EXERCISE PHYSIOLOGY

AND ANATOMY OF MOVEMENT

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FELTHAM PRESS

EXERCISE PHYSIOLOGY

CONTENTS

2 Energy Relations in Action

3 Circulation in Action

PREFACE

The aim of this book is to provide a concise but comprehensive introduction to the main ways in which the human body responds to the demands of exercise.

Exercise typically involves movement; but there are elements within exercise which may be static, involving tension and balance. Exercise may also be either concentrated into a short period of intense activity, or sustained over a longer time. Whatever the type of exercise, the body systems adjust and adapt to it, both in the short term and the long term – some more dramatically than others. The study of how the body adapts to the demands of exercise is known as **Exercise Physiology**.

Although the huge number of sports and activities available involve a wide variety of actions, they all have certain major interacting systems in common, and it is on these that attention will be focussed in this book.

Exercise always involves muscular activity, so that **Muscles and Bones in Action** is a good starting point for the study of exercise physiology.

The **Energy Relations** of muscular activity are critical, as without a continuous supply of energy, muscular contraction is not possible.

The increased use of energy by muscles during exercise results in an increase in the demand for fuel and oxygen, and in the production of waste products. Therefore the **Circulation**; and **Breathing, Gas Exchange and Transport** systems adapt accordingly.

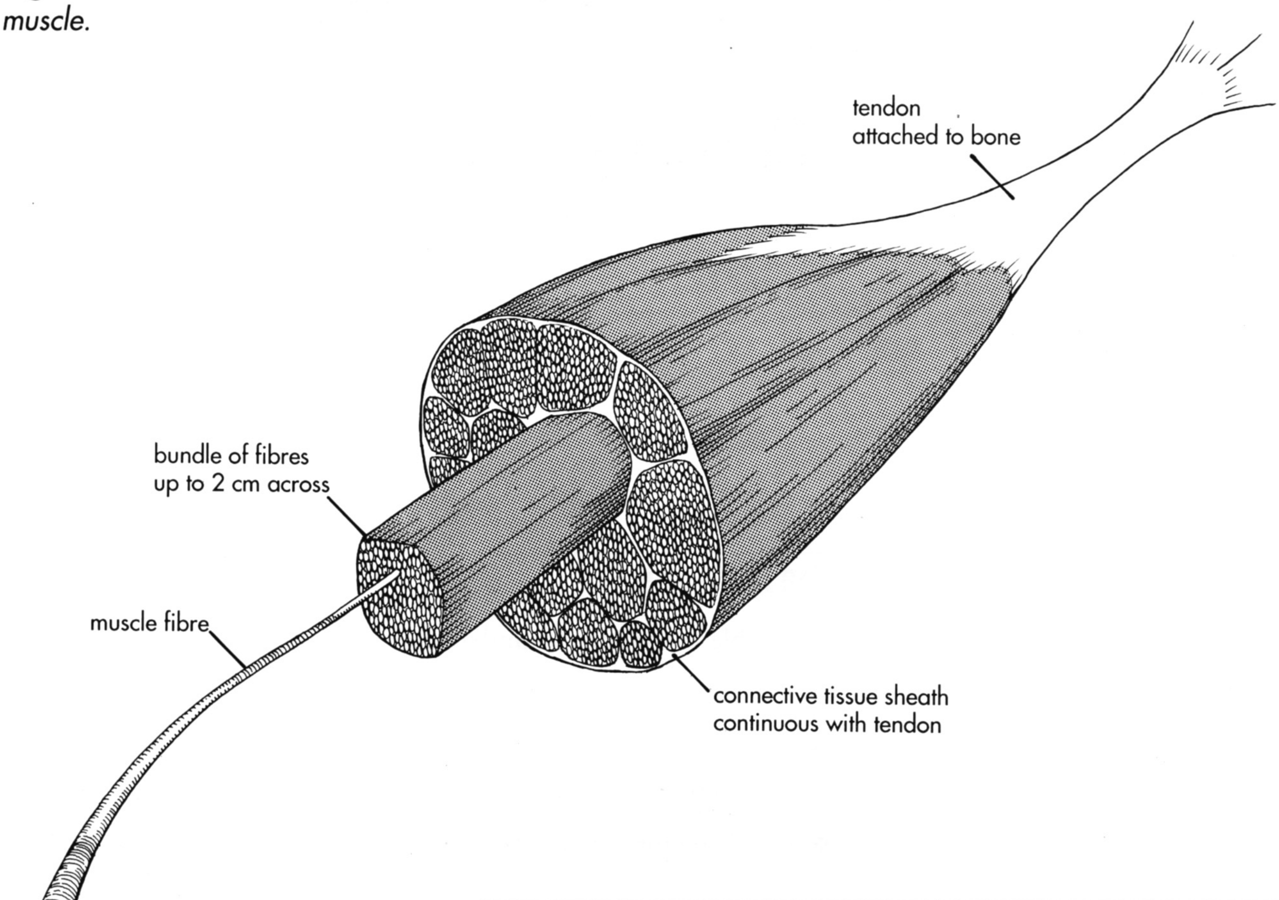
Other body systems are also involved in the response to exercise, but they either do not show such specific adaptations as those mentioned above, or they may be so closely involved with them, that they are difficult to deal with independently. Therefore these systems are either dealt with as their involvement arises, or in the Chapter on **Exercise, Fitness and Health**, where consideration is also given to the changing response of the body with age.

Training and performance applications are highlighted in sections throughout wherever relevant; and the broader principles of training are dealt with in the Chapter on **Training Principles**.

Key Points of special importance are summarised at the end of each chapter.

Photocopiable packs for staff/student use on **Measurement and Testing of Physical Performance**, and of **Assignments and Solutions** designed to help students work through this book, encourage self-appraisal, and develop examination technique,are available to accompany this volume.

Figure 1.1: *Structure of a skeletal muscle.*



1.2 Structure of a Skeletal Muscle Fibre

Each fibre is made up of many contractile protein myofibrils, and each myofibril is in turn composed of many overlapping protein threads or filaments known as myofilaments. Each myofibril is divided along its length into a repeating series of units or sarcomeres, which are the fundamental functional units of the muscle.

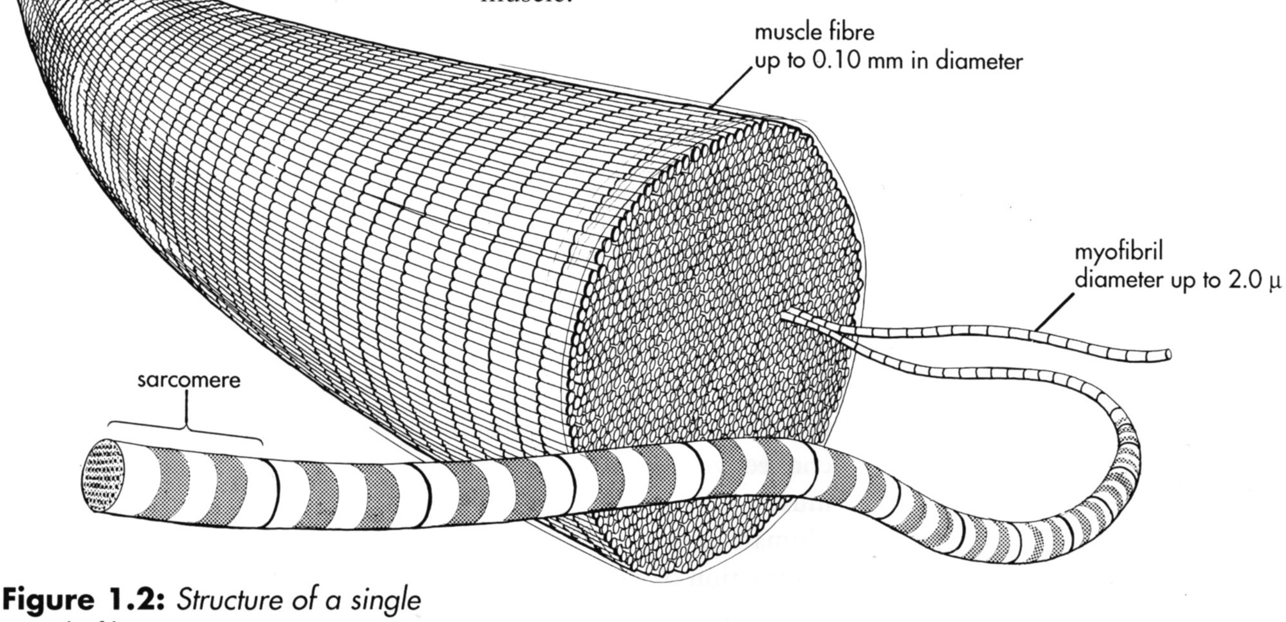
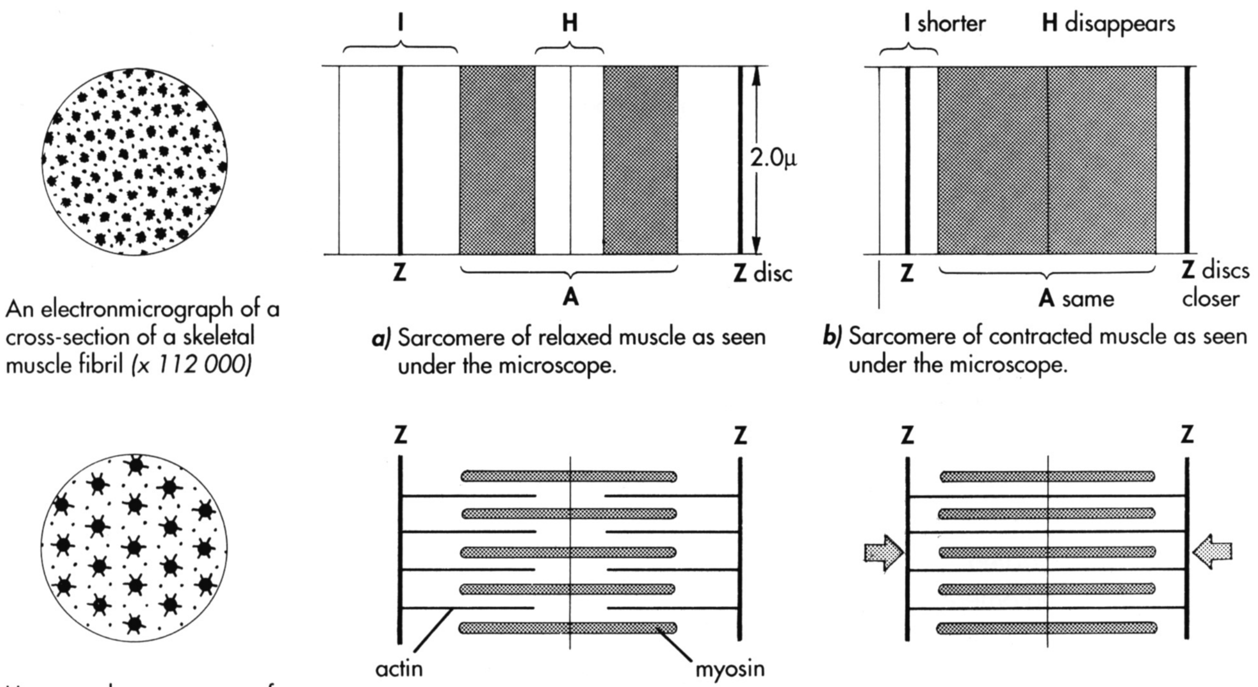


Figure 1.2: *Structure of a single muscle fibre.*

Figure 1.4: *Sliding filament mechanism.*



An electronmicrograph of a cross-section of a skeletal muscle fibril *(x 112 000)*

a) Sarcomere of relaxed muscle as seen under the microscope.

b) Sarcomere of contracted muscle as seen under the microscope.

Hexagonal arrangement of thick *(myosin)* and thin *(actin)* filaments shown in cross section in greater detail.

c) Diagramatic explanation of how the banding pattern is due to differing densities of overlapping actin and myosin filaments.

d) As for ***c*** but actin filaments have slid to the middle of the sarcomere and met in the centre, pulling the **Z** discs closer together.

Sarcomere lengths		
Fully extended	3.6μ	100%
At rest	2.2μ	59%
Fully contracted	1.6μ	44%

The force generated by a muscle is related to the degree of overlap of the actin and myosin filaments, which in turn determines the number of cross bridges that can be formed at any one time. For example, the more a muscle is stretched past an optimum length, the smaller the force that can be exerted, as there is less and less overlap between the filaments, and fewer and fewer cross bridges that can be formed.

1.3.2 MOLECULAR BASIS OF SLIDING FILAMENT MECHANISM

The myosin filaments have protein projections or cross bridges or 'heads' which extend towards the actin filaments. When the muscle is at rest the myosin cross bridges are not connected to the actin filaments, and an ATP molecule is bound to the free end of each cross bridge.

The actin filaments are associated with two other proteins which are involved in control of the contraction mechanism, namely **tropomyosin** and **troponin**.

Effect of aerobic training on skeletal muscle seen in cross section.
All fibres increase in thickness. Mitochondria, blood capillaries, glycogen stores, fat vacuoles all increase.

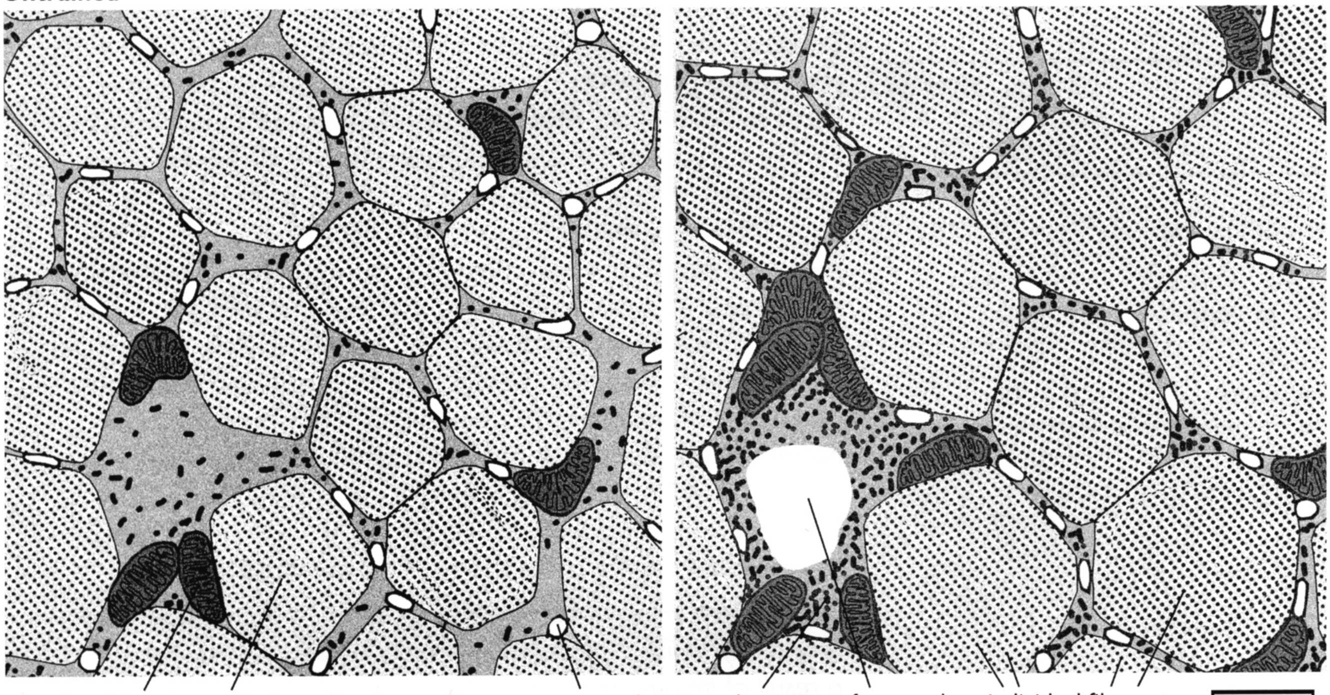
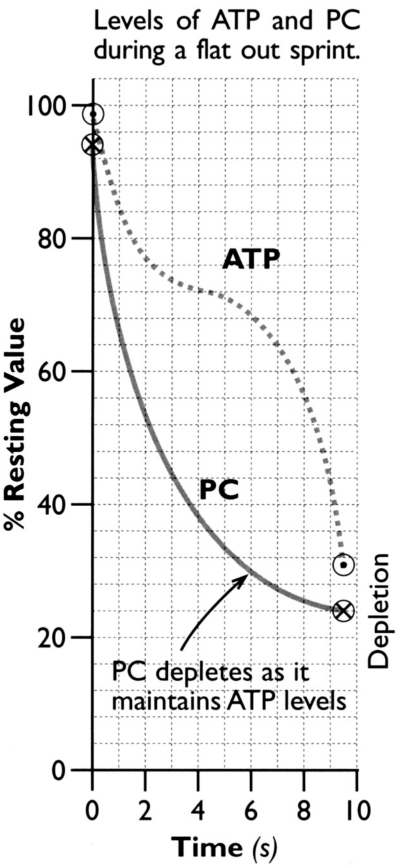


Table 1.2: *Summary of differences between fast and slow twitch muscle fibres.*

Characteristic	ST Type I *(SO)*	FT Type II	
		Type IIa *(FOG)*	Type IIb *(FG)*
Contraction time	Slow *(110 ms)*	Fast *(50 ms)*	Fast *(50 ms)*
Aerobic capacity	High	High	Low
Anaerobic capacity	Low	High	High
Force of motor unit contraction	Low	High	High
Mitochondrial number	High	High	Low
Myoglobin content	High	Medium	Low
Phosphocreatine store	Low	High	High
Glycogen store	Medium	High	High
Elasticity	Low	High	High
Activity level of myosin ATP-ase	Low	High	High
Amount of sarcoplasmic reticulum and rate of calcium release	Low	High	High
Muscle fibre	Small diameter	Large	Large
Recruitment threshold	Low	High	High



❖ *Training and Performance Applications*

All three components of the energy supply system, the ATP/PC, the anaerobic, glycolytic, and the aerobic, operate from the outset of any event involving continuous movement, but to varying degrees. For example, in a hard run 800 metres race, the ATP/PC system will fuel the quick kick off from the start. The anaerobic glycolytic system will be mainly used in the first 200-400 metres, which is the fastest phase of the race when demand for oxygen is greater than the supply. The runners gather themselves for the final lap, and by now the respiratory and circulatory systems have adjusted to the demands, so that aerobic respiration can increase. In the final kick for home, demand for oxygen again exceeds supply and the anaerobic glycolytic system floods the body with lactic acid, bringing the athlete to a virtual standstill at the end of the race, hopefully just past the finish line.

and fish. Creatine content of such foods will be sufficient for most activities, however, methods have been employed to extend the bodily storage facility, for which major claims for training and performance have been made. Creatine supplementation has been suggested with doses of 20-30g per day, consumed in 4-5 equal doses, for 5-7 days. This is known as the loading phase and will increase the total muscle creatine content. There is, however, an upper limit to intramuscular creatine content past which excess is excreted by the kidneys. This is why the loading phase is followed by a maintenance phase, with a dose of only 2-3g per day in order to preserve creatine stores. The increase in total muscle creatine of about 20% results in a significant increase in the amount of work which can be performed close to the maximum. It also results in a quicker recovery rate after exercise.

Although PC is always used to some extent at the beginning of any type of exercise to regenerate ATP, ATP is regenerated from other sources as well. If the exercise is of the speed endurance type, energy from anaerobic glycolytic respiration *(in which lactic acid is generated)* is mainly used to regenerate the ATP.

If the exercise is of the endurance type, where the oxygen delivery systems become capable of sustaining aerobic respiration *(as a result of an increase in the breathing and heart rates)*, more energy from the aerobic oxidation of glycogen, FFA and blood glucose is used as the slow twitch muscle fibres become more involved. With this system a steady state can be reached, in which ATP is regenerated at the same rate as it is broken down, and performance can be maintained for long periods.

During exercise some ATP can also be regenerated from the combination of ADP molecules:

$$\text{ADP} + \text{ADP} \rightarrow \text{ATP} + \text{AMP}$$ *(Adenosine Monophosphate)*

AMP activates respiratory enzymes, and stimulates the secretion of adrenaline, both of which increase the rate of respiration and therefore the regeneration of ATP from aerobic sources.

It is important to note that all these ways of resynthesising ATP may operate at the same time, but the relative contribution of each one depends upon the activity and its duration.

2.5 Metabolic Pathways

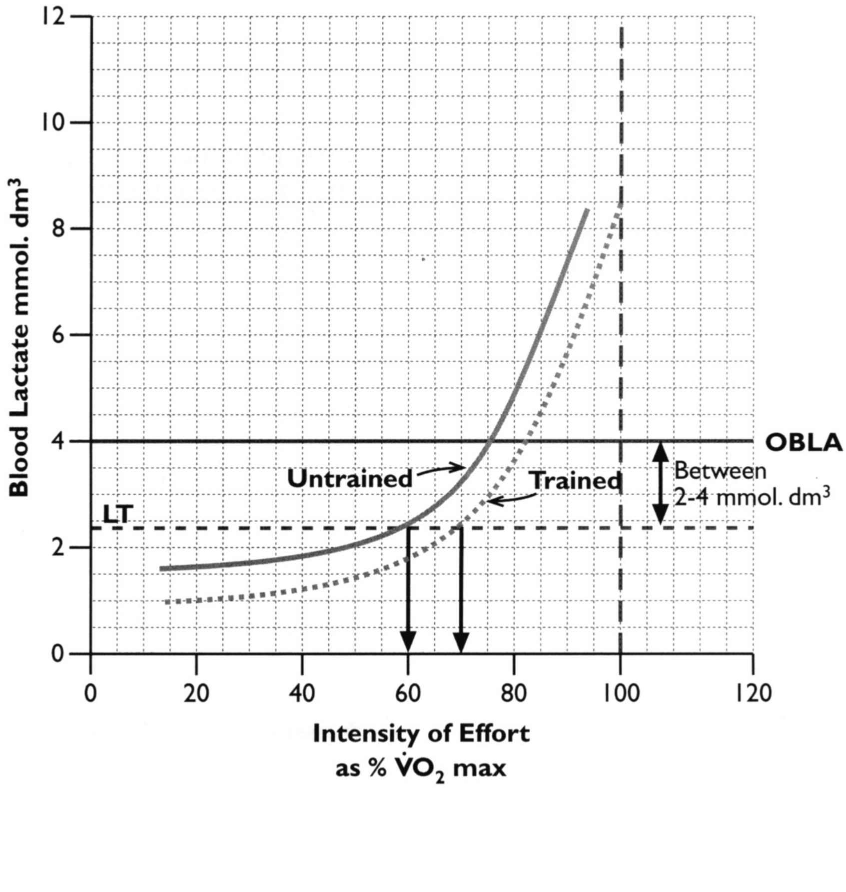
The energy that is trapped and stored in the phosphagen system originates from the energy rich respiratory substrates. It is released from the energy rich sources by a series of enzyme catalysed reactions. In these metabolic pathways the respiratory substrates are oxidised to carbon dioxide and water, in the process known as cellular respiration. The breakdown of the different respiratory substrates involves common pathways. The main pathway is that of the breakdown of carbohydrates, with the breakdown of fats and proteins linking in at different points.

❖ *Training and Performance Applications*

The lactate threshold (LT) may be expressed as a measure of exercise intensity (i.e. watts or kilometres per hour) which provides an index of functional performance, and is often used to predict athletic performance, e.g. 10km run time. Alternatively, the point can be expressed as a percentage of the person's aerobic capacity ($\dot{V}O_2$ max) (see section 4.9), indicating the relative level that can be sustained in relation to a person's aerobic capacity. This concept is now referred to as ***fractional utilisation*** *as it reflects the ability to 'utilise' (or maintain the use of) a 'fraction' (or percentage) of the aerobic capacity.*

In untrained subjects the lactate threshold (LT) may occur between 50-60% of $\dot{V}O_2$ max, whereas in elite endurance athletes the LT may be at 90% of their $\dot{V}O_2$ max. These highly trained athletes possess a very high fractional utilisation, which will allow a high exercise intensity to be maintained without the lactate accumulating and causing fatigue.

Blood lactate levels in relation to intensity of effort in untrained and trained individuals.



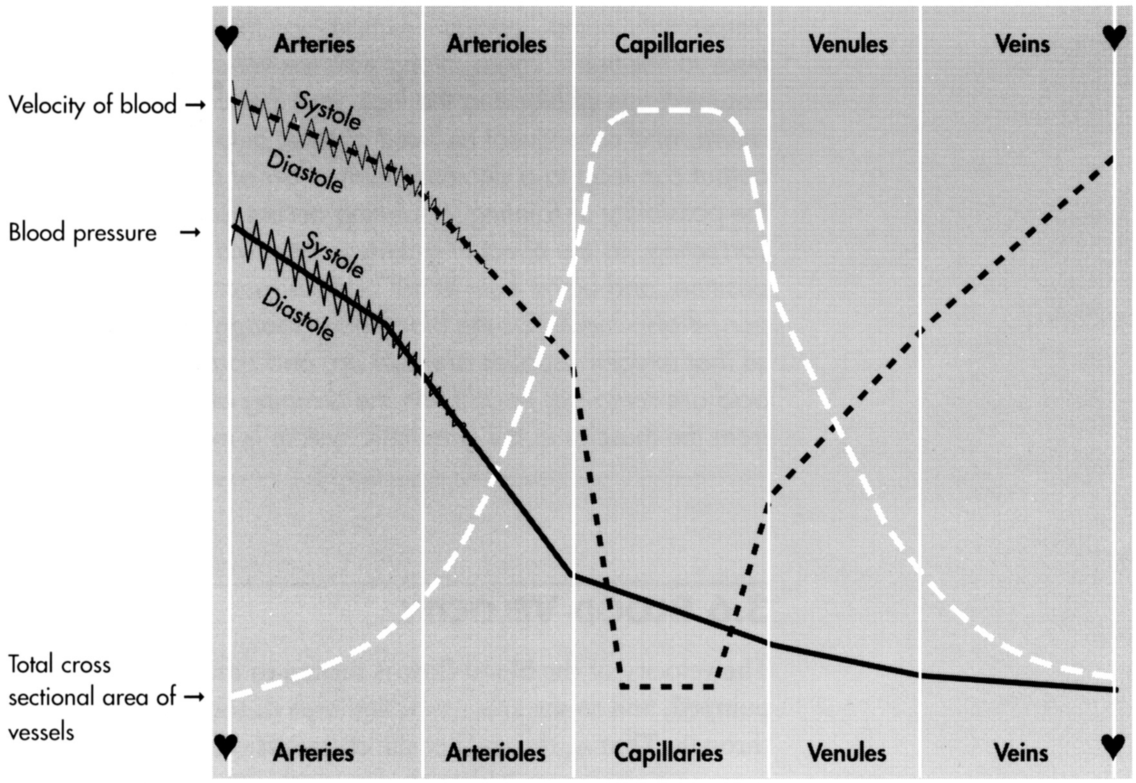
of about 25 mm). Therefore the blood slows considerably in the capillaries, which allows for efficient exchanges with the tissues.

During exercise, the flow rate through the capillaries is increased as the cardiac output increases more rapidly than the number of extra capillary beds brought into action.

The blood speeds up on leaving the capillaries as a result of the total cross-sectional area of the veins being less than that of the capillaries. Within the venous system the blood speeds up as a result of the action of the 'muscle pump' and the 'respiratory pump', and as a result of the total cross sectional area of the venous system decreasing as venules join to form veins, and veins run into the main venae cavae which return blood to the heart.

Close to the heart the velocity of the blood in the veins is similar to that of the blood in the main arteries leaving the heart. This is necessary to ensure adequate venous return to balance the cardiac output. The flow in the pulmonary circulation around the lungs, is faster than that in the general *(systemic)* circulation, because the total cross-sectional area of the vessels in the pulmonary circulation is less than that in the systemic circulation. Note that velocity and pressure should not be confused. It is possible to have a low pressure with a high velocity, as for example in the veins.

Figure 3.6: *Relationship between blood pressure, velocity and total cross sectional area of blood vessels*



GLOSSARY

Following are brief explanations of some of the important concepts and terms found in this book.

Abdomen
That part of the body containing the "viscera", ie the kidneys, liver, stomach, and intestines; separated from the thorax by the diaphragm.

Acetylcholine
A chemical *(neurohormone)* released from pre-synaptic nerve endings, which diffuses across the synapse and stimulates the initiation of an impulse in the post-synaptic membrane. Is rapidly broken down by the enzyme cholinesterase.

Acid
A chemical which dissociates *("splits up")* in solution to give hydrogen ions *(H^+)*. Have a pH less than 7. Neutralised by alkalis *(bases)*.

$$\underset{\text{Lactic acid}}{CH_3CHOHCOOH} \longrightarrow \underset{\text{Lactate ion}}{CH_3CHOHCOO^-} + \underset{\text{Hydrogen ion}}{H^+}$$

Adenosine Triphosphate (ATP)
A compound formed from ADP + P with energy released from Phosphocreatine *(PC)* and/or the breakdown *(oxidation -either aerobic or anaerobic)* of energy rich substrates e.g. glucose. Stored in all cells, especially muscle fibres. When it is broken down by enzyme action back into ADP + P the stored energy is made available for chemical or mechanical work. All the body's energy use is via ATP, which is continually broken down and resynthesised *(average daily turn-over = body weight)*.

Adipose tissue
Special tissue within which fat is stored. Found mainly under the skin *(sub-cutaneous)* and around the major organs.

Adolescence
The period in which a second growth spurt occurs and sexual maturity is achieved.

Adrenal glands
Literally "on top of the kidneys". Composed of two distinct regions, an outer cortex, and an inner medulla. The cortex secretes adrenal cortical hormones, e.g. sex hormones, aldosterone, cortisol; the medulla secretes adrenaline and noradrenaline, and is closely linked to the sympathetic nervous system.

Adrenaline
A hormone *(chemical transmitter substance)* released from the medulla of the adrenal glands and from sympathetic nerve endings, which prepares the body for "fight or flight" as a result of a "fright".

Aerobic Exercise
Exercise during which the energy needed is supplied by aerobic respiration *(oxidation)* of energy rich substrates e.g. glucose, using the oxygen that is breathed in *(fats can only be broken down aerobically)*. Such exercise can be continued for long periods.

Affinity
Attraction to, 'liking' for; e.g. haemoglobin has an affinity for oxygen, with which it forms oxyhaemoglobin.

Alactacid *(alactate)* Oxygen Debt
(alactic recovery oxygen consumption)
The oxygen necessary after exercise to replenish the ATP-PC energy stores, and to resaturate the myoglobin and tissue fluids with oxygen.

Alkali *(or base)*
A chemical which accepts hydrogen ions, thus neutralising acids. Have a pH greater than 7.

Amino Acids
Organic acids containing nitrogen. Proteins are made up of long chains of amino acids joined by peptide bonds. The body must be supplied with amino acids in the diet. There are 20 different types of amino acids in proteins of living origin. 'Non-essential' amino acids are necessary for body function but can be produced in the body by interconversions of other amino acids; about 11 so called 'essential' amino acids are not produced

INDEX

A

B

C