

Contents

Foreword by William R. Milnor	v
Preface	vii
Acknowledgments from First Edition	xi
1 Introduction	1
The development of haemodynamics as a science—2—Historical landmarks in the development of haemodynamics—4—Work on arterial elasticity and wave-velocity—8	
2 Steady flow of a liquid in cylindrical tubes	17
Laminar flow in viscous liquids—18—Applicability of Poiseuille's equation to the circulation—27—Turbulent flow—30—Bernoulli's Theorem—35—The effect of change in the size of the vascular bed—37—The measurement of peripheral resistance—41—The dimensions of the arterial tree—46	
3 The viscous properties of blood	55
The definition of variable viscosity—56—The viscosity of plasma—50—The viscous behaviour of blood—61—Effects of lower shear rate—62—Effects of tube size at higher shear rates—64—The cause of the reduced apparent viscosity—65—The causes of a cell-free zone at the wall—66—Blood viscosity in oscillatory flow—69	
4 Turbulence and disturbed flow patterns in the circulation	71
Stability of pulsatile flow—74—Reynolds number in the circulation—82—Mixing of blood—84—Curves in a tube—90—Flow at junctions—92—Valves. The effect of projections—95—The aorta and large arteries—98	
5 The velocity profile in pulsatile flow	101
The inlet length—108—Experimental measurements of the velocity profile—113	

- 6 The relation between pulsatile pressure and flow** 118
 The relation of flow to an oscillatory pressure gradient—123—
 The calculation of flow from the pressure-gradient—126—The
 effect of the size of the artery on the flow pattern—129—The
 values of α found in the circulation—131—The relation of the
 pressure-gradient to the time-derivative of the pressure—133—
 The validity of the Womersley equations when applied to arteries
 —137—Fry's solution for pressure-flow relations in the aorta
 —139
- 7 The numerical analysis of circulatory wave-forms** 146
 Procedures for calculating a flow curve—154—Calculation of
 the flow components—155—Requirements and limitations of
 a Fourier analysis—161—The significant harmonic terms in the
 flow and pulse waves—162—The validity of Fourier analysis in
 the circulation—164—Power spectrum—166—Linearity—169—
 Errors in resynthesis—172
- 8 The design of manometers** 174
 The theory of manometer behaviour—174—The practical
 problems of manometer design—182—Types of manometer in
 use—185—Amplifiers and recorders—192—The performance of
 strain-gauge manometers—194—The calibration of manometers
 —195—Artifacts in pressure recording—203
- 9 Flowmeters for pulsatile flow** 209
 The electromagnetic flowmeter—209—Performance character-
 istics—213—Ultrasonic flowmeters—217—Thermal methods—
 222—Intravascular flowmeters—224—Bernoulli meters—231—
 The hydrodynamic pendulum of Castelli. 'Bristle' flowmeters
 —235—High-speed cinematography—236—Calculation of
 phasic flow from the pressure-gradient—236
- 10 The elastic properties of the arterial wall** 238
 The physical constants of an elastic body—239—The behaviour
 of an elastic tube under a distending pressure—244—Dynamic
 behaviour of elastic materials—247—Velocity of propagation
 in an elastic tube—253—Other modes of wave-propagation—255
 —Experimental investigations—256—The structure of the arterial
 wall—262—Elastic properties of the components—263—The
 composition of the arterial wall—264—Measurement of the
 elastic parameters of the arterial wall—266—Longitudinal
 movements of the wall. The longitudinal elastic modulus—274—

- Anisotropy of the wall—276—The role of smooth muscle in the
 arterial wall—277
- 11 Pulsatile flow in an elastic tube** 283
 Movements of the wall—286—The pressure-flow relationships
 in the free elastic tube—288—The characteristics of the pro-
 pagated wave—291—Non-linearity in the equations—296—
 The effects of external restraint. The tethered and loaded tube—
 299—Wave-velocity and attenuation in the visco-elastic tube—
 302—The wave-velocity in the visco-elastic tube—306—The
 frequency dependence of wave-velocity and attenuation in arteries
 —307
- 12 Wave reflection** 309
 Reflection of a transient pulse—310—Reflected waves in a
 steady-state oscillation—313—Reflections in a transmission
 line—315—The reflection at a single arterial junction—322—
 Reflections due to a continuous change in elastic properties—326
 —The analysis of wave-reflection in the living animal—328—
 The changes in amplitude of the harmonic components of the
 pulse-wave—338—The role of elastic non-uniformity in the
 presence of damping—341—The distribution of pressures
 throughout the systemic arteries—345—Secondary reflection of
 the reflected waves at the heart—346
- 13 Arterial Impedance** 351
 Variation in the modulus and phase of the input impedance—
 353—Relations of pressure and flow waves in various parts of
 the arterial tree—355—The input impedance of the femoral
 artery—359—The input impedance in the proximal aorta—365
 —Interpretation of the aortic impedance pattern—373—The
 input impedance of the pulmonary artery—380—The input
 impedance and its relation to the work load and external power
 output of the heart—384
- 14 Wave-velocity and attenuation** 389
 The use of transient excitation to measure wave-velocity—400—
 The relationship of flow velocity to pressure wave-velocity—404
 —Axial and torsional wave-velocity—408—Wave-attenuation
 in arteries—409—The nature of the viscous component of the
 visco-elastic wall—414

15 Methods of monitoring cardiac output in man	420
The assessment of accuracy of methods used—421—Pulse contour or Windkessel models—423—Use of the 'water-hammer' formula—426—Pressure-gradient method—432	
Appendix 1. The theoretical analysis of manometer behaviour	446
Table A and Table B	452, 453
Appendix 2. The high-speed cinematograph technique for measuring blood flow velocity	454
References	459
Index	489