

Preface, ix

Abbreviations of genera, xi

## **1 THE HUMAN-MICROBE SYMBIOSIS, 1**

- 1.1 Overview of the nature and distribution of the microbial communities inhabiting humans, 1
  - 1.1.1 Difficulties encountered in determining the composition of a microbial community, 2
  - 1.1.2 Structural aspects of microbial communities, 5
    - 1.1.2.1 Microcolonies, 5
    - 1.1.2.2 Intracellular colonization, 5
    - 1.1.2.3 Biofilms, 6
  - 1.1.3 Communication in microbial communities, 8
- 1.2 Environmental determinants that affect the distribution and composition of microbial communities, 13
  - 1.2.1 Nutritional determinants, 14
  - 1.2.2 Physicochemical determinants, 18
  - 1.2.3 Mechanical determinants, 22
  - 1.2.4 Biological determinants, 23
- 1.3 Host characteristics that affect the indigenous microbiota, 27
  - 1.3.1 Age, 28
  - 1.3.2 Host genotype, 29
  - 1.3.3 Gender, 29
- 1.4 Techniques used to characterize the microbial communities inhabiting humans, 31
  - 1.4.1 Microscopy, 31
  - 1.4.2 Culture-dependent approaches, 33
  - 1.4.3 Culture-independent, molecular approaches, 35
  - 1.4.4 Functional analysis of microbial communities, 37

- 1.5 The epithelium – site of host–microbe interactions, 37
  - 1.5.1 Structure of epithelia, 38
  - 1.5.2 The epithelium as an excluder of microbes, 41
  - 1.5.3 Mucus and mucins, 41
  - 1.5.4 Innate and acquired immune responses at the mucosal surface, 46
- 1.6 Further reading, 53
  - 1.6.1 Books, 53
  - 1.6.2 Reviews and papers, 53

## **2 THE INDIGENOUS MICROBIOTA OF THE SKIN, 56**

- 2.1 Anatomy and physiology of human skin, 56
- 2.2 Cutaneous antimicrobial defense systems, 56
  - 2.2.1 Innate defense systems, 58
  - 2.2.2 Acquired immune defense systems, 60
- 2.3 Environmental determinants operating at different skin regions, 61
- 2.4 The indigenous microbiota of the skin, 67
  - 2.4.1 Members of the cutaneous microbiota, 67
    - 2.4.1.1 *Corynebacterium* spp., 67
    - 2.4.1.2 *Propionibacterium* spp., 70
    - 2.4.1.3 *Staphylococcus* spp., 71
    - 2.4.1.4 *Micrococcus* spp., 73
    - 2.4.1.5 *Malassezia* spp., 75
    - 2.4.1.6 *Acinetobacter* spp., 76
    - 2.4.1.7 *Brevibacterium* spp., 78
    - 2.4.1.8 *Dermabacter hominis*, 79
    - 2.4.1.9 *Methylobacterium* spp., 79
  - 2.4.2 Community composition at different sites, 80
  - 2.4.3 Culture-independent studies of the cutaneous microbiota, 86
  - 2.4.4 Interactions among members of the cutaneous microbiota, 88
- 2.5 Overview of the cutaneous microbiota, 90

2.6 Sources of data used to compile figures, 92

2.7 Further reading, 92

2.7.1 Books, 92

2.7.2 Reviews and papers, 92

### **3 THE INDIGENOUS MICROBIOTA OF THE EYE, 95**

3.1 Anatomy and physiology of the eye, 95

3.2 Antimicrobial defense systems of the eye, 97

3.3 Environmental determinants on the conjunctival surface, 99

3.4 The indigenous microbiota of the eye, 103

3.4.1 Members of the ocular microbiota, 103

3.4.2 Composition of the ocular microbiota, 104

3.4.3 Interactions among members of the ocular microbiota, 107

3.5 Overview of the ocular microbiota, 111

3.6 Sources of data used to compile figures, 111

3.7 Further reading, 111

### **4 THE INDIGENOUS MICROBIOTA OF THE RESPIRATORY TRACT, 113**

4.1 Anatomy and physiology of the respiratory tract, 113

4.1.1 Nose, 113

4.1.2 Pharynx, 114

4.1.3 Larynx, 114

4.1.4 Trachea, 114

4.1.5 Bronchi and bronchioles, 114

4.1.6 Alveolus, 115

4.2 Antimicrobial defense systems of the respiratory tract, 117

4.2.1 Nasal cavity, 117

4.2.2 Other regions of the conducting portion, 119

4.2.3 Respiratory portion, 119

4.3 Environmental determinants within the respiratory tract, 119

4.3.1 Atmospheric composition, 119

4.3.2 pH, 120

4.3.3 Nutrients, 120

4.3.3.1 Composition of nasal fluid, ASL, and alveolar lining fluid, 120

4.3.3.2 Contribution of microbial residents of the respiratory tract to nutrient availability, 122

4.4 Indigenous microbiota of the respiratory tract, 123

4.4.1 Members of the respiratory microbiota, 123

4.4.1.1	<i>Streptococcus</i> spp., 123
4.4.1.1.1	<i>Strep. pyogenes</i> , 124
4.4.1.1.2	<i>Strep. pneumoniae</i> , 126
4.4.1.1.3	Viridans group streptococci, 128
4.4.1.2	<i>Neisseria</i> spp., 128
4.4.1.2.1	<i>N. meningitidis</i> , 129
4.4.1.2.2	Other <i>Neisseria</i> spp., 131
4.4.1.3	<i>Haemophilus</i> spp., 131
4.4.1.3.1	<i>H. influenzae</i> , 132
4.4.1.3.2	Other <i>Haemophilus</i> spp., 134
4.4.1.4	<i>Moraxella catarrhalis</i> , 135
4.4.1.5	<i>Staphylococci</i> , 136
4.4.1.5.1	<i>Staph. aureus</i> , 136
4.4.1.5.2	CNS, 138
4.4.1.6	<i>Mollicutes</i> , 139
4.4.1.7	<i>Kingella kingae</i> , 140
4.4.2	Community composition at the various sites within the respiratory tract, 140
4.4.2.1	Nasal vestibule, 142
4.4.2.2	Nasal cavity, 143
4.4.2.3	Nasopharynx, 146
4.4.2.4	Oropharynx, 146
4.4.2.5	Lower respiratory tract, 151
4.4.3	Interactions among members of the respiratory microbiota, 152
4.5	Overview of the respiratory microbiota, 152
4.6	Sources of data used to compile figures, 155
4.7	Further reading, 157

## **5 THE INDIGENOUS MICROBIOTA OF THE URINARY SYSTEM OF FEMALES, 159**

5.1	Anatomy and physiology of the urinary system of females, 159
5.2	Antimicrobial defenses of the female urinary system, 160
5.3	Environmental determinants within the female urethra, 161
5.4	The indigenous microbiota of the female urethra, 162
5.4.1	Members of the urethral microbiota, 163
5.4.2	Community composition in the female urethra, 164
5.5	Overview of the microbiota of the urinary tract of females, 167
5.6	Sources of data used to compile figures, 168
5.7	Further reading, 168

## **6 THE INDIGENOUS MICROBIOTA OF THE REPRODUCTIVE SYSTEM OF FEMALES, 170**

- 6.1 Anatomy and physiology of the female reproductive system, 170
- 6.2 Antimicrobial defense systems of the female reproductive system, 172
  - 6.2.1 Innate defense systems, 173
  - 6.2.2 Acquired immune defense systems, 174
- 6.3 Environmental determinants at different regions of the reproductive system, 176
  - 6.3.1 Vagina, 176
  - 6.3.2 Cervix, 179
  - 6.3.3 Vulva, 179
  - 6.3.4 Contribution of the indigenous microbiota to nutrient supply within the reproductive system, 179
- 6.4 The indigenous microbiota of the female reproductive system, 181
  - 6.4.1 Members of the microbiota, 181
    - 6.4.1.1 *Lactobacillus* spp., 181
    - 6.4.1.2 *Gardnerella vaginalis*, 184
    - 6.4.1.3 *Candida albicans*, 184
    - 6.4.1.4 *Streptococcus agalactiae* (Group B streptococcus), 186
    - 6.4.1.5 *Mycoplasma hominis*, 186
    - 6.4.1.6 *Ureaplasma urealyticum*, 186
    - 6.4.1.7 *Atopobium vaginae*, 187
    - 6.4.1.8 *Mobiluncus* spp., 187
  - 6.4.2 Community composition at different sites within the female reproductive system, 187
    - 6.4.2.1 Vagina, 187
      - 6.4.2.1.1 Post-menarcheal/pre-menopausal females, 187
      - 6.4.2.1.2 Pre-menarcheal girls, 191
      - 6.4.2.1.3 Post-menopausal women, 192
      - 6.4.2.1.4 Vaginal microbiota during pregnancy, 193
    - 6.4.2.2 Cervix, 193
      - 6.4.2.2.1 Post-menarcheal/pre-menopausal females, 197
      - 6.4.2.2.2 Cervical microbiota during pregnancy, 197
    - 6.4.2.3 Vulva, 199
  - 6.4.3 Interactions between organisms colonizing the female reproductive system, 200

- 6.5 Overview of the microbiota of the female reproductive system, 202
- 6.6 Sources of data used to compile figures, 202
- 6.7 Further reading, 204
  - 6.7.1 Books, 204
  - 6.7.2 Reviews and papers, 204

## **7 THE INDIGENOUS MICROBIOTA OF THE URINARY AND REPRODUCTIVE SYSTEMS OF MALES, 207**

- 7.1 Anatomy and physiology, 207
- 7.2 Antimicrobial defenses of the male urinary and reproductive systems, 207
- 7.3 Environmental determinants within the male urinary and reproductive systems, 210
- 7.4 The indigenous microbiota of the male urinary and reproductive systems, 211
  - 7.4.1 Members of the microbiota, 211
  - 7.4.2 Microbiota of the male urethra, 212
  - 7.4.3 Microbiota of the glans penis, 216
  - 7.4.4 Microbiota of the prostate, 218
- 7.5 Overview of the microbiota of the male urinary and reproductive systems, 218
- 7.6 Sources of data used to compile figures, 219
- 7.7 Further reading, 220

## **8 THE INDIGENOUS MICROBIOTA OF THE ORAL CAVITY, 222**

- 8.1 Anatomy and physiology of the oral cavity, 222
- 8.2 Antimicrobial defense systems of the oral cavity, 225
- 8.3 Environmental determinants at the various sites within the oral cavity, 228
  - 8.3.1 Mechanical determinants, 228
  - 8.3.2 Nutritional determinants, 228
  - 8.3.3 Physicochemical determinants, 231
- 8.4 The indigenous microbiota of the oral cavity, 232
  - 8.4.1 Members of the oral microbiota, 235
    - 8.4.1.1 Oral streptococci and related Gram-positive cocci, 235
    - 8.4.1.2 *Gemella* spp., 235
    - 8.4.1.3 *Actinomyces* spp., 236
    - 8.4.1.4 *Rothia dentocariosa*, 237
    - 8.4.1.5 *Veillonella* spp., 237
    - 8.4.1.6 Anaerobic and microaerophilic Gram-negative rods, 237
      - 8.4.1.6.1 *Fusobacterium* spp., 237
      - 8.4.1.6.2 *Porphyromonas* spp., 238
      - 8.4.1.6.3 *Prevotella* spp., 239

8.4.1.6.4	Spirochaetes, 239
8.4.1.6.5	Other anaerobic species, 239
8.4.1.7	Facultatively anaerobic Gram-negative bacilli, 240
8.4.1.8	<i>Mycoplasma</i> spp., 240
8.4.1.9	<i>Megasphaera</i> spp., 241
8.4.2	Community composition at different sites, 241
8.4.2.1	Supragingival plaque, 241
8.4.2.2	Gingival crevice, 253
8.4.2.3	Tongue, 256
8.4.2.4	Other mucosal surfaces, 257
8.5	Overview of the oral microbiota, 261
8.6	Sources of data used to compile figures, 263
8.7	Further reading, 264
8.7.1	Books, 264
8.7.2	Reviews and papers, 264

## **9 THE INDIGENOUS MICROBIOTA OF THE GASTROINTESTINAL TRACT, 266**

9.1	Anatomy and physiology of the gastrointestinal tract, 267
9.2	Antimicrobial defense systems of the gastrointestinal tract, 272
9.2.1	Innate defense systems, 272
9.2.2	Acquired immune defense system, 275
9.3	Environmental determinants within different regions of the gastrointestinal tract, 276
9.3.1	Esophagus, 276
9.3.2	Stomach, 277
9.3.3	Small intestine, 277
9.3.4	Large intestine, 278
9.4	The indigenous microbiota of the gastrointestinal tract, 280
9.4.1	Members of the intestinal microbiota, 282
9.4.1.1	<i>Bacteroides</i> , 282

- 9.4.1.2 *Eubacterium*, 283
  - 9.4.1.3 *Roseburia*, 284
  - 9.4.1.4 *Clostridium*, 284
  - 9.4.1.5 *Bifidobacterium*, 284
  - 9.4.1.6 *Enterococcus*, 285
  - 9.4.1.7 *Helicobacter pylori*, 286
  - 9.4.1.8 *Enterobacteriaceae*, 286
  - 9.4.1.9 *Ruminococcus*, 287
  - 9.4.1.10 Methanogenic organisms, 287
  - 9.4.1.11 *Desulfovibrio*, 287
  - 9.4.1.12 *Acidaminococcus*, 288
  - 9.4.1.13 *Faecalibacterium prausnitzii*, 288
- 9.4.2 Community composition in different regions of the intestinal tract, 288
- 9.4.2.1 Esophagus, 288
  - 9.4.2.2 Stomach, 289
  - 9.4.2.3 Small intestine, 295
    - 9.4.2.3.1 Duodenum, 295
    - 9.4.2.3.2 Jejunum, 295
    - 9.4.2.3.3 Ileum, 301
  - 9.4.2.4 Large intestine, 302
    - 9.4.2.4.1 Cecum, 304
    - 9.4.2.4.2 Colon, 306
    - 9.4.2.4.3 Rectum, 316
- 9.4.3 Microbial interactions in the gastrointestinal tract, 317
- 9.5 Overview of the indigenous microbiota of the gastrointestinal tract, 320
- 9.6 Sources of data used to compile figures, 320
- 9.7 Further reading, 322
- 9.7.1 Books, 322
  - 9.7.2 Reviews and papers, 322

## **10 THE FUTURE, 327**

- 10.1 Further reading, 329

Index, 331