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心血管生理学

Cardiovascular Physiology

EIGHTH EDITION

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Cardiovascular Physiology

Eighth Edition

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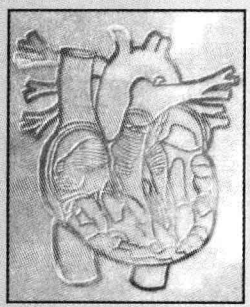
The Mosby Physiology Monograph Series

Each book in this series presents normal physiology and selectively includes pathophysiology, with clinical examples highlighted in boxes/tables throughout. Chapters are summarized with key points; key words and concepts are listed; and each book contains a set of self-study questions. Two-color diagrams throughout the books illustrate basic concepts.



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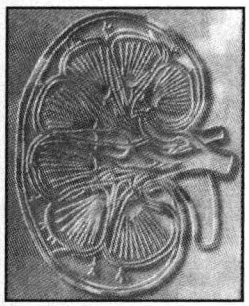

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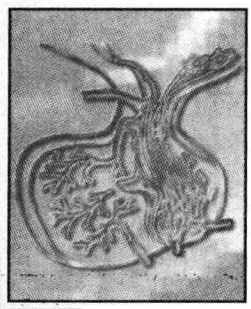

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To our Grandchildren
Alex, Ari, Christopher, Daniel, Kyle, Madelyn,
Maggie, Molly, Nicolas, Sarah, Todd, and Tracy

Preface

This book is designed for medical students, graduate students, and cardiovascular fellows. Throughout the book we have incorporated the most recent information and have indicated which subjects are still controversial. Emphasis is placed on general concepts and control mechanisms with omission of extraneous isolated facts. To present a clear view of the various regulatory mechanisms, the component parts of the system are first discussed individually. Then, to show how the entire cardiovascular system operates in an intact subject, the last chapter describes how various individual components are coordinated. As examples we describe how the body responds to two important stresses—exercise and hemorrhage.

Normal physiology serves as a frame of reference that students of medicine must comprehend before they can understand the derangements caused by disease or toxic agents. Pathophysiology is considered very selectively in this text. Many examples of abnormal function are included to illustrate and clarify normal physiological processes. These clinical examples are scattered throughout the text and are emphasized by colored boxes.

The book has been updated and revised extensively. Some old figures have been deleted and some new figures have been added to facilitate comprehension of the textual material. Carefully selected references appear at the end of each chapter. Review articles were preferred over scientific papers, and the scientific articles we included were chosen for their depth, clarity, timeliness, appropriateness, and bibliographies.

Throughout the book, *italics* are used to emphasize important facts and concepts, and **boldface type** is used for new terms and definitions. Each chapter includes a list of objectives at the beginning and a summary at the end to highlight key points. To help in review and to indicate clinical relevance of the material, case histories with multiple-choice questions are provided. Answers and a brief explanation appear at the end of the book.

We wish to thank our readers for their constructive comments in the past, and we hope that they will continue to provide the input necessary for us to improve future editions. We also wish to thank the numerous investigators and publishers who have granted us permission to use illustrations from their publications. In most cases these illustrations have been altered somewhat to increase their didactic utility. In some cases, unpublished data from our own investigations have been presented.

Robert M. Berne
Matthew N. Levy

Cardiovascular Physiology

Contents

CHAPTER 1

The Circuitry

Objectives

1. Indicate the compositions and functions of the blood vessels.
2. Indicate the relationship of vascular cross-sectional area to the velocity of blood flow in the various vascular segments.
3. Indicate the pressure changes and pathways of blood flow throughout the vasculature.

THE CIRCULATORY, ENDOCRINE, AND nervous systems constitute the principal coordinating and integrating systems of the body. Whereas the nervous system is primarily concerned with communications and the endocrine glands with regulation of certain body functions, the circulatory system serves to transport and distribute essential substances to the tissues and to remove by-products of metabolism. The circulatory system also shares in such homeostatic mechanisms as regulation of body temperature, humoral communication throughout the body, and adjustments of oxygen and nutrient supply in different physiological states.

The cardiovascular system that accomplishes these chores is made up of a pump, a series of distributing and collecting tubes, and an extensive system of thin vessels that permit rapid exchange between the tissues and the vascular channels. The primary purpose of this text is to discuss the function of the components of the vascular system and the control mechanisms (with their checks and balances) that are responsible for alteration of blood distribution necessary to meet the changing requirements of different tissues in response to a wide spectrum of physiological and pathological conditions.

Before considering the function of the parts of the circulatory system in detail, it is useful to consider it as a whole in a purely descriptive sense. The heart consists of two pumps in series: the right ventricle to propel blood through the lungs for exchange of oxygen and carbon dioxide **(the pulmonary circulation)** and the left ventricle to propel blood to all other tissues of the body **(the systemic circulation).** Unidi-

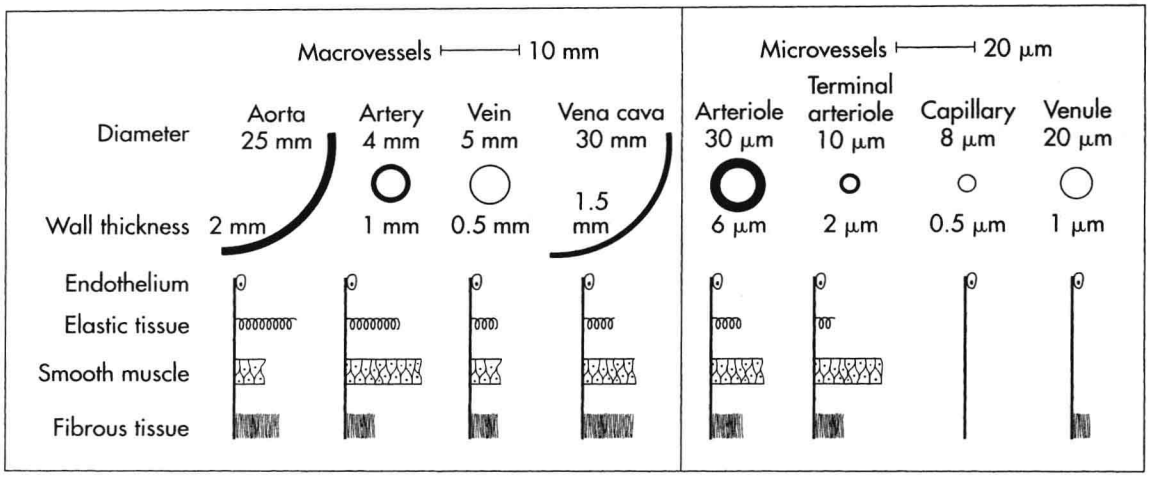

Figure 1-1 ■ Internal diameter, wall thickness, and relative amounts of the principal components of the vessel walls of the various blood vessels that compose the circulatory system. Cross sections of the vessels are not drawn to scale because of the huge range from aorta and venae cavae to capillary. (Redrawn from Burton AC: *Physiol Rev* 34:619, 1954.)

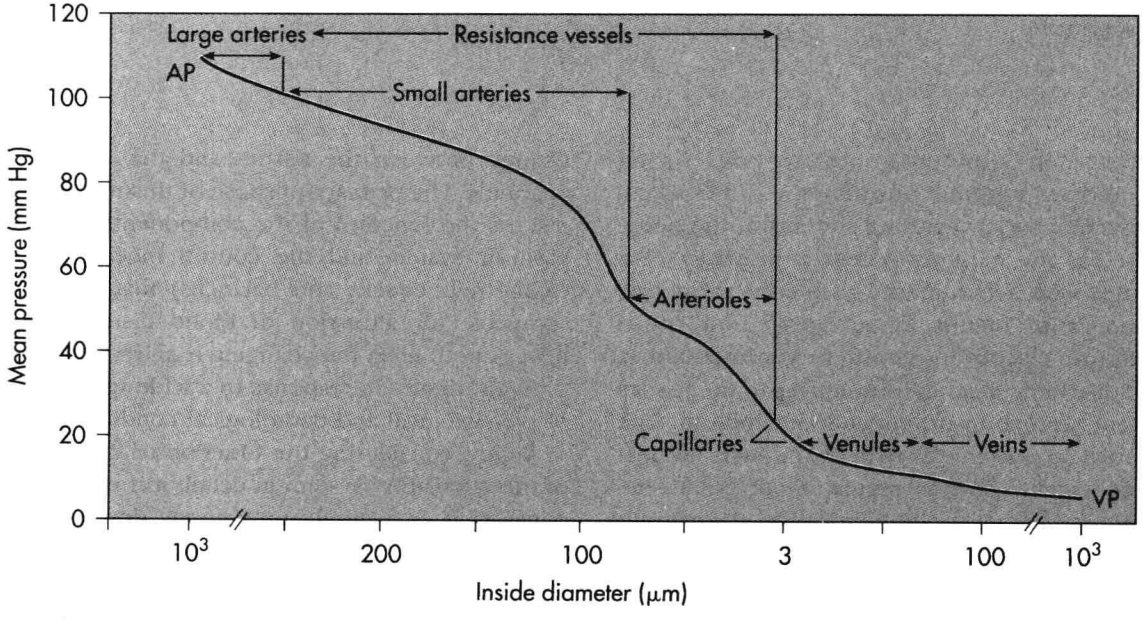

Figure 1-2 ■ Pressure drop across the vascular system in the hamster cheek pouch. *AP*, Mean arterial pressure; *VP*, venous pressure. (Redrawn from Davis MJ, et al: *Am J Physiol* 250:H291, 1986.)

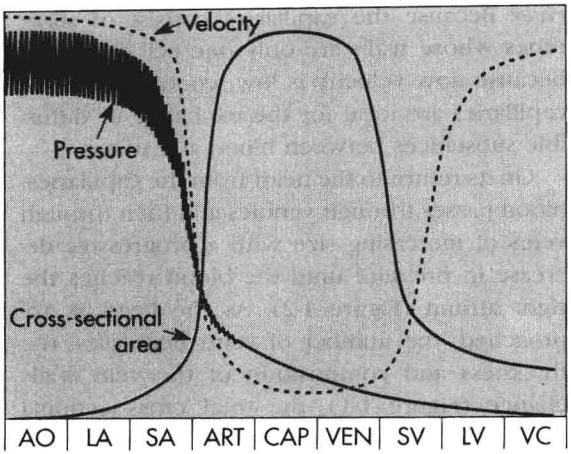

Figure 1-3 ■ Phasic pressure, velocity of flow, and cross-sectional area of the systemic circulation. ***The important features are the inverse relationship between velocity and cross-sectional area, the major pressure drop across the small arteries and arterioles, and the maximal cross-sectional area and minimal flow rate in the capillaries. AO,*** **Aorta;** ***LA,*** **large arteries;** ***SA,*** **small arteries;** ***ART,*** **arterioles;** ***CAP,*** **capillaries;** ***VEN,*** **venules;** ***SV,*** **small veins;** ***LV,*** **large veins;** ***VC,*** **venae cavae.**

rectional flow through the heart is achieved by the appropriate arrangement of effective flap valves. Although the cardiac output is intermittent, continuous flow to the periphery occurs by distension of the aorta and its branches during ventricular contraction **(systole)** and elastic recoil of the walls of the large arteries with forward propulsion of the blood during ventricular relaxation **(diastole).** Blood moves rapidly through the aorta and its arterial branches. The branches become narrower and their walls become thinner and change histologically toward the periphery. From the aorta, a predominantly elastic structure, the peripheral arteries become more muscular until the muscular layer predominates at the arterioles (Figure 1-1).

In the large arteries, frictional resistance is relatively small, and pressures are only slightly less than in the aorta. However, the small arteries offer moderate resistance to blood flow, and this resistance reaches a maximal level in the arterioles, sometimes referred to as the stopcocks of the vascular system. Hence *the pressure drop is significant in the small arteries and is greatest in the arterioles* (Figure 1-2). Adjustment in the degree of contraction of the circular muscle of these small vessels permits regulation of tissue blood flow and aids in the control of arterial blood pressure.

In addition to a sharp reduction in pressure across the arterioles, there is also a change from pulsatile to steady flow as pressure continues to decline from the arterial to the venous end of the capillaries (Figure 1-3). *The* ***pulsatile arterial blood flow,*** *caused by the intermittency of cardiac ejection, is damped at the capillary level by the combination of distensibility of the large arteries and frictional resistance in the arterioles.*

BOX 1-1

In a patient with hyperthyroidism **(Graves disease),** the basal metabolism is elevated and is often associated with arteriolar vasodilation. This reduction in arteriolar resistance diminishes the dampening effect on the pulsatile arterial pressure and is manifest as pulsatile flow in the capillaries, as observed in the finger nail bed of patients with this ailment.

Many capillaries arise from each arteriole so that the *total cross-sectional area of the capillary bed is very large, despite the fact that the cross-sectional area of each capillary is less than that of each arteriole. As a result, blood flow velocity becomes quite slow in the capillaries (Figure 1-3), analogous to the decrease in velocity of flow seen at the wide regions of a*