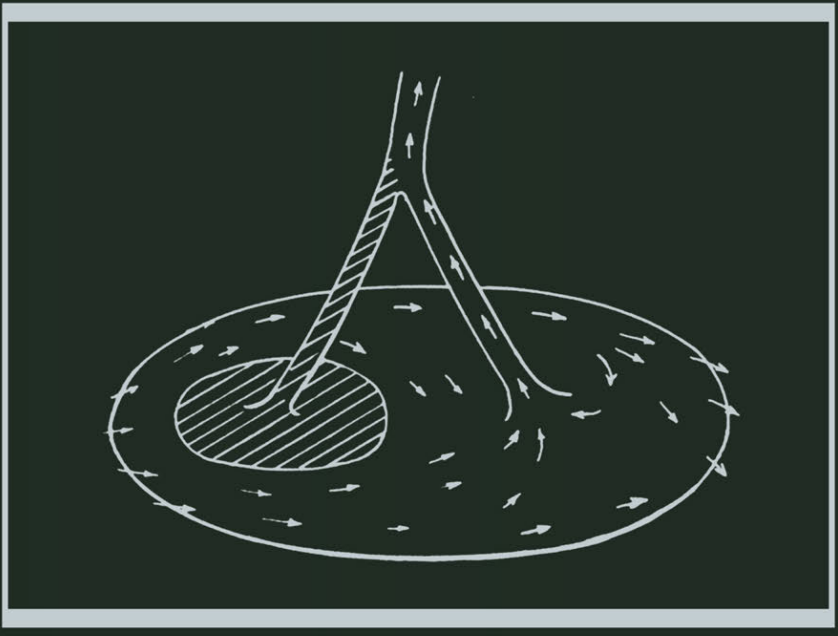
Y.C.Fung

Biodynamics

Circulation



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Preface

This book is a continuation of my *Biomechanics*. The first volume deals with the mechanical properties of living tissues. The present volume deals with the mechanics of circulation. A third volume will deal with respiration, fluid balance, locomotion, growth, and strength. This volume is called *Biodynamics* in order to distinguish it from the first volume. The same style is followed. My objective is to present the mechanical aspects of physiology in precise terms of mechanics so that the subject can become as lucid as physics.

The motivation of writing this series of books is, as I have said in the preface to the first volume, to bring biomechanics to students of bioengineering, physiology, medicine, and mechanics. I have long felt a need for a set of books that will inform the students of the physiological and medical applications of biomechanics, and at the same time develop their training in mechanics. In writing these books I have assumed that the reader already has some basic training in mechanics, to a level about equivalent to the first seven chapters of my *First Course in Continuum Mechanics* (Prentice Hall, 1977). The subject is then presented from the point of view of life science while mechanics is developed through a sequence of problems and examples. The main text reads like physiology, while the exercises are planned like a mechanics textbook. The instructor may fill a dual role: teaching an essential branch of life science, and gradually developing the student's knowledge in mechanics.

The style of one's scientific approach is decided by the way one looks at a problem. In this book I try to emphasize the mathematical threads in the study of each physical problem. Experimental exploration, data collection, model experiments, in vivo observations, and theoretical ideas can be wrapped together by mathematical threads. The way problems are formulated, the kind of questions that are asked, are molded by this basic thought.

Much of the book can be read, however, with little mathematics. Those passages in which mathematics is essential are presented with sufficient details to make the reading easy.

This book begins with a discussion of the physics of blood flow. This is followed by the mechanics of the heart, arteries, veins, microcirculation, and pulmonary blood flow. The coupling of fluids and solids in these organs is the central feature. How morphology and rheology are brought to bear on the analysis of blood flow in organs is illustrated in every occasion. The basic equations of fluid and solid mechanics are presented in the Appendix. The subject of mass transfer, the exchange of water, oxygen, carbon dioxide, and other substances between blood and red cells and between capillary blood vessels and extravascular space, is deferred to the third volume, *Biodynamics: Flow, Motion, and Stress*, in order to keep the three volumes at approximately the same size.

Circulation is a many-sided subject. What we offer here is an understanding of the mechanics of circulation. We present methods and basic equations very carefully. The strengths and weaknesses of various methods and unanswered questions are discussed fully. To apply these methods to a specific organ, we need a data base. We must have a complete set of morphometric data on the anatomy, and rheological data on the materials of the organ. Unfortunately, such a data base does not exist for any organ of any animal. A reasonably complete set has been obtained for the lungs of the cat. Hence the analysis of the blood flow in the lung is presented in detail in Chapter 6. We hope that a systematic collection of the anatomical and rheological data on all organs of man and animals will be done in the near future so that organ physiology can be elevated to a higher level.

Blood circulation has a vast literature. The material presented here is necessarily limited in scope. Furthermore, there are still more things unknown than known. Progress is very rapid. Aiming at greater permanency, I have limited my scope to a few fundamental aspects of biomechanics. For handbook information and literature survey, the reader must look elsewhere. Many exercises are proposed to encourage the students to formulate and solve new problems. The book is not offered as a collection of solved problems, but as a way of thinking about problems. I wish to illustrate the use of mechanics as a simple, reliable tool in life science, and no more. A reasonably extensive bibliography is given at the end of each chapter, some with annotations from which further references can be found. Perhaps the author can be accused of quoting frequently papers and people familiar to him; he apologizes for this personal limitation and hopes that he can be forgiven because it is only natural that an author should talk about his own views. I have tried, however, never to forget mentioning the existence of other points of view.

I wish to express my thanks to many authors and publishers who permitted me to quote their publications and reproduce their figures and data in this book. I wish to mention especially Drs. Michael Yen, Sidney Sobin, Jen-Shih

Lee Benjamin Zweifach, Paul Patitucci, Geert Schmid-Schoenbein, William Conrad, Lawrence Talbot, H. Werlé, John Maloney, Paul Stein, and John Hardy who supplied original photographs for reproduction. I wish also to thank many of my colleagues, friends, and former students who read parts of the manuscripts and offered valuable suggestions. To Virginia Stephens I am grateful for typing the manuscript. Finally, I wish to thank the editorial and production staff of Springer-Verlag for their care and cooperation in producing this book.

In spite of great care and effort on my part, I am sure that many mistakes and defects remain in the book. I hope you will bring these to my attention so that I can improve in the future.

La Jolla, California YUAN-CHENG FUNG