this chapter, he has acquired a knowledge base so that he can become an expert in exercise testing equal to almost anyone.

Over the years I have been privileged to know several of the authors and have followed their publications. Their contributions to our knowledge base in this field have been considerable. Acquiring this book and becoming familiar with its contents will set you apart in the field of exercise testing.

Myrvin H. Ellestad
Long Beach, CA
July 2008

Preface

With more than 40 years of experience between us teaching exercise testing on the national level, it is a pleasure for us to present a book on exercise testing for primary physicians. As primary care physicians, we both share strong interests in sports medicine, exercise promotion and testing, and prevention of cardiovascular disease. It is our desire to develop a text that primary care physicians can use to assess fitness, encourage and prescribe exercise, and discuss tools to evaluate our patients and athletes. We also wanted to share the basic and advanced concepts behind exercise testing so that readers can master the principles and use the exercise test in their practices. We strongly believe that the exercise test is invaluable for many of these purposes and should be widely used by primary care physicians.

Over the years we have been fortunate to teach and write with many of the national leaders in the field of exercise and exercise testing including Drs. Myrvin Ellestad, Victor Froelicher, and Nora Goldschlager. We have included these nationally recognized leaders as coauthors in this text and we appreciate their support.

It is our desire to help the reader know when statements are evidence based and the strength of the evidence. To that end, we have used a common rating system, used by the American College of Cardiology and others. When possible statements and recommendations will be categorized into three classes, based on the evidence and consensus of experts:

- Class I: There is evidence and/or general agreement that a given procedure, treatment, or recommendation is useful and effective.
- Class II: There is conflicting evidence and/or a divergence of opinions about the usefulness/efficacy of a treatment, procedure, or recommendation
    - Class IIa: Weight of evidence/opinion is in favor of usefulness/efficacy
    - Class IIb: Usefulness/efficacy is less well established.
- Class III: Conditions for which there is evidence and/or general agreement that the treatment/procedure is not useful/effective or actually harmful.

In addition, where applicable we use the following levels of evidence:

- Level of evidence A: Data were derived from multiple randomized clinical trials that involved large numbers of patients.

- Level of evidence B: Data were derived from a limited number of randomized trials that involved small numbers of patients or from careful analysis of nonrandomized studies or observational registries.
- Level of evidence C: Expert consensus was the primary basis for the recommendation.

The book is divided into initial chapters on the physiology of exercise and the performance of the exercise test. This includes the equipment, protocols, and interpretation. The next section discusses common abnormal examples, exercise testing coupled with imaging techniques, and the important area of risk stratification. This includes using the exercise test and other tests to stratify patients with chest pain, asymptomatic patients, preoperative patients, and those after angioplasty and coronary artery bypass graft (CABG) surgery.

Because health promotion is essential to improving our patients' lives, we included a chapter on using the exercise test and other tools in our practices to create lifestyle changes. The medical–legal aspects of exercise testing are also discussed.

The final section deals with fitness and sports medicine topics. It is important for primary physicians to understand how to evaluate and promote fitness. Since gas analysis is the best way to directly measure fitness, we felt it was important to introduce readers to gas analysis as an additional component of the exercise test. The last two chapters deal with testing both asymptomatic and symptomatic athletes. Finally, we have included a chapter using case studies to illustrate many of the important and interesting points. We certainly want to thank all of the authors for their contributions toward making this book a reality, for without their efforts we could never have finished this project. Also, many thanks to the help and patience of our editor, Margaret Burns.

We sincerely hope the readers find this text helpful in the day-to-day management of patients as we all strive to improve the lives of our patients. As we battle against obesity, diabetes, and heart disease in the US, we hope this reference enables the primary care physicians to promote fitness and exercise as well as to use tools herein to evaluate the diseases associated with obesity and inactivity.

On a personal note we would like to acknowledge our families for their support. I (RDW) would like to thank my wife, Dara, for her constant encouragement. And I (CHE) would like to thank my father, Paul Evans, for his loving support and lifelong commitment to a personal exercise program. Dad, you certainly set a great example, and now in your eighties, you are still reaping the benefits. May my boys and I continue this great tradition.

St. Petersburg, FL, USA
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July 2008

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Part I
Performing the Exercise Test

Chapter 1
Exercise Physiology for Graded Exercise Testing: A Primer for the Primary Care Clinician

Francis G. O'Connor, Matthew T. Kunar, and Patricia A. Deuster

Exercise testing is an advanced clinical procedure used by providers to assess functional capacity for the purpose of guiding cardiovascular and pulmonary diagnoses and therapies. Numerous clinical guidelines, texts, and consensus statements have been published to assist clinicians in the identification of indications and criteria for treadmill stress testing, as well as procedures for test performance and interpretation [1–4]. However, the physiology of exercise testing, which is the foundation for exercise testing, is often overlooked in resource publications, as well as during the clinical training of providers. Education in exercise physiology is largely limited to the pre-clinical years, despite the fact that progress in cardiovascular exercise physiology is ongoing. This chapter functions as a primer for the primary care clinician who conducts exercise testing: core concepts pertaining to energy metabolism, skeletal muscle physiology, and cardiovascular and pulmonary physiology are reviewed. Additionally current concepts pertaining to testing for maximal aerobic power, factors that influence both test performance and results, and the physiology of myocardial ischemia and ST-segment depression are discussed.

Skeletal Muscle and Energy Production

Skeletal Muscle Physiology

The end-organ of exercise is skeletal muscle. Skeletal muscle can be subdivided anatomically into fascicles, which contain approximately 150 myofibers (muscle cells) (Fig. 1.1). Each muscle cell is composed of many myofibrils (5–10,000). Each myofibril in turn contains approximately 4,500 sarcomeres, which constitute

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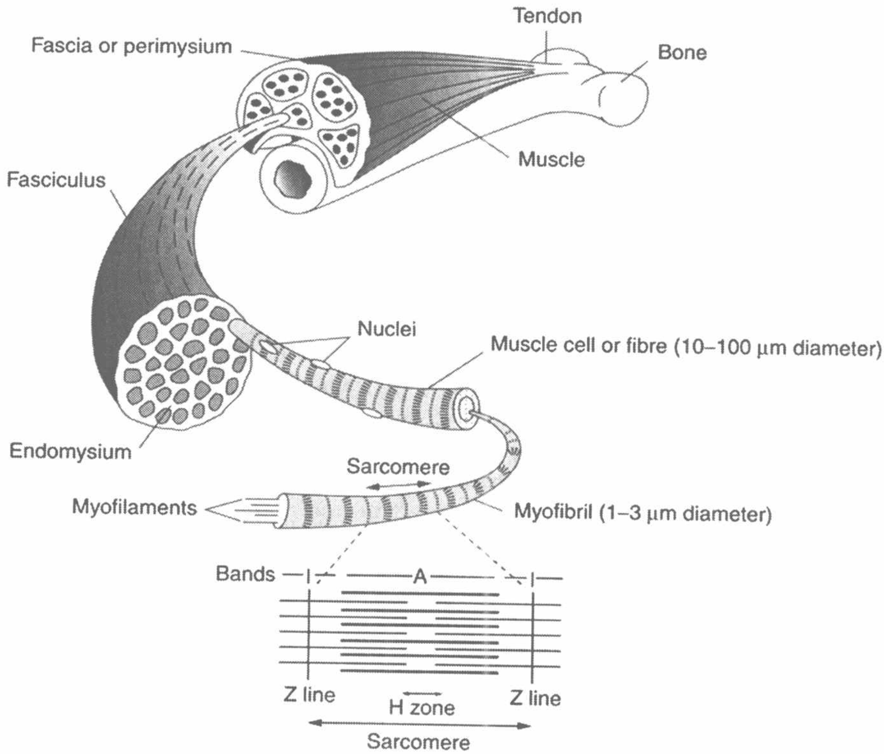

Fig. 1.1 Basic anatomy and structure of skeletal muscle physiology

the functional unit of the muscle cell. Sarcomeres are composed of two distinct myofilaments: thick and thin, with myosin and actin being the primary thick and thin myofilament proteins, respectively. Troponin, tropomyosin, titin, nebulin, and desmin are other important proteins that maintain the structure and function of the myofilaments.

Muscle Contraction

The dominant theory of muscle contraction is the sliding filament theory, which states that muscle contraction occurs when myosin heads bind to actin. The subsequent binding of adenosine triphosphate (ATP) to myosin breaks the actin–myosin bond and allows myosin to bind to another actin site farther along the thin filament. The process of myosin binding, releasing, and rebinding to actin forces the myofilaments to slide past each other in a ratchet-like fashion to create a series of cross-bridge linkages. This cross-bridging creates an oscillatory pattern with no more than 50% of the myosin heads attached to actin at any given moment.

Muscle Fiber Types

Skeletal muscle consists of two major fiber types: type I (slow twitch) and type II (fast twitch). Overall, type I fibers are characterized by lower force production, power, and speed, but greater endurance than type II fibers. Type I fibers have lower glycogen stores and myosin-ATP-ase activity and more mitochondria than their type II counterpart. The abundance of mitochondria and the high activities of enzymes involved in aerobic metabolism are associated with resistance to fatigue and ability to sustain submaximal activities. Type II muscle fibers, which can be classified into at least two other types (type IIa and type IIx), exhibit an approximately three to five times faster time to peak tension than type I fibers and are recruited preferentially during high-intensity exercise [5–12]. In fact, a hierarchical order of fiber activation with increasing intensity of exercise has been shown [13]. Type II fibers also have higher rates of cross-bridge turnover than type I fibers, and thus require more ATP per unit of time and are readily fatigued [5, 6]. Additionally, type II fibers exhibit greater activities of the enzyme lactate dehydrogenase (LDH) than type I fibers [14]. LDH, as discussed below, catalyzes the reversible reduction of pyruvate to lactate with accompanying oxidation of NADH to nicotinamide adenine dinucleotide (NAD+), in an effort to maintain ATP in the absence of oxygen.

The distribution of fiber types varies as a function of genetics and training. The proportions of type I and type II fibers in untrained persons are approximately 53 and 47%, respectively, whereas the proportion of type II fibers in resistance and endurance-trained individuals averages 67 and 50%, respectively [5, 6, 10–12]. The metabolic and mechanical profiles of fiber types can adapt in response to training, but the adaptations are training specific [11, 12].

Energy Metabolism

As indicated earlier, the process that facilitates muscular contraction is entirely dependent on the body's ability to provide and rapidly replenish ATP. Minimal amounts of ATP are stored for muscle contraction, but ATP can be derived from three specific energy systems: the immediate or creatine phosphate system; the short-term or glycolytic system; and the long-term or oxidative/aerobic system. Muscle fiber types at rest have intrinsically different contents of creatine phosphate (CP), ATP, and Inorganic Phosphate (Pi).

The immediate or phosphagen system consists of adenosine diphosphate (ADP), ATP, creatine (C), and CP. ATP is produced/regenerated when the enzyme creatine kinase catalyzes the transfer of phosphate from CP to ADP. Muscle fibers store approximately four times more CP than ATP, with type II fibers storing almost twice as much as type I fibers [15]. The CP system sustains energy during very short bursts of maximal power (Table 1.1).

The short-term or glycolytic system provides 1–1.6 min of energy for muscular activity. At the onset of any exercise, the oxygen demand is greater than the supply, so glucose from glycogen is converted to pyruvate for a net yield of 2 ATP. For glycolytic production of ATP to continue in the absence of oxygen, nicotinamide