*Journal of Antimicrobial Chemotherapy* (2002) **50**, 805–810
DOI: 10.1093/jac/dkg009

JAC

# Microbiology of polymicrobial abscesses and implications for therapy

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**Abscesses that develop as a result of introduction of the normal flora into a normally sterile body site are often polymicrobial. This review summarizes past studies published by our group on the microbiology of polymicrobial abscesses that occur at various body sites. *Staphylococcus aureus* and Group A β-haemolytic streptococci are the most prevalent aerobes in skin and soft tissue abscesses and are isolated at all body sites. In contrast, organisms that colonize the mucous membranes predominated in infections adjacent to these membranes. In this fashion, organisms of the gastrointestinal and cervical flora (enteric Gram-negative bacilli and *Bacteroides fragilis* group) were found most often in intra-abdominal and buttock and leg lesions. Group A β-haemolytic streptococci, pigmented *Prevotella* and *Porphyromonas* spp., and *Fusobacterium* spp. were most commonly found in lesions of the mouth, head, neck and fingers. These organisms probably reached these sites from the oral cavity, where they are part of the normal flora. Drainage of the abscess is the treatment of choice. Appropriate management of these mixed aerobic and anaerobic infections may also require the administration of antimicrobials that are effective against both the aerobic and anaerobic components of the infections.**

Keywords: abscess, *Bacteroides* spp., therapy, anaerobic bacteria, synergy

## Introduction

Abscesses that develop as a result of introduction of the normal flora into a normally sterile body site are often polymicrobial in nature. Flora can gain access to the sterile site by direct extension or secondary to laceration or perforation. Because of the uniqueness of the normal flora at various body sites, the microbiology of such abscesses is generally predictable by their location.

This review summarizes our past studies of the microbiology of polymicrobial abscesses that occur at various body sites. These were retrospective studies accomplished by reviewing the clinical and microbiology laboratory records of patients whose specimens from infected sites were processed for the presence of aerobic and anaerobic bacteria. These studies demonstrated the polymicrobial aetiology of abscesses and the association of their bacterial flora with the anatomical site of the infection. The implications of the microbiology for the management of abscesses are discussed.

## Role of the normal flora in polymicrobial abscesses

In most mucous membranes, anaerobes outnumber aerobic and facultative bacteria in ratios ranging from 10:1 to 10 000:1, with anaerobic Gram-negative bacilli (AGNB) predominating.[1,2] Species of the *Bacteroides fragilis* group that colonize the gastrointestinal tract (GIT) are usually isolated in intra-abdominal and rectal abscesses; pigmented *Prevotella* and *Porphyromonas* and *Fusobacterium* spp. that colonize the oral cavity are present mainly in oral cavity abscesses, and *Prevotella bivia* and *Prevotella disiens*, which predominate in the cervical canal, are most often recovered in pelvic abscesses. The predominant aerobes and facultative organisms in abdominal and rectal abscesses are Enterobacteriaceae and staphylococci, and *Neisseria gonorrhoeae* are common in pelvic abscesses (Table 1).

The bacterial flora of the GIT is very dynamic, and changes in the flora influence the type and severity of post-perforation

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Published by Oxford University Press

**Table 1.** Microbiological characteristics of 676 cutaneous abscesses[23]

| | Abscesses | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | head | neck | breast | trunk | arm | hand | leg | inguinal | buttock | perirectal | extra genital | total |
| Number of specimens | 158 | 43 | 40 | 123 | 13 | 21 | 12 | 32 | 35 | 136 | 63 | 676 |
| Type of bacterial growth, number of specimens | | | | | | | | | | | | |
| aerobic only | 45 | 20 | 7 | 53 | 3 | 13 | 8 | 7 | 8 | 9 | 4 | 177 |
| anaerobic only | 51 | 14 | 18 | 41 | 4 | 4 | 3 | 15 | 15 | 55 | 23 | 243 |
| both | 62 | 9 | 15 | 29 | 6 | 4 | 1 | 10 | 12 | 72 | 36 | 256 |
| Number of bacterial isolates per specimen | | | | | | | | | | | | |
| aerobic | 0.8 | 1.0 | 0.7 | 1.1 | 1.1 | 1.3 | 1.1 | 0.7 | 0.7 | 0.9 | 0.9 | 0.9 |
| anaerobic | 1.4 | 1.6 | 1.4 | 1.3 | 1.7 | 0.7 | 0.9 | 1.8 | 1.4 | 2.2 | 1.9 | 1.6 |
| total | 2.2 | 2.6 | 2.1 | 2.4 | 2.8 | 2.0 | 2.0 | 2.5 | 2.1 | 3.1 | 2.8 | 2.5 |

infection. The stomach and upper bowel flora contain $10^4$ organisms/g or fewer, the lower ileum up to $10^8$ organisms/g and the colon up to $10^{11}$ organisms/g, most of which are anaerobes.[3] The low number of organisms in the stomach is believed to be due to the detrimental effect of the low pH of the stomach on the organisms ingested from the oropharynx. The contents of the gut slowly becomes alkaline at the lower intestine. This change, the effect of bile and the decrease in oxygen tension in the lower intestine allow for the selection of bile-resistant organisms and an increase in the number of strict anaerobes. A high number of organisms in the upper GIT can, however, be found in patients with decreased stomach acidity or those with a shorter GIT or anastomosis.

Variations in the number of bacteria in the GIT account for the differences that are observed in cultures of the peritoneal cavity after perforations. Three different isolates per specimen and ~$10^7$ organisms/g were recovered from perforation of the small intestine, whereas 26 different bacterial isolates and $10^{12}$ organisms/g were isolated from specimens of colonic perforation.[4] This high load of microorganisms is believed to account for the higher frequency (50%) of the infections that follow colonic injury, compared with that after chest injuries (18%), found by Dellinger *et al*.[5] The higher number of organisms in the distal part of the colon also explains why infection developed in 45% of patients with descending-colon injuries, compared with ~13% in the other sites of the colon.

## Microbiology of abscesses of endogenous origin

Gram-positive anaerobic cocci are normal skin inhabitants and part of the normal faecal flora.[2] These cocci are also isolated from intra-abdominal abscesses.[6–12] They were isolated as frequently as AGNB from abscesses of the perineal region and were also isolated frequently from non-perineal cutaneous abscesses.

Organisms belonging to the *B. fragilis* group, which predominate in the faeces, were cultured most frequently from abscesses of the perirectal area.[3] *Prevotella melaninogenica*, which occurs in stool as well as in the oral cavity,[2] was also recovered from this site and from the head.

The microbiology of intra-abdominal abscesses that develop following perforation of viscera is composed of similar patterns of organisms and is made up of the gastrointestinal flora at the level of the perforation (Table 2). The predominant anaerobic bacteria are the *B. fragilis* group, *Peptostreptococcus* spp. and *Clostridium* spp., whereas the most commonly isolated aerobic and facultative bacteria are Enterobacteriaceae and Group D *Enterococcus* spp. These organisms were recovered from a variety of intra-abdominal,[6] retroperitoneal,[7] visceral (e.g. pancreatic,[8] hepatic, splenic[9]) and perirectal[10] abscesses (post-diverticulitis rupture[11] and subphrenic[12]). A similar pattern also exists in the microbiology of pelvic, vulvo-vaginal[13] and prostatic[14] abscesses, which originate from the rectal and cervical flora.[2,3] The predominant anaerobic bacteria are *P. bivia*, *P. disiens* and peptostreptococci, whereas the common aerobic and facultative bacteria include Enterobacteriaceae, *N. gonorrhoeae* and Group B streptococci (Table 2).

The microbiology of dental, oro-facial and neck abscesses is mainly that of the oral flora organisms (Table 3).[15] These include peritonsillar,[16] retropharyngeal,[17] parotic[18] and cervical lymph gland[19] abscesses. The main anaerobes are pigmented *Prevotella* and *Porphyromonas*, *Fusobacterium* spp. and *Peptostreptococcus* spp. The most commonly isolated aerobes and facultative bacteria are *Streptococcus pyogenes* and *Staphylococcus aureus*.

The microbiology of skin and soft tissue abscesses is also related to their location.[15,20–23] *S. pyogenes* and *S. aureus*, which colonize the skin all over the body, can be recovered at

**Table 2.** Predominant isolates in abscesses at various body sites

| Infection site | Anaerobic bacteria | Facultative and miscellaneous bacteria |
|---|---|---|
| Skin and subcutaneous wounds and abscesses | *B. fragilis* group (rectal), *Prevotella* and *Porphyromonas* spp. (oral) | *S. aureus*, *S. pyogenes*, *Escherichia coli* (rectal), Enterobacteriaceae |
| Head and neck | *Prevotella* and *Porphyromonas* spp., *Fusobacterium* spp., *Peptostreptococcus* spp. | *S. pyogenes*, *S. aureus* |
| Abdomen | *B. fragilis* group, *Peptostreptococcus* spp., *Clostridium* spp. | *E. coli*, Enterobacteriaceae |
| Pelvis | *P. bivia*, *P. disiens*, *B. fragilis* group | *N. gonorrhoeae*, streptococci, *Chlamydia trachomatis*, Enterobacteriaceae |

all locations. The location of the abscess is of paramount importance in the emergence of the other organism(s) that may also be involved in the infection. Under appropriate conditions of lowered tissue resistance, almost any of the common bacteria can initiate an infectious process. Cultures from lesions frequently contain several bacterial species; as might be expected, the organisms found most frequently are the 'normal flora' of these regions (Table 2).

Aspirates from abscesses of the perineal and oral regions tend to yield organisms found in stool or mouth flora.[21–23] Conversely, pus obtained from abscesses in areas remote from the rectum or mouth contain primarily constituents of the microflora indigenous to the skin, such as *S. pyogenes* and *S. aureus*. Multiple anaerobic organisms are usually recovered from the perineal region, whereas only about one aerobe per abscess is present at other sites (Table 1). Anaerobes are also recovered alone, without aerobes, more often from the perineal area. Mixed aerobic and anaerobic infections are more prevalent in the perirectal, head, finger and nail bed areas. The similarities in the rates of isolation of mixed aerobic and anaerobic flora and the high rate of recovery of anaerobes in these areas are of particular interest. This may be due, in the last two areas, to the introduction of mouth flora, which is predominantly anaerobic, onto the fingers by sucking or nail biting, which are common activities among children. This is parallel to the acquisition of infection following human bites and clenched fist injuries in which anaerobic mouth flora was the source of most bacterial isolates.[24]

The polymicrobial nature of abdominal, pelvic and skin and soft tissue (proximal to the oral or rectal areas) abscesses is apparent in the majority of patients, where the number of isolates in an infectious site varies between two and six[1,2] (Tables 1 and 3). The average number of isolates is 3.6 in skin and soft tissue infections (2.6 anaerobes and 1.0 aerobe) per specimen,[21–23] five in intra-abdominal infection (3.0 anaerobes and 2.0 aerobes) per specimen and four in pelvic infections (2.8 anaerobes and 1.2 aerobes) per specimen.[13,14] Polymicrobial infections are known to be more pathogenic for experimental animals than those involving single organisms.[25,26] The number of isolates in these polymicrobial abscesses varies from two to six (Tables 1 and 3), and is generally higher when reported in studies in which stricter methods for collection, transportation and cultivation of anaerobic organisms are employed.[17,18,24,27]

## Management

Surgical drainage is the treatment of choice for abscesses. Evacuation of the abscess cavity serves two major purposes: to obtain good bacteriological specimens for maximal antibiotic efficiency and to remove and thus prevent local spread of purulent material. Drainage can be accomplished during surgery, or by aspiration guided by ultrasound or computerized tomography (CT).[28] Although antimicrobial drugs may prevent suppuration if given early, or prevent spread of an existing abscess, they cannot be substituted for surgical drainage. Heat application can relieve the pain and speed suppuration and liquefaction. Elevation of the affected part reduces the oedema and pain.

The early administration of antibiotics can abort the development of an abscess. Once the suppuration has appeared, however, drugs generally become incapable of eradicating the infecting organisms. Several antibiotics can be partially inactivated by the pus, whereas others can maintain their potency. Another factor that decreases the activity of antibiotics that are active only against multiplying organisms (penicillins and cephalosporins) is the failure of offending bacteria to multiply well in pus. Phagocytosis, which is essential to complete elimination of bacteria, is reduced in the abscess cavity. Because of the combination of these two factors, many abscesses are resistant to antimicrobial therapy.

Because anaerobic bacteria are frequently associated with abscesses, especially in areas adjacent to the mucosal surfaces, physicians should anticipate their presence if antimicrobial therapy is employed. Gram's stain of aspirated pus and appropriate aerobic and anaerobic techniques can help the physician select proper therapy. Because some of the anaerobes are

**Table 3.** Predominant isolates from abscesses

| | Abdominal | | | | | | | | Urogenital | | | | Head and neck | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | abdomen | retroperitoneal | diverticulitis | perirectal | liver | spleen | pancreatic | subphrenic | Burtholm's cyst | prostate | testicular | scrotal | periapical | cervical lymphadenitis | parotic | peritonsilllar | retropharyngeal |
| Reference | 6 | 7 | 11 | 10 | 9 | 9 | 8 | 12 | 14 | 14 | 14 | 14 | 20 | 19 | 18 | 16 | 17 |
| Number of patients | 83 | 161 | 22 | 144 | 48 | 29 | 46 | 52 | 26 | 3 | 6 | 15 | 32 | 40 | 23 | 34 | 14 |
| Aerobic bacteria | | | | | | | | | | | | | | | | | |
| *S. pyogenes* | | 1 | | 9 | 3 | 1 | | 4 | | | | 1 | | 4 | 1 | 10 | 3 |
| *Enterococcus* spp. | | 19 | 3 | 9 | 8 | 3 | 11 | 9 | | 1 | | 5 | | | | | |
| *S. aureus* | | 11 | 1 | 34 | 4 | 4 | 6 | 5 | 2 | | 1 | 5 | 1 | 8 | 8 | 6 | 5 |
| *M. catarrhalis* | | | | | | | | | | | | | | | | 5 | 2 |
| *Haemophilus* spp. | 1 | | | | | | | | | | | | 2 | | 2 | 7 | 4 |
| *E. coli* | 57 | 60 | 15 | 19 | 11 | 5 | 18 | 28 | 6 | 2 | | | | 1 | 1 | | |
| *K. pneumoniae* | 8 | 20 | 3 | 3 | 5 | 3 | 12 | 3 | 2 | | | | | 1 | | | |
| *P. aeruginosa* | 4 | 9 | 1 | 4 | 2 | 1 | 5 | 3 | | | | 2 | | 1 | | | |
| *Enterobacter* spp. | 1 | 8 | | 1 | | | 4 | 4 | 1 | | | | | | | | |
| *Proteus* spp. | 2 | 8 | 1 | 12 | 2 | 3 | 3 | 4 | 3 | 1 | | 1 | | | | | |
| *S. marcescens* | | 6 | 1 | | 3 | | 3 | 3 | | | | | | | | | |
| *N. gonorrhoeae* | | 4 | | 2 | 1 | | | | 4 | | | | | | | | |
| Enterobacteriaceae | | 20 | 2 | 16 | | 1 | 6 | 2 | 3 | 2 | | | | | | | |
| Subtotal | 107 | 204 | 35 | 131 | 43 | 23 | 77 | 83 | 24 | 6 | 3 | 15 | 23 | 18 | 16 | 49 | 26 |
| Anaerobic bacteria | | | | | | | | | | | | | | | | | |
| *Peptostreptococcus* spp. | 24 | 95 | 6 | 72 | 18 | 11 | 26 | 33 | 12 | 1 | 3 | 7 | 18 | 5 | 5 | 16 | 18 |
| *Veillonella* spp. | 2 | 10 | 1 | 6 | 3 | 1 | 6 | 6 | 2 | | | 1 | 2 | 1 | | 5 | 3 |
| *Eubacterium* spp. | 2 | 6 | 1 | 11 | | | 1 | 4 | | | | 1 | 2 | | 1 | 1 | 4 |
| *P. acnes* | | 13 | | 2 | 3 | 3 | 4 | 4 | | | | | 1 | 4 | 4 | 3 | 1 |
| *C. perfringens* | 6 | 10 | 2 | 4 | 5 | 2 | 4 | 6 | 1 | | | | | | | | |
| *Clostridium* spp. | 13 | 13 | 3 | 11 | 5 | 1 | 3 | 7 | | | | 2 | | | | | 2 |
| *Fusobacterium* spp. | 4 | 14 | 1 | 21 | 10 | 3 | 5 | 5 | 2 | | | | 9 | | 3 | 11 | 14 |
| *B. fragilis* | 47 | 34 | 14 | 58 | 7 | 2 | 6 | 11 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| *B. fragilis* group | 11 | 32 | 7 | 27 | 6 | 3 | 11 | 14 | 2 | 1 | 2 | | 1 | | | | |
| *P. melaninogenica* | 5 | 5 | 2 | 18 | 1 | 1 | 2 | 2 | 2 | | 1 | 2 | 3 | 3 | 1 | 7 | 10 |
| *P. intermedia* | | 7 | | 12 | 2 | 2 | 3 | 3 | 1 | | | 1 | 2 | 2 | 3 | 3 | 4 |
| *P. asaccharolytica* | 4 | 3 | 1 | 20 | | | | | 3 | | 1 | 2 | 1 | 2 | | 5 | 4 |
| *P. oralis* | | 2 | | 2 | | | | | 1 | | | 1 | 4 | | | 1 | 3 |
| *P. disiens* | | 1 | | 6 | 1 | | 1 | 1 | | | | | | | | | |
| *P. bivia* | | 2 | | 14 | | | | | 4 | | | 3 | | | | | |
| *Bacteriodes* spp. | 3 | 12 | 1 | 19 | | | 4 | 7 | 6 | 1 | | 6 | 4 | 2 | 1 | 4 | 11 |
| *P. gingivalis* | | | | | | | | | | | | | 7 | | | | |
| Subtotal | 128 | 268 | 37 | 325 | 73 | 33 | 81 | 111 | 43 | 4 | 8 | 28 | 55 | 24 | 20 | 58 | 78 |
| Total | 235 | 472 | 72 | 256 | 116 | 56 | 158 | 194 | 67 | 10 | 11 | 33 | 78 | 42 | 36 | 107 | 104 |

*M. catarrhalis*, *Moraxella catarrhalis*; *K. pneumoniae*, *Klebsiella pneumoniae*; *P. aeruginosa*, *Pseudomonas aeruginosa*; *S. marcescens*, *Serratia marcescens*; *P. acnes*, *Propionibacterium acnes*; *C. perfringens*, *Clostridium perfringens*; *P. melaninogenica*, *Prevotella melaninogenica*; *P. intermedia*, *Prevotella intermedia*; *P. asaccharolytica*, *Porphyromonas asaccharolytica*; *P. oralis*, *Prevotella oralis*; *P. gingivalis*, *Porphyromonas gingivalis*.

resistant to penicillin, therapy should also include appropriate coverage of these organisms in more serious infections.

A careful attempt should be made to identify the causative microorganisms, including anaerobes, and as many of the isolated aerobic and anaerobic bacteria produce β-lactamase and are resistant to penicillins,[29] antimicrobial agents effective against these organisms should be used. If anaerobic organisms are isolated, metronidazole, clindamycin, a carbapenem (i.e. imipenem), cefoxitin or the combination of a penicillin and a β-lactamase inhibitor are the drugs of choice.[1,2] Metronidazole is also a very potent amoebicide. An aminoglycoside, a quinolone (in adults) or a third-generation cephalosporin should be added if Gram-negative enteric bacteria are present, and if *S. aureus* is present anti-staphylococcal agents should be used. Antimicrobial agents, especially when used without surgical drainage, should be given for at least 6–8 weeks. A shorter course, of 4–6 weeks, may be used when good surgical drainage has been achieved, but more precise recommendations for the treatment of liver and spleen abscesses have not yet been determined in prospective studies.

Appropriate management of mixed aerobic and anaerobic infections requires the administration of antimicrobials that are effective against both aerobic and anaerobic components of the infection[1,2] in addition to surgical correction and drainage of pus. When such therapy is not given, the infection may persist, and more serious complications may occur.[30]

A number of factors should be considered when choosing appropriate antimicrobial agents. They should be effective against all target organism(s), induce little or no resistance, achieve sufficient levels in the infected site, have minimal toxicity and have maximal stability and longevity.

Antimicrobials often fail to cure the infection. Some of the reasons they do not work are the development of bacterial resistance, achievement of insufficient tissue levels, incompatible drug interaction and the development of an abscess. The environment of an abscess is detrimental for many antimicrobials. The abscess fibrotic capsule interferes with the penetration of antimicrobial agents, and the low pH and the presence of binding proteins or inactivating enzymes (i.e. β-lactamases) may impair the activity of many antimicrobials. The low pH and the anaerobic environment within the abscess are especially deleterious toward the aminoglycosides and quinolones.[31] It should be remembered that an acidic environment, high osmolarity and the presence of an anaerobic environment can develop in an infection site without the presence of an abscess.[30]

## References


**1.** Brook, I. (2002). *Pediatric Anaerobic Infection: Diagnosis and Management*, 3rd edn. Marcel Dekker, New York, NY, USA.

**2.** Finegold, S. M. (1977). *Anaerobic Bacteria in Human Disease*. Academic Press, New York, NY, USA.

**3.** Sullivan, A., Edlund, C. & Nord, C. E. (2001). Effect of antimicrobial agents on the ecological balance of human microflora. *Lancet Infectious Diseases* **1**, 101–14.

**4.** Bartlett, J. G. (1995) Intra-abdominal sepsis. *Medical Clinics of North America* **79**, 599–617.

**5.** Dellinger, E. P., Oreskovich, M. R., Wertz, M. J., Hamasaki, V. & Lennard, E. S. (1984). Risk of infection following laparotomy for penetrating abdominal injury. *Archives of Surgery* **119**, 20–7.

**6.** Brook, I. (1989). A 12 year study of aerobic and anaerobic bacteria in intra-abdominal and post surgical abdominal wound infections. *Surgery, Gynecology and Obstetrics* **169**, 387–92.

**7.** Brook, I. & Frazier, E. H. (1998) Aerobic and anaerobic microbiology of retroperitoneal abscesses. *Clinical Infectious Diseases* **26**, 938–41.

**8.** Brook, I. & Frazier, E. H. (1996). Microbiological analysis of pancreatic abscess. *Clinical Infectious Diseases* **22**, 384–5.

**9.** Brook, I. & Frazier, E. H. (1998). Microbiology of liver and spleen abscesses. *Journal of Medical Microbiology* **47**, 1075–80.

**10.** Brook, I. & Frazier, E. H. (1997). The aerobic and anaerobic bacteriology of perirectal abscesses. *Journal of Clinical Microbiology* **35**, 2974–6.

**11.** Brook, I. & Frazier, E. H. (2000). Aerobic and anaerobic microbiology in intra-abdominal infections associated with diverticulitis. *Journal of Medical Microbiology* **49**, 827–30.

**12.** Brook, I., & Frazier, E. H. (1999). Microbiology of subphrenic abscesses: a 14-year experience. *American Surgeon* **65**, 1049–53.

**13.** Brook, I., Frazier, E. H. & Thomas, R. L. (1991). Aerobic and anaerobic microbiologic factors and recovery of beta-lactamase-producing bacteria from obstetric and gynecologic infection. *Surgery, Gynecology and Obstetrics* **172**, 138–44.

**14.** Brook, I. (1989). Anaerobic bacteria in suppurative genitourinary infections. *Journal of Urology* **141**, 889–93.

**15.** Brook, I. (1987). Microbiology of abscesses of the head and neck in children. *Annals of Otology, Rhinology and Laryngology* **96**, 429–33.

**16.** Brook, I., Frazier, E. H. & Thompson, D. H. (1991) Aerobic and anaerobic microbiology of peritonsillar abscess. *Laryngoscope* **101**, 289–92.

**17.** Brook, I. (1987). Microbiology of retropharyngeal abscesses in children. *American Journal of Diseases of Childhood* **141**, 202–4.

**18.** Brook, I., Frazier, E. H. & Thompson, D. H. (1991). Aerobic and anaerobic microbiology of acute suppurative parotitis. *Laryngoscope* **101**, 170–2.

**19.** Brook, I. & Frazier, E. H. (1998). Microbiology of cervical lymphadenitis in adults. *Acta Otolaryngologica* **118**, 443–6.

**20.** Brook, I., Frazier, E. H. & Gher, M. E. (1991). Aerobic and anaerobic microbiology of periapical abscess. *Oral Microbiology and Immunology* **6**, 123–5.

**21.** Meislin, H. W., Lerner, S. A., Graves, M. H., McGehee, M. D., Kocka, F. E., Morello, J. A. *et al.* (1977). Cutaneous abscesses. Anaerobic and aerobic bacteriology and outpatient management. *Annals of Internal Medicine* **87**, 145–9.

**22.** Brook, I. & Finegold, S. M. (1981) Aerobic and anaerobic bacteriology of cutaneous abscesses in children. *Pediatrics* **67**, 891–5.

**23.** Brook, I. & Frazier, E. H. (1990). Aerobic and anaerobic bacteriology of wounds and cutaneous abscesses. *Archives of Surgery* **125**, 1445–51.

**24.** Talan, D. A., Citron, D. M., Abrahamian, F. M., Moran, G. J. & Goldstein, E. J. (1999). Bacteriologic analysis of infected dog and cat bites. Emergency Medicine Infection Study Group. *New England Journal of Medicine* **340**, 85–92.

**25.** Thadepalli, H., Gorbach, S. L. & Keith, L. (1973). Anaerobic infections of the female genital tract: bacteriology and therapeutic implementation. *American Journal of Obstetrics and Gynecology* **117**, 1034–9.

**26.** Altermeier, W. A. (1942). The pathogenicity of the bacteria of appendicitis. *Surgery* **11**, 374–8.

**27.** Bennion, R. S., Baron, E. J., Thompson, J. E., Jr, Downes, J., Summanen, P., Talan, D. A. *et al*. (1990). The bacteriology of gangrenous and perforated appendicitis—revisited. *Annals of Surgery* **211**, 165–71.

**28.** Podnos, Y. D., Jimenez, J. C. & Wilson, S. E. (2002). Intra-abdominal sepsis in elderly persons. *Clinical Infectious Diseases* **35**, 62–8.

**29.** Finegold, S. M. (1999). *In vitro* efficacy of beta-lactam/beta-lactamase inhibitor combinations against bacteria involved in mixed infections. *International Journal of Antimicrobial Agents* **12**, *Suppl. 1*, S9–14 (discussion S26–7).

**30.** Brook, I. (1999). Anaerobic infections. *Reviews in Medical Microbiology* **10**, 137–53.

**31.** Wright, D. H., Gunderson, B. W., Hovde, L. B., Ross, G. H., Ibrahim, K. H. & Rotschafer, J. C. (2002). Comparative pharmacodynamics of three newer fluoroquinolones versus six strains of staphylococci in an *in vitro* model under aerobic and anaerobic conditions. *Antimicrobial Agents and Chemotherapy* **46**, 1561–3.