Basic Physiology for Anaesthetists

Second Edition

Dr David Chambers is a Consultant Neuroanaesthetist at Salford Royal NHS Foundation Trust, Salford, UK. His interests include anaesthesia for awake craniotomy, total intravenous anaesthesia and postgraduate anaesthetic training. He co-organises the North West Final FRCA exam practice course.

Dr Christopher Huang is Professor of Cell Physiology at Cambridge University. His research interests have covered signalling processes in skeletal myocytes and osteoclasts, cellular electrolyte homeostasis, cerebral cortical spreading depression and cardiac arrhythmogenesis. He was editor of the *Journal of Physiology, Monographs of the Physiological Society* and *Biological Reviews*.

Dr Gareth Matthews is a National Institute of Health Research Academic Clinical Fellow in Cardiology at Cambridge University Hospitals NHS Foundation Trust. He is also a Fellow in Medicine at Murray Edwards College, University of Cambridge, where he supervises undergraduate physiology. His research interest is the pathophysiology of cardiac arrhythmia.

Basic Physiology for Anaesthetists

Second Edition

David Chambers
Salford Royal NHS Foundation Trust

Christopher Huang
University of Cambridge

Gareth Matthews
University of Cambridge

CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre,
New Delhi – 110025, India

79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781108463997
DOI: 10.1017/9781108565011

First published 2015
Second edition 2019

Printed in the United Kingdom by TJ International Ltd. Padstow Cornwall.

A catalogue record for this publication is available from the British Library.

Library of Congress Cataloging-in-Publication Data
Names: Chambers, David, 1979- author. | Huang, Christopher, 1951- author. | Matthews, Gareth, 1987- author.
Title: Basic physiology for anaesthetists / David Chambers, Christopher Huang, Gareth Matthews.
Description: Second edition. | Cambridge, United Kingdom ; New York, NY : Cambridge University Press, 2019. | Includes bibliographical references and index.
Identifiers: LCCN 2019009280 | ISBN 9781108463997 (pbk. : alk. paper)
Subjects: | MESH: Physiological Phenomena | Anesthesiology–methods
Classification: LCC RD82 | NLM QT 104 | DDC 617.9/6–dc23
LC record available at https://lccn.loc.gov/2019009280

ISBN 978-1-108-46399-7 Paperback

DC:
To Sally, for not vetoing this second edition.

CH:
To friends and teachers: Charles Michel, Morrin Acheson, Richard Adrian, Sir David Weatherall and John Ledingham. *In memoriam absentium, in salutem praesentium.*

GM:
To my wife, Claire, and our beautiful baby daughter, Eleanor. I also remain indebted to Professor Christopher Huang for fostering my original interest in physiology, as well as supporting me throughout my career.

Contents

Section 4 Neurophysiology

Section 5 Gastrointestinal Tract

Section 6 Kidney and Body Fluids

Section 7 Blood and Immune System

Section 8 Energy Balance

Section 9 Endocrine Physiology

Section 10 Developmental Physiology

Section 11 Environmental Physiology

Foreword

This second edition of *Basic Physiology for Anaesthetists* has carried forward the style, depth and content that made the first edition such a great success. It covers all aspects of human physiology that are essential for the art and science that is modern anaesthesia. Patients need to be reassured that their anaesthetists are well informed of the workings of the human body in health as well as disease.

The authors are both expert physiology scientists and clinicians – this combination is clearly seen in the book's structure. Each chapter explains the physiology and is followed by the clinical applications relevant to the speciality. The illustrations are simple line drawings that are easy to follow and, importantly for trainee anaesthetists, easy to recall or even reproduce in the exam setting. Not only should this book be essential reading for those new to the speciality or those preparing for exams, but established specialists and consultants should have access to a copy to give structure to their teaching, as well as to rekindle fading knowledge. Those sitting anaesthesia exams can be confident that many of those responsible for testing their knowledge will themselves have consulted this book!

Dr Russell Perkins FRCA
Consultant Anaesthetist, Royal Manchester Children's Hospital
Member of Council and Final FRCA Examiner, Royal College of Anaesthetists

Preface to the Second Edition

'Why are you writing a second edition? Surely nothing in classical physiology ever changes?' One of us (DC) has been asked these questions several times. It is true that many of the fundamental physiological concepts described in this second edition of *Basic Physiology for Anaesthetists* remain the same. What does change, however, is how we apply that physiological knowledge clinically. In the four years since we wrote the first edition of this book, high-flow nasal oxygen therapy has revolutionised airway management, cancer surgery has become the predominant indication for total intravenous anaesthesia and new classes of oral anticoagulants have emerged, to name but a few developments. All of these changes in daily anaesthetic practice are underpinned by a thorough understanding of basic physiology.

To that end, in addition to thoroughly revising and updating each chapter, we have added six new chapters, including those on the physiology of the eye and upper airway and on exercise testing. We have also sought to include more pathophysiology, such as cardiac ischaemia and physiological changes in obesity. We have tried to remain true to the principles with which we wrote the first edition, keeping the concepts as simple as possible whilst remaining truthful and illustrating each chapter with points of clinical relevance and easily reproducible line diagrams. In response to positive feedback, the question-and-answer style remains to best help readers prepare for postgraduate oral examinations.

Preface to the First Edition

An academically sound knowledge of both normal and abnormal physiology is essential for day-to-day anaesthetic practice, and consequently for postgraduate specialist examinations.

This project was initiated by one of us (DC) following his recent experience of the United Kingdom Fellowship of the Royal College of Anaesthetists examinations. He experienced difficulty locating textbooks that would build upon a basic undergraduate understanding of physiology. Many of the anaesthesia-related physiology books he encountered assumed too much prior knowledge and seemed unrelated to everyday anaesthetic practice.

He was joined by a Professor in Physiology (CH) and a Translational Medicine and Therapeutics Research Fellow (GM) at Cambridge University, both actively engaged in teaching undergraduate and postgraduate physiology and in physiological research.

This book has been written primarily for anaesthetists in the early years of their training, and specifically for those facing postgraduate examinations. In addition, the account should provide a useful summary of physiology for critical care trainees, senior anaesthetists engaged in education and training, physician assistants in anaesthesia, operating department practitioners and anaesthetic nurses.

We believe the strength of this book lies in our mixed clinical and scientific backgrounds, through which we have produced a readable and up-to-date account of basic physiology and provided links to anaesthetic and critical care practice. We hope to bridge the gap between the elementary physiology learnt at medical school and advanced anaesthesia-related texts. By presenting the material in a question-and-answer format, we have aimed to emphasize strategic points and give the reader a glimpse of how each topic might be assessed in an oral postgraduate examination. Our numerous illustrations seek to simplify and clearly demonstrate key points in a manner that is easy to replicate in an examination setting.

Abbreviations

ACA	anterior cerebral artery
ACE	angiotensin-converting enzyme
ACh	acetylcholine
AChE	acetylcholinesterase
ACI	anterior circulation infarct
AChR	acetylcholine receptor
ACom	anterior communicating artery
ADH	antidiuretic hormone
ADP	adenosine diphosphate
AF	atrial fibrillation
AGE	alveolar gas equation
AMP	adenosine monophosphate
ANP	atrial natriuretic peptide
ANS	autonomic nervous system
APTT	activated partial thromboplastin time
ARDS	acute respiratory distress syndrome
ARP	absolute refractory period
ATP	adenosine triphosphate
AV	atrioventricular
BBB	blood–brain barrier
BMR	basal metabolic rate
BNP	brain natriuretic peptide
BSA	body surface area
CA	carbonic anhydrase
C_aO_2	arterial oxygen content
CBF	cerebral blood flow
CC	closing capacity
CCK	cholecystokinin
CI	cardiac index
CMR	cerebral metabolic rate
CNS	central nervous system
CO	cardiac output
CoA	coenzyme A
COHb	carboxyhaemoglobin
COPD	chronic obstructive pulmonary disease
CPET	cardiopulmonary exercise test
CPP	cerebral perfusion pressure
CRPS	complex regional pain syndrome
CSF	cerebrospinal fluid
C_vO_2	venous oxygen content
CVP	central venous pressure
CVR	cerebral vascular resistance
DASI	Duke activity status index
DBP	diastolic blood pressure
DCML	dorsal column-medial lemniscal
DCT	distal convoluted tubule
DHPR	dihydropyridine receptor
DNA	deoxyribonucleic acid
DOAC	direct-acting oral anticoagulant
DRG	Dorsal respiratory group
ECF	extracellular fluid
ECG	electrocardiogram
EDPVR	end-diastolic pressure-volume relationship
EDV	end-diastolic volume
EEG	electroencephalogram
EF	ejection fraction
EPO	erythropoietin
ER	endoplasmic reticulum
ESPVR	end-systolic pressure-volume relationship
ESV	end-systolic volume
ETT	endotracheal tube
FAD	flavin adenine dinucleotide
FEV_1	forced expiratory volume in 1 s
F_iO_2	fraction of inspired oxygen
FRC	functional residual capacity
FTc	flow time corrected
FVC	forced vital capacity
GABA	γ-amino butyric acid
GBS	Guillain–Barré syndrome
GCS	Glasgow coma scale
GFR	glomerular filtration rate
GI	gastrointestinal
Hb	haemoglobin
HbA	adult haemoglobin
HbF	foetal haemoglobin
HCN	hyperpolarisation-activated cyclic nucleotide gated
HFNO	High-flow nasal oxygen
HPV	hypoxic pulmonary vasoconstriction
HR	heart rate
ICA	internal carotid artery
ICF	intracellular fluid
ICP	intracranial pressure
IRI	ischaemic reperfusion injury
IVC	inferior vena cava
LA	left atrium
LBBB	left bundle branch block
LMA	laryngeal mask airway
LOH	loop of Henle
LOS	lower oesophageal sphincter
LV	left ventricle
LVEDP	left ventricular end-diastolic pressure
LVEDV	left ventricular end-diastolic volume
LVESV	left ventricular end-systolic volume

LVF	left ventricular failure
MAC	minimum alveolar concentration
MAO	monoamine oxidase
MAP	mean arterial pressure
MCA	middle cerebral artery
MET	metabolic equivalent of a task
MetHb	methaemoglobin
MG	myasthenia gravis
MI	myocardial infarction
MPAP	mean pulmonary artery pressure
MW	molecular weight
N_2O	nitrous oxide
NSTEMI	non-ST elevation myocardial infarction
NAD^+	nicotinamide adenine dinucleotide
NMDA	*N*-methyl-D-aspartate
NMJ	neuromuscular junction
OER	oxygen extraction ratio
OSA	obstructive sleep apnoea
PAC	pulmonary artery catheter
P_aCO_2	arterial tension of carbon dioxide
P_aO_2	arterial tension of oxygen
P_B	barometric pressure
PCI	percutaneous coronary intervention
PCT	proximal convoluted tubule
PCA	posterior cerebral artery
PCom	posterior communicating artery
PCWP	pulmonary capillary wedge pressure
PE	pulmonary embolism
PEEP	positive end-expiratory pressure
$PEEP_e$	extrinsic positive end-expiratory pressure
$PEEP_i$	intrinsic positive end-expiratory pressure
PEFR	peak expiratory flow rate
PNS	peripheral nervous system
PPP	pentose phosphate pathway
PRV	polycythaemia rubra vera
PV	peak velocity
PVA	pressure-volume area
PT	prothrombin time
PTH	parathyroid hormone
PVR	pulmonary vascular resistance
RA	right atrium
RAA	renin–angiotensin–aldosterone
RAP	right atrial pressure
RBC	red blood cell
RBF	renal blood flow
RMP	resting membrane potential
RNA	ribonucleic acid
ROS	reactive oxygen species
RR	respiratory rate
RRP	relative refractory period
RSI	rapid sequence induction
RV	right ventricle
RVEDV	right ventricular end-diastolic volume
RVF	right ventricular failure
RyR	ryanodine receptor
SA	sinoatrial
S_aO_2	arterial haemoglobin oxygen saturation
SBP	systolic blood pressure
SD	stroke distance
SR	sarcoplasmic reticulum
SSEP	somatosensory evoked potential
STEMI	ST elevation myocardial infarction
SV	stroke volume
SVC	superior vena cava
SVI	stroke volume index
SVR	systemic vascular resistance
SVT	supraventricular tachycardia
SVV	stroke volume variation
TF	tissue factor
TIMI	thrombolysis in myocardial infarction
TLC	total lung capacity
TOE	trans-oesophageal echocardiography
$\dot{V}/\dot{Q}$	ventilation–perfusion
$\dot{V}_A$	alveolar ventilation
V_A	alveolar volume
VC	vital capacity
V_D	dead space volume
$\dot{V}_E$	minute ventilation
V_T	tidal volume
VF	ventricular fibrillation
VRG	ventral respiratory group
VT	ventricular tachycardia
VTI	velocity-time integral
vWF	von Willebrand factor