BLOOD FLOW
THEORY AND PRACTICE

Edited by

D. E. M. Taylor A. L. Stevens

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Royal College of Surgeons, London

A. L. Stevens
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PREFACE

In 1980, the Biological Engineering Society held an International Conference on "Blood Flow—Theory and Practice" in London. It became apparent during the meeting that there were certain areas where advances were being made of major importance, which were of great interest in the study of the dynamics of the peripheral circulation in health and disease.

Rather than embark on the more traditional production of Proceedings of the conference it was decided that it would be of more use to select from key areas and to produce a book, which although suggested by the Conference, was more selective. In addition, all contributions were updated and, where considered desirable by the authors, expanded by the addition of new material. Chapters not directly suggested by the papers at the Conference were also commissioned.

The objective has been to produce a co-ordinated series of contributions from leading authorities which will form an up to date review of areas of active growth in the study of the haemodynamics of the peripheral circulation and the investigation of peripheral circulatory disease. As such, it should appeal to the basic scientist, the clinician and the scientific officer with an interest in both normal and abnormal haemodynamics.

September 1982 D. E. M. Taylor

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Section 1

DISTURBANCES OF FLOW

1. INTRODUCTION

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I. INTRODUCTION

Many of the methods used to investigate flow in blood vessels, whether invasive or non-invasive, make assumptions of axisymmetry and of predominantly stable flow patterns. Similar constraints apply to the use of methods such as Fourier or Laplace transformation in evaluating the state of the vascular system. A proper appreciation of both the scope and the limitations of current methods of investigation of haemodynamics in vascular disease requires a knowledge of the type, duration and propogation of the flow disturbances produced. There is already an extensive fluid dynamic literature including mathematical analysis, of the effects of either change of calibre, or projections into the flowfield, for steady state flow in rigid cylindrical tubes. Much less is known of these effects in visco-elastic tubes subjected to pulsatile flow.

In this section, four chapters outline efforts made to elucidate some of the problems. The two principal questions which it has been attempted to answer are:

(1) How far beyond a discontinuity is turbulence propogated?
(2) How may the turbulent and the underlying steady components in a flow wave form be separated and quantitated clinically.

II. PROPAGATION OF TURBULENCE

The question of initiation and of the temporal and spatial propagation of turbulence is dealt with from model studies by Buss (Chapter 2) and Clark (Chapter 3), while experimental animal studies are reported by Thiele and his colleagues (Chapter 5). A most important finding is that of conditional turbulence, in which although laminar flow no longer exists, eddy or vorticeal systems formed are relatively stable and to some extent predictable. It appears that the length of propagation relative to the dimensions of the tube and of the stenosis may be linear within the biological range (Clark: Chapter 3), and this will be of importance in evaluating the extent of, say, a common iliac stenosis from a femoral artery Doppler flow wave form. However, stroke volume also appears to play a role in the extent of propagation.

The extent and propagation of flow disturbance also appears to be related to the configuration and length of the stenosis, as well as to the area reduction ratio (Buss, Chapter 2; Thiele *et al.*, Chapter 5), but relatively independent of whether or not the flow narrowing is axisymmetric.

These studies have given new information in this important area, but they have probably provided more questions than answers. Clinically we are still trying to evaluate the flow effects of arterial stenosis on the basis of mainly descriptive criteria based on previous experience, rather than on quantitative methods based firmly on a physical and mathematical analysis of the system.

III. CLINICAL EVALUATION OF TURBULENCE

Kitney *et al.* (Chapter 4) and Thiele and his colleagues (Chapter 5) deal with the problem of evaluating flow disturbances from the analysis of flow wave forms. From the theoretical point of view this should be a simple problem, one merely regards the signal as a function having two components, a real function which is consistent and represents the underlying stable flow, and a noise function which is inconsistent and represents turbulence. That is

$$\phi(xt) = \phi\mathrm{R}(x.t) + \phi\mathrm{N}(x.t)$$

where $\phi(xt)$ = wave form observed, $\phi R(xt)$ = stable component, $\phi N(xt)$ = turbulent component.

Several theoretical methods exist to evaluate the two component functions from a times series of individual cycles. In practice evaluation is no such simple problem. Kitney *et al.* give an excellent account in Chapter 4 of some of the problems and suggested solutions for analysing the flow disturbance components of Doppler flow signals. While the former represents an inductive approach, Thiele and his colleagues use deductive