MEDICAL MICROBIOLOGY AND INFECTION

Lecture Notes

Tom Elliott
Anna Casey
Peter Lambert
Jonathan Sandoe

5th Edition

WILEY-BLACKWELL

with self-test

CLINICAL CASES UNCOVERED

Get the most from clinical practice, with *Clinical Cases Uncovered*

No other series is quite like *Clinical Cases Uncovered*, where you can rehearse for life in clinical practice with easy-to-use and well-instructed walk-through scenarios. Each case is presented as you would see it and the use of real-life experiences means the decisions and outcomes are factually based. Along the way to determining a diagnosis and identifying treatments, you learn about variable symptoms, danger signs and get overviews of all the common, classical and atypical presentations.

Background to the subject and how to approach the patient are covered in an introductory section and once you have worked through the range of cases you can test yourself with a selection of MCQs, EMQs and SAQs. This distinct blend of learning means you will improve time and again, greatly enhancing your decision-making skills. With such a wide range of subjects covered you will soon see the benefit of the CCU approach.

The series so far…

Acute Medicine: Clinical Cases Uncovered
978-1-4051-6883-0

Cardiology: Clinical Cases Uncovered
978-1-4051-7800-6

Endocrinology and Diabetes: Clinical Cases Uncovered
978-1-4051-5726-1

General Practice: Clinical Cases Uncovered
978-1-4051-6140-4

Haematology: Clinical Cases Uncovered
978-1-4051-8322-2

Hepatology: Clinical Cases Uncovered
978-1-4443-3246-9

Infectious Disease: Clinical Cases Uncovered
978-1-4051-6891-5

Nephrology: Clinical Cases Uncovered
978-1-4051-8990-3

Neurology: Clinical Cases Uncovered
978-1-4051-6220-3

Obstetrics and Gynaecology: Clinical Cases Uncovered
978-1-4051-8671-1

Paediatrics: Clinical Cases Uncovered
978-1-4051-5984-5

Psychiatry: Clinical Cases Uncovered
978-1-4051-5983-8

Radiology: Clinical Cases Uncovered
978-1-4051-8474-8

Respiratory Medicine: Clinical Cases Uncovered
978-1-4051-5895-4

Surgery: Clinical Cases Uncovered
978-1-4051-5898-5

Gastroenterology: Clinical Cases Uncovered
978-1-4051-6975-2

Medical Microbiology and Infection

Lecture Notes

Edited by

Tom Elliott BM BS BMedSci PhD DSc MRCP FRCPath
Consultant Medical Microbiologist
The Queen Elizabeth Hospital
University Hospitals Birmingham NHS Foundation Trust
Birmingham, UK

Anna Casey BSc PhD
Clinical Research Scientist
Department of Clinical Microbiology
The Queen Elizabeth Hospital
University Hospitals Birmingham NHS Foundation Trust
Birmingham, UK

Peter Lambert BSc PhD DSc
Professor of Microbiology
School of Life and Health Sciences
Aston University
Birmingham, UK

Jonathan Sandoe Mb ChB PhD FRCPath
Consultant Microbiologist and Honorary Senior Lecturer
Department of Microbiology
Leeds Teaching Hospitals NHS Trust and University of Leeds
Leeds, UK

Fifth Edition

WILEY-BLACKWELL
A John Wiley & Sons, Ltd., Publication

Blackwell Publishing was acquired by John Wiley & Sons in February 2007. Blackwell's publishing program has been merged with Wiley's global Scientific, Technical and Medical business to form Wiley-Blackwell.

Registered office: John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial offices:
9600 Garsington Road, Oxford, OX4 2DQ, UK
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK
111 River Street, Hoboken, NJ 07030-5774, USA

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com/wiley-blackwell.

First published (As Lecture Notes on Bacteriology) 1967
First Edition 1975
Second Edition 1978
Reprinted 1979, 1983, 1986
Third Edition 1997
International edition 1997
Reprinted 2003, 2004
Fourth Edition 2007
Fifth Edition 2011

Library of Congress Cataloging-in-Publication Data

Lecture notes. Medical microbiology and infection / Tom Elliott . . . [et al.]. – 5th ed.
p. ; cm.
Medical microbiology and infection
Includes bibliographical references and index.
ISBN-13: 978-1-4443-3465-4 (pbk. : alk. paper)
ISBN-10: 1-4443-3465-4 (pbk. : alk. paper) 1. Medical microbiology–Outlines, syllabi, etc. I. Elliott, Tom (Thomas Stuart Jackson) II. Title: Medical microbiology and infection.
[DNLM: 1. Microbiology. 2. Communicable Diseases–microbiology. QW 4]
QR46.G49 2011
616.9'041–dc22

2011012045

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

Set in 8.5pt/11pt Utopia font by Thomson Digital, Noida, India.

1 2011

Contents

Preface v
Contributors vii

Basic microbiology

1 Basic bacteriology, 3
Peter Lambert

2 Classification of bacteria, 12
Peter Lambert

3 Staphylococci, 16
Tom Elliott and Peter Lambert

4 Streptococci and enterococcci, 20
Anna Casey

5 Clostridia, 26
Tony Worthington

6 Other Gram-positive bacteria, 30
Anna Casey

7 Gram-negative cocci, 36
Jonathan Sandoe

8 Enterobacteriaceae, 40
Peter Lambert

9 *Haemophilus* and other fastidious Gram-negative bacteria, 45
Jonathan Sandoe

10 *Pseudomonas, Legionella* and other environmental Gram-negative bacilli, 51
Peter Lambert

11 *Campylobacter*, *Helicobacter* and *Vibrio*, 54
Martin Skirrow, Cliodna McNulty and Tom Elliott

12 *Treponema*, *Borrelia* and *Leptospira*, 58
Susan O'Connell

13 Gram-negative anaerobic bacteria, 62
Peter Lambert

14 Chlamydiaceae, *Rickettsia, Coxiella*, Mycoplasmataceae and Anaplasmataceae, 64
Jonathan Sandoe

15 Basic virology, 69
Peter Mackie

16 Major virus groups, 75
Peter Mackie

17 Basic mycology and classification of fungi, 93
Elizabeth Johnson

18 Parasitology: protozoa, 101
Peter Chiodini

19 Parasitology: helminths, 112
Peter Chiodini

Antimicrobial agents

20 Antibacterial agents, 127
Peter Lambert

21 Antifungal agents, 144
Elizabeth Johnson

22 Antiviral agents, 147
Eleni Nastouli

Infection

23 Diagnostic laboratory methods, 157
Tony Worthington

24 Epidemiology and prevention of infection, 167
Barry Cookson

25 Upper respiratory tract infections, 177
Jonathan Sandoe

26 Lower respiratory tract infections, 183
Shruti Khurana

27 Tuberculosis and mycobacteria, 189
Sumeet Singhania

28 Gastrointestinal infections, 193
Tariq Iqbal

29 Liver and biliary tract infections, 202
David Mutimer

30 Urinary tract infections, 207
Chris Catchpole

31 Genital infections, 210
Kaveh Manavi

32 Infections of the central nervous system, 220
Erwin Brown

33 Bacteraemia and bloodstream infections, 229
Tom Elliott

34 Device-related infections, 233
Tom Elliott

35 Cardiovascular infections, 238
Richard Watkin

36 Bone and joint infections, 241
Jonathan Sandoe

37 Skin and soft-tissue infections, 246
Supriya Narasimhan and Rabih Darouiche

38 Infections in the compromised host, 257
Tom Elliott

39 Infections caused by antimicrobial-resistant bacteria, 260
David Livermore

40 Perinatal and congenital infections, 264
James Gray

41 Human immunodeficiency virus, 271
Kaveh Manavi

42 Miscellaneous viral infections, 277
John Cheesbrough

Self-assessment

Self-assessment questions, 285

Answers to self-assessment questions, 300

General subject index, 309

Organism index, 317

Preface

The magnitude of recent changes in the field of medical microbiology has warranted this fifth edition of *Lecture Notes*: *Medical Microbiology and Infection*. While these changes have been encompassed in new chapters, this edition continues to maintain the well-received and user-friendly format of earlier editions, highlighting the pertinent key facts in medical microbiology and providing a sound foundation of knowledge which students can build on. The book for the first time is multi-authored, with chapters being written by recognised experts in their field.

This fifth edition is arranged into three main sections: basic microbiology, antimicrobial agents and infection. It covers all aspects of microbiology, including bacteriology, virology, mycology and parasitology. As in previous editions, the text is supported throughout with colour figures to illustrate the key points.

This book is written specifically for students in medicine, biomedicine, biology, dentistry, science and also pharmacology, who have an interest in medical microbiology at both undergraduate and postgraduate levels. In addition, this book will serve as a useful *aide memoire* for doctors sitting MRCS and MRCP examinations, as well as other healthcare professionals, for example biomedical scientists, working towards state registration.

Contributors

Erwin Brown Consultant Microbiologist, Department of Medical Microbiology, Frenchay Hospital, North Bristol NHS Trust, Bristol, UK

Anna Casey Clinical Research Scientist, Department of Clinical Microbiology, The Queen Elizabeth Hospital, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK

Chris Catchpole Consultant Microbiologist, Department of Clinical Microbiology, Worcestershire Royal Hospital, Worcestershire Acute Hospitals NHS Trust, Worcester, UK

John Cheesbrough Consultant Microbiologist, Department of Microbiology, Royal Preston Hospital, Lancashire Teaching Hospitals NHS Foundation Trust, Preston, Lancashire, UK

Peter Chiodini Consultant Parasitologist and Honorary Professor, The Hospital for Tropical Diseases and The London School of Hygiene and Tropical Medicine, London, UK

Barry Cookson Director of the Laboratory of Healthcare-associated Infection, Health Protection Agency, Microbiology Services, Colindale, London, UK

Rabih Darouiche VA Distinguished Service Professor, Departments of Medicine, Surgery and Physical Medicine & Rehabilitation and Director, Center for Prostheses Infection, Baylor College of Medicine, Houston, Texas, USA

Tom Elliott Consultant Microbiologist, The Queen Elizabeth Hospital, University Hospitals NHS Foundation Trust, Birmingham, UK

James Gray Consultant Microbiologist, Department of Medical Microbiology, Birmingham Children's Hospital NHS Foundation Trust, Birmingham, UK

Tariq Iqbal Consultant Physician and Gastroenterologist, Department of Gastrointestinal Medicine, The Queen Elizabeth Hospital, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK

Elizabeth Johnson Director of the Health Protection Agency Mycology Reference Laboratory, Bristol, UK

Shruti Khurana Specialist Registrar, Department of Respiratory Medicine, Manchester Royal Infirmary, Central Manchester University Hospitals NHS Foundation Trust, Manchester, UK

Peter Lambert Professor of Microbiology, School of Life and Health Sciences, Aston University, Birmingham, UK

David Livermore Director, Antibiotic Resistance Monitoring and Reference Laboratory, Health Protection Agency, Microbiology Services, Colindale, London, UK

Peter Mackie Consultant Clinical Scientist, Department of Microbiology, The General Infirmary at Leeds, Leeds Teaching Hospitals NHS Trust, Leeds, UK

Kaveh Manavi Consultant Physician HIV/Genitourinary Medicine, Department of Genitourinary Medicine, The Queen Elizabeth Hospital, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK

Cliodna McNulty Consultant Microbiologist, Health Protection Agency, Microbiology Department, Gloucestershire Royal Hospital, Gloucestershire Hospitals NHS Trust, Gloucester, UK

David Mutimer Consultant Hepatologist, Department of Liver Medicine, The Queen Elizabeth Hospital, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK

Supriya Narasimhan Assistant Professor, Division of Infectious Diseases, Department of Medicine, Drexel University, Pittsburgh, USA

Eleni Nastouli Consultant Virologist and Honorary Consultant in Paediatric Infectious Diseases, Department of Virology, University College London Hospitals NHS Trust and Great Ormond Street Hospital for Children NHS Trust, London, UK

Susan O'Connell Consultant Microbiologist, Lyme Borreliosis Unit, Health Protection Agency Microbiology Laboratory, Southampton General Hospital, Southampton University Hospitals NHS Trust, Southampton, UK

Jonathan Sandoe Consultant Microbiologist and Honorary Senior Lecturer, Department of Microbiology, Leeds Teaching Hospitals NHS Trust and University of Leeds, Leeds, UK

Sumeet Singhania Specialist Registrar, Department of Respiratory Medicine, Manchester Royal Infirmary, Central Manchester University Hospitals NHS Foundation Trust, Manchester, UK

Martin Skirrow Honorary Emeritus Consultant Microbiologist, Health Protection Agency, Microbiology Department, Gloucestershire Royal Hospital, Gloucestershire Hospitals NHS Trust, Gloucester, UK

Richard Watkin Consultant Cardiologist, Good Hope Hospital, Heart of England NHS Foundation Trust, Sutton Coldfield, Birmingham, UK

Mark Woodhead Consultant in General and Respiratory Medicine and Honorary Senior Lecturer, Department of Respiratory Medicine, Manchester Royal Infirmary, Central Manchester University Hospitals NHS Foundation Trust and University of Manchester, Manchester, UK

Tony Worthington Senior Lecturer in Microbiology, School of Life and Health Sciences, Aston University, Birmingham, UK

Part 1

Basic microbiology

1

Basic bacteriology

Peter Lambert
Aston University, Birmingham, UK

Bacterial structure

Bacteria are single-celled prokaryotic microorganisms, and their DNA is not contained within a separate nucleus as in eukaryotic cells. They are approximately 0.1–10.0 μm in size (Figure 1.1) and exist in various shapes, including spheres (cocci), curves, spirals and rods (bacilli) (Figure 1.2). These characteristic shapes are used to classify and identify bacteria. The appearance of bacteria following the Gram stain is also used for identification. Bacteria which stain purple/blue are termed Gram-positive, whereas those that stain pink/red are termed Gram-negative. This difference in response to the Gram stain results from the composition of the cell envelope (wall) (Figure 1.3), which are described below.

Cell envelope

Cytoplasmic membrane

A cytoplasmic membrane surrounds the cytoplasm of all bacterial cells and are composed of protein and phospholipid; they resemble the membrane surrounding mammalian (eukaryotic) cells but lack sterols. The phospholipids form a bilayer into which proteins are embedded, some spanning the membrane. The membrane carries out many functions, including the synthesis and export of cell-wall components, respiration, secretion of extracellular enzymes and toxins, and the uptake of nutrients by active transport mechanisms.

Mesosomes are intracellular membrane structures, formed by folding of the cytoplasmic membrane. They occur more frequently in Gram-positive than in Gram-negative bacteria. Mesosomes present at the point of cell division of Gram-positive bacteria are involved in chromosomal separation; at other sites they may be associated with cellular respiration and metabolism.

Cell wall

Bacteria maintain their shape by a strong rigid outer cover, the cell wall (Figure 1.3).

Gram-positive bacteria have a relatively thick, uniform cell wall, largely composed of peptidoglycan, a complex molecule consisting of linear repeating sugar subunits cross-linked by peptide side chains (Figure 1.4a). Other cell-wall polymers, including teichoic acids, teichuronic acids and proteins, are also present.

Gram-negative bacteria have a thinner peptidoglycan layer and an additional outer membrane that differs in structure from the cytoplasmic membrane (Figure 1.4b). The outer membrane contains lipopolysaccharides on its outer face, phospholipids on its inner face, proteins and lipoproteins which anchor it to the peptidoglycan. Porins are a group of proteins that form channels through which small hydrophilic molecules, including nutrients, can cross the outer membrane. Lipopolysaccharides are

Medical Microbiology and Infection Lecture Notes, Fifth Edition. Edited by Tom Elliott, Anna Casey, Peter Lambert and Jonathan Sandoe.

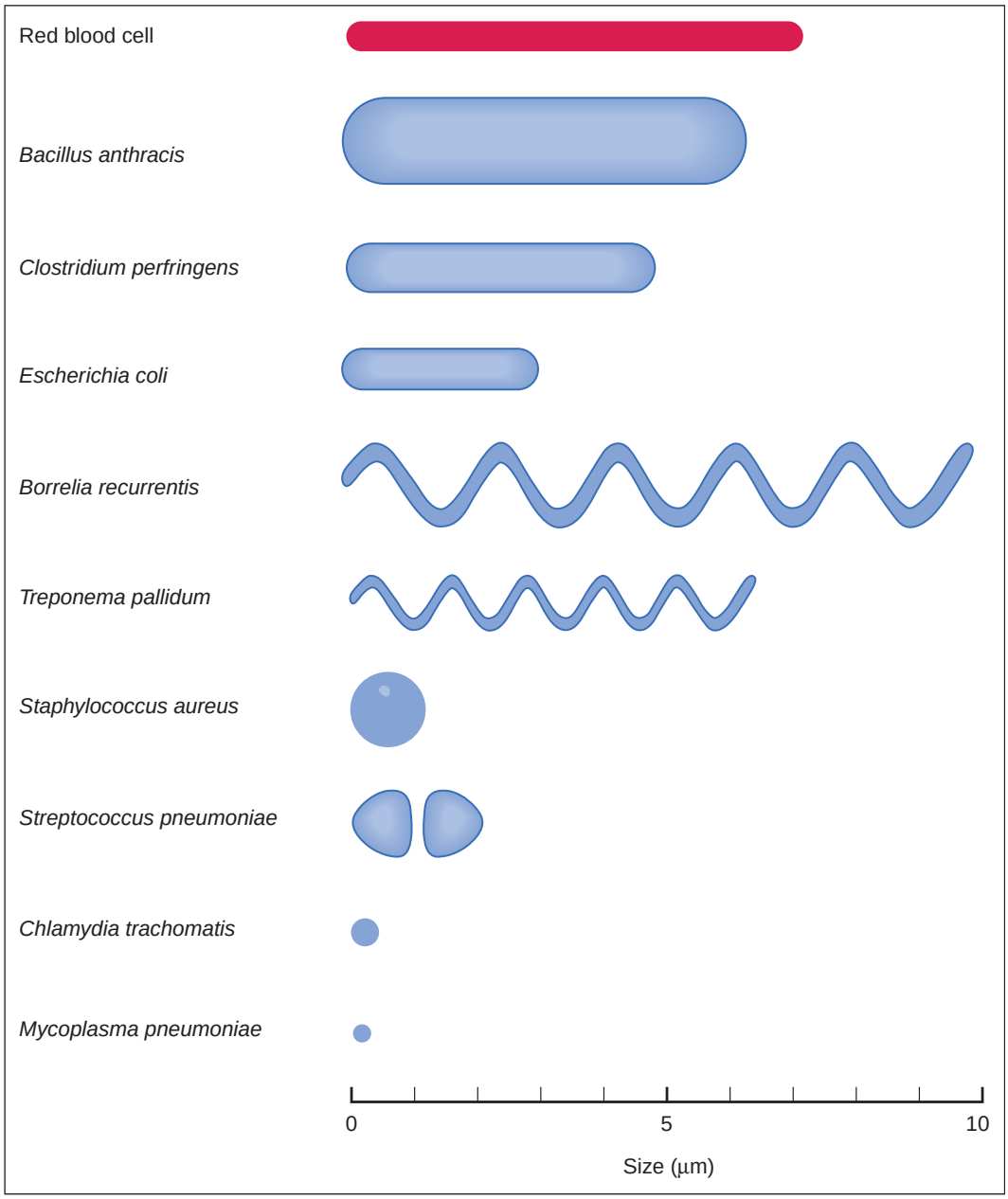

Figure 1.1 Shape and size of some clinically important bacteria.

a characteristic feature of Gram-negative bacteria and are also termed 'endotoxins' or 'pyrogen'. Endotoxins are released on cell lysis and have important biological activities involved in the pathogenesis of Gram-negative infections; they activate macrophages, clotting factors and complement, leading to disseminated intravascular coagulation and septic shock (Chapter 33).

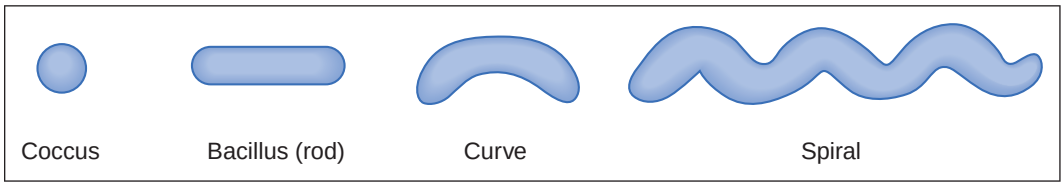

Figure 1.2 Some bacterial shapes.

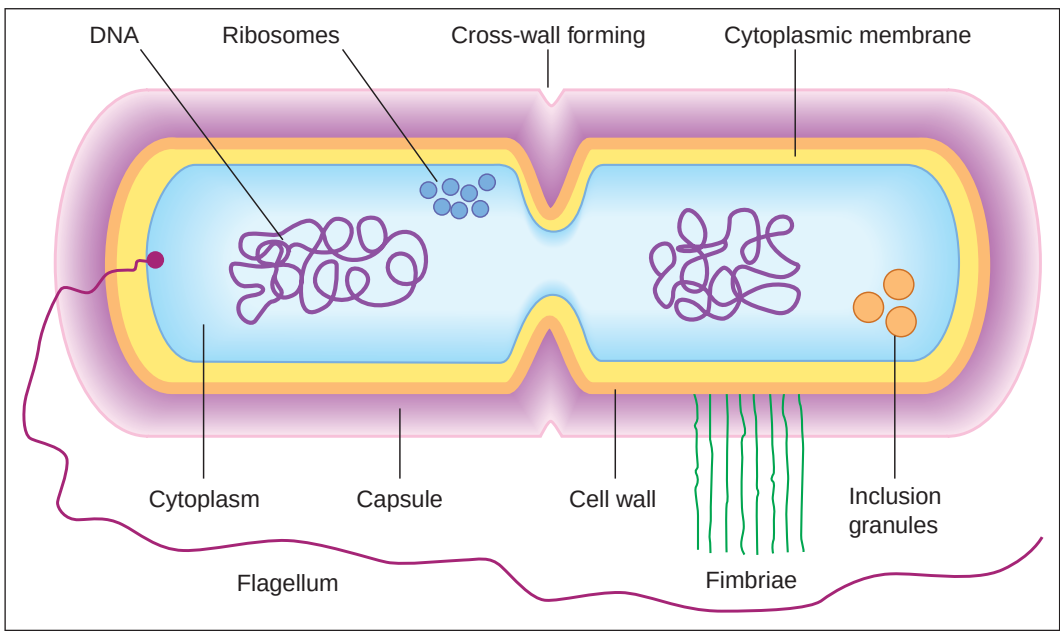

Figure 1.3 A section of a typical bacterial cell.

Mycobacteria have a distinctive cell wall structure and composition that differs from that of Gram-positive and Gram-negative bacteria. It contains peptidoglycan but has large amounts of high molecular weight lipids in the form of long chain length fatty acids (mycolic acids) attached to polysaccharides and proteins. This high lipid content gives the mycobacteria their acid fast properties (retaining a stain on heating in acid), which allows them to be distinguished from other bacteria (e.g. positive Ziehl-Neelsen stain).

The cell wall is important in protecting bacteria against external osmotic pressure. Bacteria with damaged cell walls, e.g. after exposure to β-lactam antibiotics such as penicillin, often rupture. However, in an osmotically balanced medium, bacteria deficient in cell walls may survive in a spherical form called protoplasts. Under certain conditions some protoplasts can multiply and are referred to as L-forms. Some bacteria, e.g. mycoplasmas, have no cell wall at any stage in their life cycle.

The cell wall is involved in bacterial division. After the nuclear material has replicated and separated, a cell wall (septum) forms at the equator of the parent cell. The septum grows in, produces a cross-wall and eventually the daughter cells may separate. In many species the cells can remain attached, forming groups, e.g. staphylococci form clusters and streptococci form long chains (Figure 1.5).

Capsules

Some bacteria have capsules external to their cell walls (Figure 1.3). These structures are bound

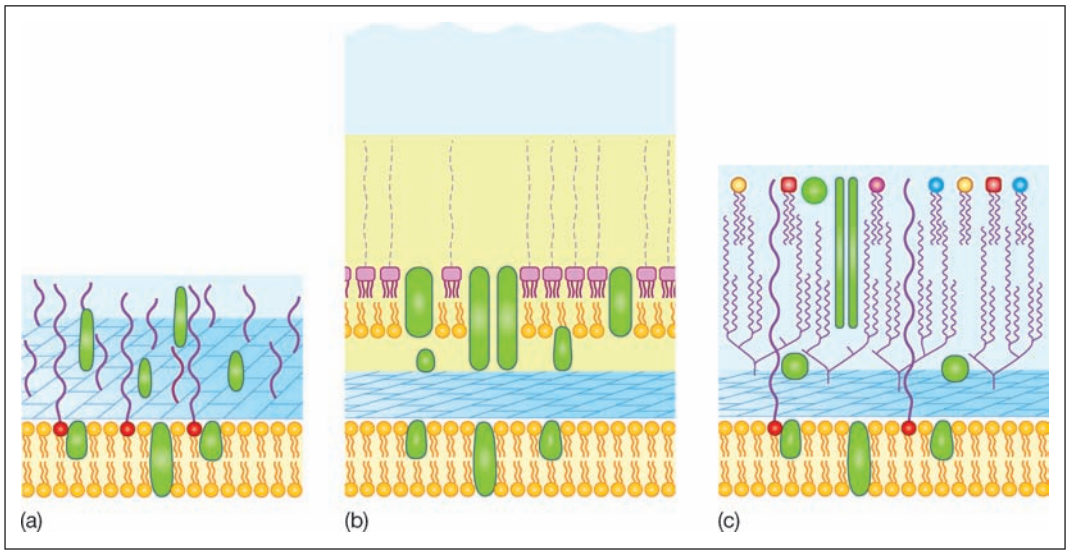

Figure 1.4 Cell wall and cytoplasmic membrane of (a) Gram-positive bacteria, (b) Gram-negative bacteria and (c) mycobacteria. The Gram-positive bacterial cell wall has a thick peptidoglycan layer with associated molecules (teichoic acids, teichuronic acids and proteins). The Gram-negative bacterial cell wall contains lipopolysaccharides, phospholipids and proteins in an outer membrane linked to a thin inner peptidoglycan layer. The mycobacterial cell wall contains long chain length fatty acids (mycolic acids).

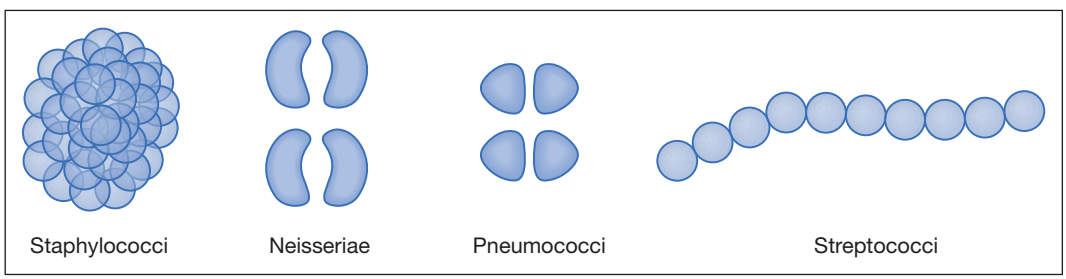

Figure 1.5 Some groups of bacteria.

to the bacterial cell and have a clearly defined boundary. They are usually polysaccharides with characteristic compositions that can be used to distinguish between microorganisms of the same species (e.g. in serotyping). Capsular antigens can be used to differentiate between strains of the same bacterial species, e.g. in the typing of *Streptococcus pneumoniae* for epidemiological purposes. The capsules are important virulence determinants in both Gram-positive and Gram-negative bacteria, because they may protect the bacteria from host defences and, in some bacteria, aid attachment to host cells.

Bacterial slime and biofilm

Extracellular slime layers are produced by some bacteria. They are more loosely bound to the cell surface than capsules and do not form a clearly defined surface boundary. The slime layer is composed predominantly of complex polysaccharides (glycocalyx), which acts as a virulence

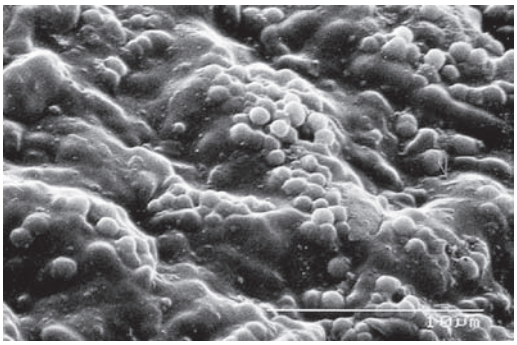

Figure 1.6 Scanning electronmicrograph of *Staphylococcus epidermidis* embedded in slime attached to a catheter.

factor through the formation of biofilm, e.g. by facilitating the attachment of *Staphylococcus epidermidis* onto artificial surfaces, such as intravascular cannulae (Figure 1.6), replacement joints and heart valves. Once formed, biofilms present a major problem for treatment and may require removal of the biomedical device.

Flagella

Bacterial flagella are spiral-shaped surface filaments consisting mainly of the protein, flagellin. They are attached to the cell envelope as single (monotrichous) or multiple (peritrichous) forms (Figure 1.7).

Flagella facilitate movement (motility) in bacteria by rapid rotation. They can be observed under the light microscope with special stains. Flagella are usually detected for diagnostic purposes by observing motility in a bacterial suspension or by spreading growth on solid media. The antigenic nature of the flagella may be used to differentiate between and identify strains of *Salmonella* spp.

Fimbriae

Fimbriae (also termed pili) are thin, hair-like appendages on the surface of many Gram-negative, and some Gram-positive, bacteria (Figure 1.3). They are approximately half the width of flagella, and are composed of proteins called pilins. In some bacteria they are distributed over the entire cell surface.

Fimbriae are virulence factors enabling bacteria to adhere to particular mammalian cell surfaces, an important initial step in colonisation of mucosal surfaces, e.g. *Neisseria gonorrhoeae* produce fimbriae that bind to specific receptors of cervical epithelial cells, whereas *Streptococcus pyogenes* have fimbriae containing 'M' protein, which facilitates adhesion to human cells in the pharynx.

Specialised fimbriae are involved in genetic material transfer between bacteria, a process called conjugation.

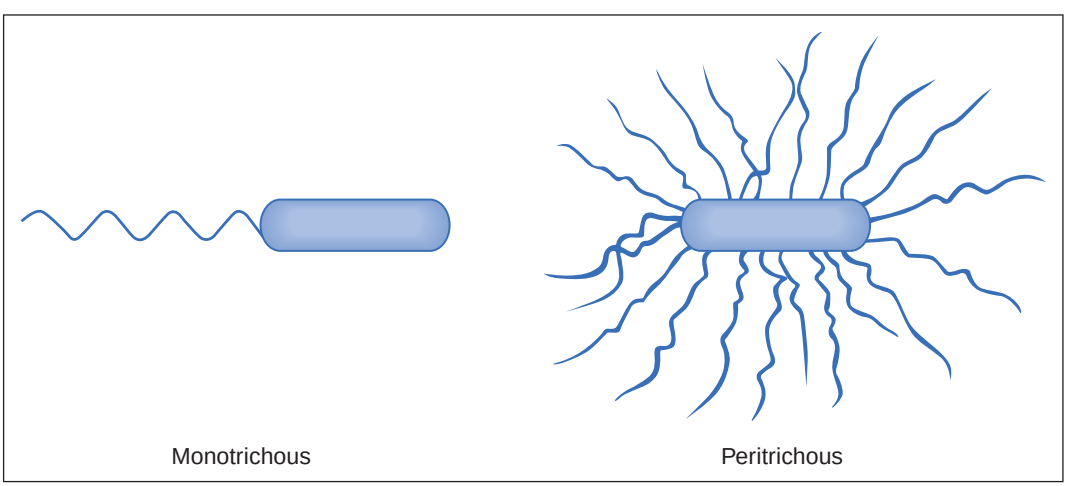

Figure 1.7 Arrangements of bacterial flagella.

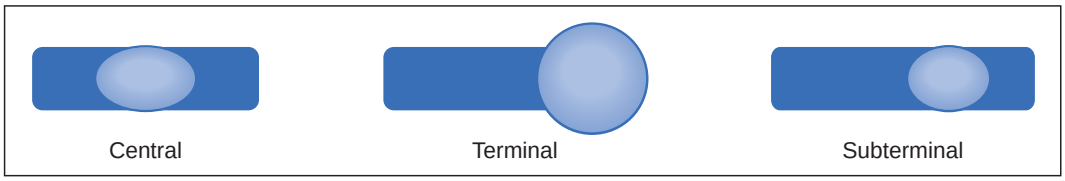

Figure 1.8 Size, shape and position of bacterial spores (from left to right): non-projecting, oval, central, e.g. *Bacillus anthracis*; projecting, spherical, terminal, e.g. *Clostridium tetani*; non-projecting, oval, subterminal, e.g. *C. perfringens*.

Intracellular structures

Nuclear material

The bacterial chromosome consists of a single circular molecule of double-stranded DNA, which is maintained in a compact form within the cell by supercoiling. When released from the cell and uncoiled the DNA would be about 1 mm long (10 to 100-times the length of the cell). Additional smaller extra-chromosomal DNA molecules, called plasmids, may also be present in bacteria. The chromosome usually codes for all the essential functions required by the cell; some plasmids control important phenotypic properties of pathogenic bacteria, including antibiotic resistance and toxin production. Extracellular nuclear material for encoding virulence and antibiotic resistance may also be transferred between bacteria and incorporated into the recipient's chromosome or plasmid. Transfer of genes encoding for virulence or antibiotic resistance may account for bacteria becoming resistant to antibiotics and for low-virulent bacteria becoming pathogenic.

Ribosomes

The cytoplasm has many ribosomes, which contain both ribonucleic acid (RNA) and proteins. Ribosomes are involved in protein synthesis.

Inclusion granules

Various cellular inclusions, which serve as energy and nutrient reserves, may be present in the bacterial cytoplasm. The size of these inclusions may increase in a favourable environment and decrease when conditions are adverse, e.g. *Corynebacterium diphtheriae* may contain high-energy phosphate reserves in inclusions termed 'volutin granules'.

Endospores

Endospores (spores) are small, metabolically dormant cells with a thick, multi-layered coat, formed intracellularly by members of the genera *Bacillus* and *Clostridium* (Figure 1.8). They are highly resistant to adverse environmental conditions and may survive desiccation, disinfectants or boiling water for several hours.

Spores are formed in response to limitations of nutrients by a complex process (sporulation) involving at least seven stages. When fully formed, they appear as oval or round cells within the vegetative cell. The location is variable, but is constant in any one bacterial species (Figure 1.9). Spores can remain dormant for long periods of time. However, they are able to revert to actively-growing cells (i.e. germinate) relatively rapidly in response to certain conditions such as the presence of specific sugars, amino acids or bile salts.

Spores also have an important role in the epidemiology of certain human diseases, such as anthrax, tetanus, gas gangrene and infection caused by *Clostridium difficile*.

The eradication of spores is of particular importance in some processes, e.g. the production of sterile products including pharmaceuticals and surgical instruments, in routine hospital ward and care centre cleaning, and in food preservation.

Bacterial growth

Most bacteria will grow on artificial culture media prepared from extracts from animal or plant tissues, which supply pre-formed nutrients and vitamins. However, some bacteria, e.g. *Mycobacterium leprae* (leprosy) and *Treponema pallidum*

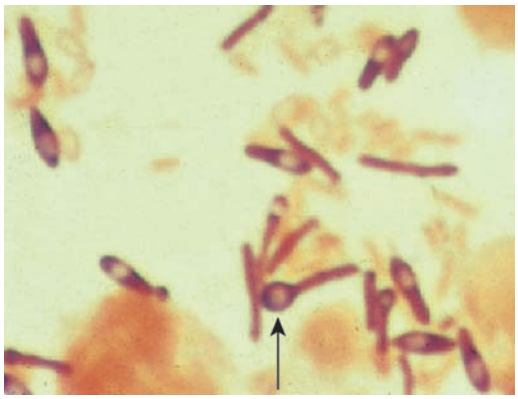

Figure 1.9 Gram-stain of *Clostridium sporogenes* (showing oval subterminal spores) and a *Clostridium tetani* with a terminal spore (arrowed).

(syphilis), cannot yet be grown *in vitro*; other bacteria, e.g. *Chlamydia* spp. and *Rickettsia* spp., only replicate intracellularly within host cells and are therefore grown in tissue culture.

Under suitable conditions (nutrients, temperature and atmosphere) a bacterial cell will increase in size and then divide by binary fission into two identical cells. These two cells are able to grow and divide at the same rate as the parent cell, provided that conditions including nutrient supply remain stable. This results in an exponential or logarithmic growth rate. The time required for the number of bacteria in a culture to double is called the generation time, e.g. *Escherichia coli* has a generation time of about 20 minutes under optimal conditions. By contrast, *Mycobacterium tuberculosis* has a generation time of 24 hours.

Requirements for bacterial growth

Most bacteria of medical importance require carbon, nitrogen, water, inorganic salts and a source of energy for growth. They have various gaseous, temperature and pH requirements, and can utilise a range of carbon, nitrogen and energy sources. Some bacteria also require special growth factors, including amino acids and vitamins.

Growth requirements are important in selecting the various culture media required in diagnostic microbiology and in understanding the tests for identifying bacteria.

Carbon and nitrogen sources

Bacteria are classified into two main groups according to the type of compounds that they can utilise as a carbon source:

1 *Autotrophs* utilise inorganic carbon from carbon dioxide and nitrogen from ammonia, nitrites and nitrates; they are of minor medical importance.
2 *Heterotrophs* require organic compounds as their major source of carbon and energy; they include most bacteria of medical importance.

Atmospheric conditions

Carbon dioxide

Bacteria require CO_2 for growth; adequate amounts are present in the air or are produced during metabolism by the microorganisms themselves. A few bacteria, however, require additional CO_2 for growth, e.g. *Neisseria meningitidis*, *Campylobacter jejuni*.

Oxygen

Bacteria may be classified into four groups according to their O_2 requirements:

1 *Obligate (strict) aerobes*: grow only in the presence of oxygen, e.g. *Pseudomonas aeruginosa*.
2 *Microaerophilic bacteria*: grow best in low oxygen concentrations, e.g. *Campylobacter jejuni*.
3 *Obligate (strict) anaerobes*: grow only in the absence of free oxygen, e.g. *Clostridium tetani*.
4 *Facultative anaerobes*: grow in the presence or absence of oxygen, e.g. *Escherichia coli*.

Temperature

Most pathogenic bacteria grow best at 37 °C. However, the optimum temperature for growth is occasionally higher, e.g. for *C. jejuni*, it is 42 °C. The ability of some bacteria to grow at low temperatures (0–4 °C) is important in food microbiology; *Listeria monocytogenes*, a cause of food poisoning, will grow slowly at 4 °C and has resulted in outbreaks of food poisoning associated with cook-chill products.

pH

Most pathogenic bacteria grow best at a slightly alkaline pH (pH 7.2–7.6). There are a few exceptions: *Lactobacillus acidophilus*, present in the

vagina of post-pubescent females, prefers an acid medium (pH 4.0). It produces lactic acid, which keeps the vaginal secretions acid, thus preventing many pathogenic bacteria from establishing infection. *Vibrio cholerae*, the cause of cholera, prefers an alkaline environment (pH 8.5).

Growth in liquid media

When bacteria are added (inoculated) into a liquid growth medium, subsequent multiplication can be followed by determining the total number of live microorganisms (viable counts) at various time intervals. The growth curve produced normally has four distinct phases (Figure 1.10):

1 *Lag phase* (*A*): the interval between inoculation of a fresh growth medium with bacteria and the commencement of growth;
2 *Log phase* (*B*): the phase of exponential growth; the growth medium becomes visibly turbid at approximately 1×10^6 cells/ml;
3 *Stationary phase* (*C*): the growth rate slows as nutrients become exhausted, waste products accumulate, and the rate of cell division equals the rate of death; the total viable count remains relatively constant;
4 *Decline phase* (*D*): the rate of bacterial division is slower than the rate of death, resulting in a decline in the total viable count.

Note that the production of waste products by bacteria, particularly CO_2, and the uptake of O_2 have been utilised in the development of semi-automated instruments to detect bacterial growth in blood samples obtained from patients with suspected bloodstream infection.

Growth on solid media

Liquid growth media containing the nutrients needed for bacterial growth can be solidified with agar, a polysaccharide extracted from seaweed. Heating during sterilisation of the medium melts the agar, which then remains liquid until the temperature falls to approximately 40 °C, when it produces a transparent solid gel. Solid media are normally set in Petri dishes ('agar plates'). When spread across the surface of an agar plate, most bacteria grow as visible colonies. Each colony comprises millions of bacterial cells that emanated from either a single cell or a cluster of cells. The appearance of the bacterial colony (colonial morphology) assists in identification.

Growth on laboratory media

To grow bacteria *in vitro*, the microbiologist has to take into account the physiological requirements. Various types of liquid and solid media have been

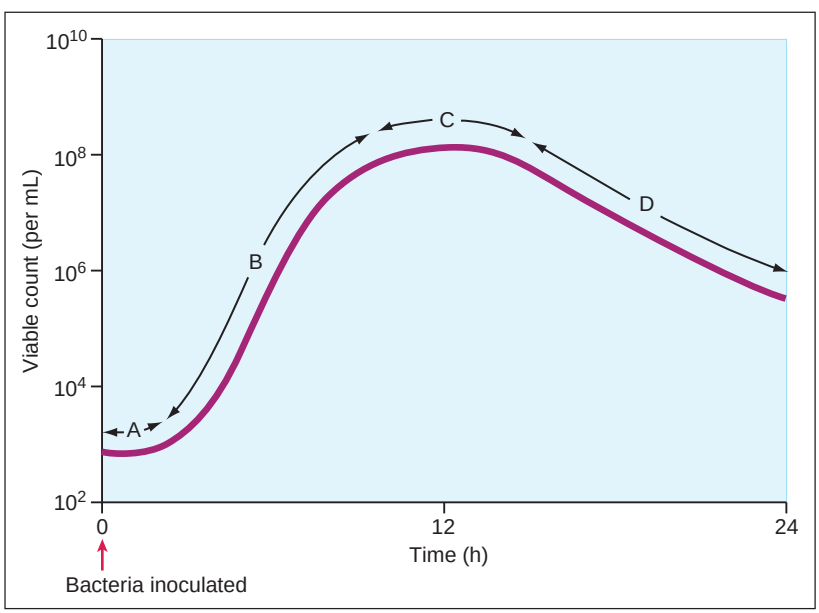

Figure 1.10 Bacterial growth curve showing the four phases: (A) lag; (B) log or exponential; (C) stationary; and (D) decline (death).

developed for the diagnostic microbiology laboratory.

Simple media

Many bacteria will grow in or on simple media, e.g. nutrient broth/nutrient agar that contains 'peptone' (polypeptides and amino acids from the enzymatic digestion of meat) and 'meat extract' (water-soluble components of meat containing mineral salts and vitamins).

Enriched media

These contain additional nutrients for the isolation of more fastidious bacteria that require special conditions for growth, e.g. agar containing whole blood (blood agar) or agar containing lysed blood (chocolate agar).

Selective media

These are designed to facilitate growth of some bacteria, while suppressing the growth of others, and include:

- *mannitol salt agar* which contains increased NaCl (salt) concentration for the recovery of staphylococci;
- *MacConkey agar*, which contains bile salts and allows the growth of bile-tolerant bacteria only; and
- *antibiotics*, which are frequently added to media to allow only certain bacteria to grow while suppressing or killing others.

Indicator media

These are designed to aid the detection and recognition of particular pathogens. They are often based on sugar fermentation reactions that result in production of acid and the subsequent colour change of a pH indicator, e.g. MacConkey agar contains lactose and a pH indicator (neutral red); lactose-fermenting bacteria (e.g. *Escherichia coli*) produce acid and form pink colonies, whereas non-lactose fermenting bacteria (e.g. *Salmonella* spp.) do not produce acid and form pale yellow colonies. This property facilitates the recognition of possible *Salmonella* colonies among normal bowel flora. Note that indicator media may also contain selective agents including antibiotics or substances such as bile salts and crystal violet to suppress growth of most Gram-positive microorganisms. MacConkey agar is therefore both a selective medium and an indicator medium.

2

Classification of bacteria

Peter Lambert
Aston University, Birmingham, UK

Bacterial taxonomy and nomenclature

The classification of microorganisms is essential for the understanding of clinical microbiology. Bacteria are designated by a binomial system, with the genus name (capital letter) followed by the species name (without capital letter), e.g. *Escherichia coli* or *Staphylococcus aureus*. Names are often abbreviated, e.g. *E. coli* and *S. aureus*.

Many nomenclature problems exist with this system that can lead to confusion, e.g. 'bacillus' refers to any rod-shaped bacteria, whereas the genus *Bacillus* includes only the aerobic spore-bearing rods. Other complications include the use of alternative terminology. *Streptococcus pneumoniae* is referred to as the pneumococcus, *Neisseria meningitidis* as the meningococcus and *Neisseria gonnorhoeae* as the gonococcus. Occasionally, collective terms are used, e.g. the term 'coliform' may indicate *E. coli* or a closely related Gram-negative bacillus found within the gut, and the term 'coagulase-negative staphylococci' means staphylococci other than *S. aureus*. In this text, conventional terminology is used and, where appropriate, common alternatives are indicated.

Bacterial classification

Medically important bacteria can be subdivided into five main groups according to their cell shape (morphology) and staining reactions. The basic shapes of bacteria include cocci, bacilli, and spiral and variable shaped (pleomorphic) forms. Each of these morphological forms is further subdivided by their staining reactions, predominantly the Gram and acid-fast stains (Table 2.1). Bacteria are divided primarily into Gram-positive or Gram-negative microorganisms. Other characteristics, including the ability to grow in the presence (aerobic) or absence (anaerobic) of oxygen, spore formation and motility, are used to divide the groups further. Subdivision of these groups into genera is made on the basis of various factors, including culture properties (e.g. conditions required for growth and

Medical Microbiology and Infection Lecture Notes, Fifth Edition. Edited by Tom Elliott, Anna Casey, Peter Lambert and Jonathan Sandoe.

colonial morphology), antigenic properties and biochemical reactions. The medically important genera based on this classification are shown in Table 2.2 (Gram-positives) and Table 2.3 (Gram-negatives).

Table 2.1 Main groups of bacteria

I	Gram-positive cocci, bacilli and branching bacteria
II	Gram-negative cocci, bacilli and comma-shaped bacteria
III	Spiral-shaped bacteria
IV	Acid-fast bacteria
V	Cell-wall-deficient bacteria

Other bacterial groups

Spiral bacteria

These are relatively slender spiral-shaped filaments, which are classified into three clinically important genera:

1 *Borrelia*: these are relatively large, motile spirochaetes and include *Borrelia vincenti* and *Leptotrichia buccalis*, which cause Vincent's angina, *Borrelia recurrentis*, which causes relapsing fever and *Borrelia burgdorferi*, which causes Lyme disease.
2 *Treponema*: these are thinner and more tightly spiralled than *Borrelia*. Examples include *Treponema pallidum* (causes syphilis) and *Treponema pertenue* (causes yaws).
3 *Leptospira*: these are finer and even more tightly coiled than the *Treponema* spp. (species plural). They are classified within the single species of

Table 2.2 Classification of Gram-positive bacterial pathogens

GRAM-POSITIVE BACTERIA

Grouping	Aerobic/anaerobic growth	Genus	Examples of clinically important species
Gram-positive cocci			
Clusters	Both	*Staphylococcus*	*S. aureus, S. epidermidis, S. saprophyticus*
Chains/pairs	Both	*Streptococcus* and *Enterococcus*	*S. pneumoniae, S. pyogenes, E. faecalis*
Chains	Anaerobic	*Peptostreptococcus*	*P. magnus, P. asaccharolyticus*
Gram-positive bacilli			
Sporing	Aerobic	*Bacillus*	*B. anthracis*, *B. cereus*
Non-sporing	Both	*Corynebacterium*	*C. diphtheriae*
	Aerobic or microaerophilic	*Listeria*	*L. monocytogenes*
	Anaerobic or microaerophilic	*Lactobacillus*	*L. acidophilus*
Sporing	Anaerobic	*Clostridium*	*C. difficile*, *C. botulinum*, *C. perfringens*, *C. tetani*
Non-sporing	Anaerobic	*Propionibacterium*	*P. acnes*
Branching	Anaerobic	*Actinomyces*	*A. israeli*
	Aerobic	*Nocardia*	*N. asteroides*

Table 2.3 Classification of Gram-negative bacterial pathogens

GRAM-NEGATIVE BACTERIA				
Shape	**Aerobic/anaerobic growth**	**Major grouping**	**Genus**	**Examples of clinically important species**
Cocci	Aerobic		*Neisseria*	*N. gonorrhoeae*
				N. meningitidis
Cocci	Anaerobic		*Veillonella*	*V. parvula*
Bacilli		Enterobacteriaceae ('Coliforms')	*Enterobacter*	*E. cloacae*
			Escherichia	*E. coli*
			Klebsiella	*K. pneumoniae*
			Proteus	*P. mirabilis*
			Salmonella	*S. typhimurium*
			Serratia	*S. marcescens*
			Shigella	*S. sonnei*
			Yersinia	*Y. enterocolitica*
Bacilli	Aerobic		*Pseudomonas*	*P. aeruginosa*
Comma shaped	Both	Vibrios	*Vibrio*	*V. parahaemolyticus*
				V. cholerae
			Campylobacter	*C. jejuni*
			Helicobacter	*H. pylori*
Bacilli	Varies with genus		*Bordetella*	*B. pertussis*
			Brucella	*B. abortus*
			Haemophilus	*H. influenzae,*
				H. parainfluenzae
			Eikenella	*E. corrodens*
			Pasteurella	*P. multocida*
Bacilli	Aerobic		*Legionella*	*L. pneumophila*
Bacilli	Anaerobic		*Bacteroides*	*B. fragilis*
			Fusobacterium	*F. nucleatum*

Leptospira interrogans, which is divided serologically into two complexes. There are over 130 serotypes in the interrogans complex, many of which are pathogenic, including *L. icterohaemorrhagiae* (causes Weil's disease) and *L. canicola* (causes lymphocytic meningitis).

Acid-Fast Bacilli

These include the genus *Mycobacterium*. They are identified by their acid-fast staining reaction, which reflects their ability to resist decolorisation with acid, after being stained with hot carbol fuchsin, e.g. Ziehl-Neelsen stain. Mycobacteria are generally difficult to stain by Gram's method. They can be simply divided into the following main groups:

1 Tubercle bacilli: *Mycobacterium tuberculosis* and *Mycobacterium bovis* (Chapter 27)
2 Leprosy bacillus: *Mycobacterium leprae*
3 Atypical mycobacteria: some tuberculosis-like illnesses in humans are caused by other species of mycobacteria. They are sometimes also referred to as mycobacteria other than tuberculosis (MOTT). They can grow at 27°C,

42°C or 45°C; some produce pigment when growing in light and are called photochromogens, whereas others produce pigment in light or darkness and are referred to as scotochromogens. Unlike *M. tuberculosis*, other mycobacteria can be rapid growers. All these species of mycobacteria are commonly referred to as the atypical mycobacteria; examples include *Mycobacterium kansasii* (photochromogenic), *Mycobacterium avium-intracellulare* (non-pigmented) and *Mycobacterium chelonei* (fast growing).

Cell-wall-deficient bacteria

Some bacteria do not form cell walls and are called mycoplasmas. Pathogenic species include *Mycoplasma pneumoniae* and *Ureaplasma urealyticum*. It is important to distinguish mycoplasmas from other cell-wall-deficient forms of bacteria, which can be defined as either L-forms or protoplasts:

- *L-forms* are cell-wall-deficient forms of bacteria, which are produced by removal of a bacterium's cell wall, e.g. with cell-wall-acting antibiotics such as the β-lactams. L-Forms are able to multiply and their colonial morphology is similar to the 'fried egg' appearance of the mycoplasmas.
- *Protoplasts* are bacteria that have also had their cell walls removed. They are metabolically active and can grow, but are unable to multiply. They survive only in an osmotically stabilised medium.

3

Staphylococci

Tom Elliott[1] *and Peter Lambert*[2]
[1]University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK
[2]Aston University, Birmingham, UK

Of the many species of staphylococci that are associated with humans, only a limited number are clinically important; these include *Staphylococcus aureus*, *S. epidermidis* and *S. saprophyticus*. Their principal characteristics are shown in Table 3.1.

Definition

Gram-positive cocci; usually arranged in clusters; non-motile; catalase positive; non-sporing; grow over a wide temperature range (10–42 °C), with an optimum of 37 °C; aerobic and facultatively anaerobic; grow on simple media.

Classification

1 *Colonial morphology*: *S. aureus* colonies are grey to golden yellow (Figure 3.1); *S. epidermidis* and *S. saprophyticus* colonies are white. Staphylococci may produce haemolysins, resulting in haemolysis on blood agar.
2 *Coagulase test*: *S. aureus* possesses the enzyme coagulase, which acts on plasma to form a clot. Other staphylococci (e.g. *S. epidermidis* and *S. saprophyticus*) do not possess this enzyme and are often termed, collectively, 'coagulase-negative staphylococci' (CoNS). There are three methods to demonstrate the presence of coagulase:
   (a) *tube coagulase test*: diluted plasma is mixed with a suspension of the bacteria; after incubation, clot formation indicates *S. aureus*
   (b) *slide coagulase test*: a more rapid and simple method in which a drop of plasma is added to a suspension of staphylococci on a glass slide; visible clumping indicates the presence of coagulase.
   (c) *latex agglutination test*: cells are mixed with coated latex particles; visible agglutination provides simultaneous detection of staphylococci containing coagulase and/or protein A.
3 *Deoxyribonuclease (DNAase) production*: *S. aureus* possesses an enzyme, DNAase, which depolymerises and hydrolyses DNA; other staphylococci rarely possess this enzyme.
4 *Protein A detection*: *S. aureus* possesses a cell-wall antigen, protein A; antibodies to protein A agglutinate *S. aureus* but not other staphylococci.
5 *Novobiocin sensitivity*: useful for differentiating between species of coagulase-negative staphylococci; *S. saprophyticus* is novobiocin resistant and *S. epidermidis* is sensitive.

Medical Microbiology and Infection Lecture Notes, Fifth Edition. Edited by Tom Elliott, Anna Casey, Peter Lambert and Jonathan Sandoe.

Table 3.1 Main characteristics of staphylococci

Characteristic	*S. aureus*	*S. epidermidis*	*S. saprophyticus*
Coagulase	+	−	−
Deoxyribonuclease	+	−	−
Novobiocin	S	S	R
Colonial appearance	Golden-yellow	White	White
Body sites which may be colonised	Nose Mucosal surfaces Faeces Skin	Skin Mucosal surfaces	Periurethra Faeces
Common infections	Skin (boils, impetigo, furuncles, wound infections) Abscesses Osteomyelitis Septic arthritis Sepsis Infective endocarditis Prosthetic device-related infections	Prosthetic device-related infections e.g. artificial valves, heart, intravenous catheters, CSF shunts	Urinary tract infections in sexually active young women

+, present; −, absent; CSF, cerebrospinal fluid, S, sensitive R, resistant.

S. aureus

Epidemiology

S. aureus is a relatively common human commensal: nasal carriage occurs in 30–50% of healthy adults, faecal carriage in about 20% and skin carriage in 5–10%, particularly the axilla and perineum. *S. aureus* is spread via droplets and skin scales, which contaminate clothing, bed linen and other environmental sources.

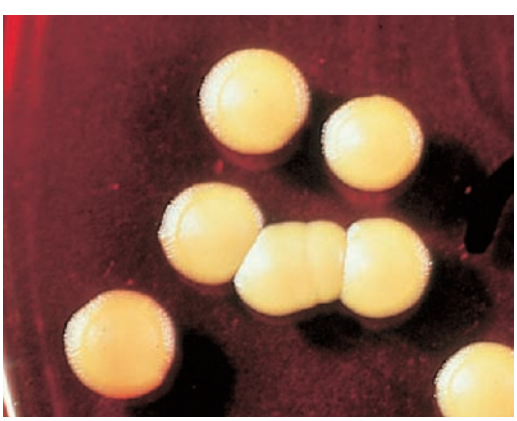

Figure 3.1 *S. aureus* colonies on a blood agar plate (2–3 mm diameter).

Morphology and identification

On microscopy, *S. aureus* is seen as typical Gram-positive cocci in 'grape-like' clusters. It is both coagulase and DNAase positive (Figure 3.2). Other biochemical tests can be performed for full identification.

Pathogenicity

S. aureus causes disease because of its ability to adhere to cells, spread in tissues and form abscesses, produce extracellular enzymes and exotoxins (Table 3.2), combat host defences and resist treatment with many antibiotics.

Adhesins

S. aureus has a wide repertoire of adhesins known as MSCRAMMs (microbial surface components

Figure 3.2 Plate containing DNA showing clear zones around DNAase-producing staphylococci (arrowed). DNAase-negative staphylococci shown below.

recognizing adhesive matrix molecules), which mediate adherence to host cells; these include protein A, fibrinogen and fibronectin-binding and collagen-binding protein.

Exotoxins and enzymes

- *Coagulase*: *S. aureus* produces coagulase, an enzyme that coagulates plasma. Coagulase results in fibrin deposition, which interferes with phagocytosis and increases the ability of the microorganism to invade tissues.
- *Other enzymes*: *S. aureus* may also produce staphylokinase (results in fibrinolysis), hyaluronidase (dissolves hyaluronic acid), proteases (degrades proteins) and lipases (solubilises lipids).
- *Haemolysin, leukotoxin and leukocidin*: several exotoxins are produced by *S. aureus*; α-toxin (haemolysin) lyses erythrocytes and damages platelets; β-toxin degrades sphingomyelin and is toxic for many types of cell, including erythrocytes; leukocidin (Panton Valentine leukocidin, PVL) lyses white blood cells and damages membranes and susceptible cells.
- *Enterotoxins*: there are six soluble enterotoxins that are produced by almost half of all *S. aureus* strains. They are heat stable (resistant at 100 °C for 30 min), unaffected by gastrointestinal enzymes and are a cause of food poisoning, principally associated with vomiting.
- *Exfoliative/epidermolytic toxin*: some strains produce a toxin that can result in generalised

Table 3.2 Pathogenicity factors produced by *S. aureus*

Factor	Effect
MSCRAMMs	Mediate adherence to host cells
Protein A	Evade host defence/inhibits phacocytosis
Fibronectin-binding protein	Mediates binding to fibronectin
Fibrinogen-binding protein	Clumping factors
Capsule	Evade host defences
Coagulase	Generates protective fibrin layer around *S. aureus*
Staphylokinase	Fibrinolysis
Proteases	Degrade antibacterial proteins and matrix proteins
Lipases	Promote interstitial spreading of microorganism
Hyaluronidase	Degrades hyaluronic acid
α-Haemolysin	Lyses erythrocytes, damages platelets
β-Haemolysin	Degrades sphingomyelin/toxic for cells
Leukocidin/leucotoxin	Lyse white blood cells
Exotoxins, e.g. enterotoxins	Food poisoning with profuse vomiting
Superantigens, e.g. TSST, exfoliative toxin	Toxic shock syndrome, scalded skin syndrome

NB: Toxin production varies between strains of *S. aureus*.

desquamation of the skin (staphylococcal scalded skin syndrome).
- *Toxic shock syndrome toxin* (*TSST*): this is associated with shock and desquamation of skin, and is usually related to an underlying *S. aureus* infection.
- Staphylococcal enterotoxins, TSSTs and exfoliative toxin are 'superantigens', all of which bind non-specifically to specific white cells, resulting in over production of cytokines, giving rise to a toxic shock-like presentation.

Cell envelope

Over 90% of all clinical isolates of *S. aureus* strains possess a polysaccharide capsule that interferes with opsonisation and phagocytosis. *S. aureus* also possesses a cell-wall protein (protein A) that binds the Fc component of the antibody, preventing complement activation.

Antibiotic resistance

Many strains of *S. aureus* are resistant to the antibiotic meticillin and are termed 'meticillin-resistant *S. aureus*' (MRSA). Most resistance depends on the production of an additional penicillin-binding protein, which is encoded by an acquired *mecA* gene. Many strains of MRSA are now resistant to multiple antibiotics.

Laboratory diagnosis

Laboratory diagnosis is by microscopic detection of the microorganism in clinical samples, direct isolation from the infected site or blood cultures, and detection of serum antibodies to staphylococcal haemolysin and DNAase. *S. aureus* strains can be typed ('fingerprinted') by conventional methods, including biotype and antibiogram. *S. aureus* can also be genotyped by molecular methods, including pulsed field gel electrophoresis (PFGE). Typing of *S. aureus* is useful in epidemiological studies.

Treatment and prevention

Antimicrobial agents, such as flucloxacillin, remain the first-line treatment for sensitive strains of *S. aureus*; however, the increase in infections caused by MRSA has required the use of glycopeptide antibiotics such as vancomycin. Resistance to vancomycin has been reported but is still rare. MRSA can cause sepsis, ranging from wound infections to urinary tract infections and severe sepsis and septic shock. Epidemic strains of MRSA (EMRSA) have also been recognised. Prevention of spread through effective infection control procedures, including MRSA decolonisation, is therefore important.

Associated infections

- *Skin*: boils, impetigo, furuncles, wound infections, staphylococcal scalded skin syndrome;
- *Respiratory*: pneumonia, lung abscesses, exacerbations of chronic lung disease;
- *Skeletal*: most common cause of osteomyelitis and septic arthritis;
- *Invasive*: bloodstream infection, infective endocarditis, deep abscesses (brain, liver, spleen), toxic shock syndrome;
- *Gastrointestinal*: toxin-mediated food poisoning;
- *Device related*: indwelling catheters, prosthetic joints and heart valves.

S. epidermidis

- *S. epidermidis* is both coagulase and DNAase negative and is present in large numbers on the human skin and mucous membranes.
- *S. epidermidis* is a cause of bacterial endocarditis, particularly in patients with prosthetic heart valves and in drug addicts. It is also a major cause of infections of implanted devices such as cerebrospinal shunts, hip prostheses, central venous and peritoneal dialysis catheters.
- The microorganism colonises implanted devices by attaching firmly onto artificial surfaces. Some strains also produce a slime layer (glycocalyx), which appears to facilitate adhesion and protect the microorganism from antibiotics and host defences. The increased use of implanted devices, particularly central venous catheters, has resulted in *S. epidermidis* becoming one of the most frequently isolated microorganisms from blood cultures. *S. epidermidis* occasionally causes urinary tract infections, particularly in catheterised patients. When isolated from hospitalised patients, *S. epidermidis* is often resistant to antibiotics such as flucloxacillin and erythromycin, necessitating the use of glycopeptide antibiotics (e.g. vancomycin).

S. saprophyticus

S. saprophyticus is both coagulase and DNAase negative and is frequently associated with urinary tract infections in sexually active young women, occasionally resulting in severe cystitis with haematuria.

4

Streptococci and enterococci

Anna Casey
University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK

Streptococci

Definition

Gram-positive cocci arranged in pairs or chains (Figure 4.1); facultatively anaerobic; non-sporing; non-motile; catalase-negative; most are capsulate; optimum growth at 37 °C; sometimes require enriched media; many species exhibit characteristic haemolysis on blood agar. Many streptococci are human commensals (most notably of the upper respiratory tract).

Classification

Streptococci are classified by:

1 *The type of haemolysis observed on blood agar*:
   (a) α-*haemolysis*: a greenish zone forms around colonies due to partial haemolysis of erythrocytes (Figure 4.2). An example of an α-haemolytic species is *Streptococcus pneumoniae*.
   (b) β-*haemolysis*: a clear zone forms around colonies due to complete haemolysis of erythrocytes (Figure 4.2).
   (c) γ-*haemolysis*: no zone is formed, as erythrocytes are not lysed. These streptococci are more commonly referred to as non-haemolytic streptococci.
2 *Serological detection of cell wall antigens*: streptococci can be classified alphabetically according to the possession of specific cell wall antigens (Lancefield groups A–H and K–V). Antibodies that react with these antigens are used to group streptococci and are particularly useful in the identification of β-haemolytic species. These groups are important to distinguish, as they can cause specific infections.
3 *Biochemical reactions*: some streptococci are difficult to classify by the above characteristics, therefore biochemical tests can be useful in their identification.

α-Haemolytic streptococci

Streptococcus pneumoniae (pneumococcus)

Epidemiology

S. pneumoniae is a commensal of the upper respiratory tract.

Medical Microbiology and Infection Lecture Notes, Fifth Edition. Edited by Tom Elliott, Anna Casey, Peter Lambert and Jonathan Sandoe.