Nonfermenting Gram-negative bacteria (GNB) are typified by *Pseudomonas* and *Achromobacter* species, which are widely distributed in natural environments, including soil, water, rhizosphere, and agriculture. Less is known about other nonfermenters, such as *Stenotrophomonas maltophilia*, *Burkholderia cepacia* complex, and *Achromobacter xylosoxidans*, which largely share the same environmental niche and are increasingly being recognized as emerging pathogens in hospitalized, immunocompromised, and cystic fibrosis (CF) patients.

**Classification and Taxonomy**

The taxonomy of this group of organisms continues to change as more information is gathered (see - Fig. 1). *S. maltophilia* was originally classified within the genus *Pseudomonas*, but it was reassigned to the Gammaproteobacteria class, initially within the genus *Xanthomonas*, and subsequently moved to *Stenotrophomonas* with seven other named species. Genomic subtyping among *S. maltophilia* isolates demonstrates remarkable diversity suggesting that

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**Abstract**

*Stenotrophomonas maltophilia*, *Achromobacter xylosoxidans*, and nonmelioid *Burkholderia* species, namely, *Burkholderia cepacia* complex, collectively are a group of troublesome nonfermenters. Although not inherently virulent organisms, these environmental Gram negatives can complicate treatment in those who are immunocompromised, critically ill in the intensive care unit and those patients with suppurative lung disease, such as cystic fibrosis. Through a range of intrinsic antimicrobial resistance mechanisms, virulence factors, and the ability to survive in biofilms, these opportunistic pathogens are well suited to persist, both in the environment and the host. Treatment recommendations are hindered by the difficulties in laboratory identification, the lack of reproducibility of antimicrobial susceptibility testing, the lack of clinical breakpoints, and the absence of clinical outcome data. Despite trimethoprim–sulfamethoxazole often being the mainstay of treatment, resistance is widely encountered, and alternative regimens, including combination therapy, are often used. This review will highlight the important aspects and unique challenges that these three nonfermenters pose, and, in the absence of clinical outcome data, our therapeutic recommendations will be based on reported antimicrobial susceptibility and pharmacokinetic/pharmacodynamic profiles.

**Keywords**

- antimicrobial resistance
- nonfermenting Gram-negative bacteria
- biofilm
- cystic fibrosis
- immunocompromised patient
- intensive care unit
- antimicrobial susceptibility testing

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**Stenotrophomonas, Achromobacter, and Nonmelioid Burkholderia Species: Antimicrobial Resistance and Therapeutic Strategies**

Iain J. Abbott, MBBS¹  Anton Y. Peleg, MBBS, PhD, MPH, FRACP²,³

¹Victorian Infectious Diseases Reference Laboratory, Peter Doherty Institute, Victoria, Australia
²Department of Infectious Diseases, The Alfred Hospital, Victoria, Australia
³Department of Microbiology, Monash University, Clayton, Victoria, Australia

Address for correspondence Iain J. Abbott, MBBS, Victorian Infectious Diseases Reference Laboratory, Doherty Institute, 792 Elizabeth Street, Melbourne, Victoria, Australia 3000 (e-mail: iainabbott@gmail.com).

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S. maltophilia may represent a “complex” of species. The Burkholderia genus, also originally of the genus Pseudomonas, contains more than 60 species and is found within the Betaproteobacteria class and Burkholderiales order. B. cepacia is referred to as a “complex” as it contains at least 17 genetically related species, formally designated as numbered genomovars (see Table 1). B. multivorans (genomovar II) and B. cenocepacia (genomovar III) are the most commonly identified and clinically relevant species within the complex. B. cenocepacia is further split into four phylogenetic lineages (IIA, IIB, IIC, and IID) based on the polymorphism of the recA gene. In CF, patients colonized with B. cenocepacia, especially lineage IIA, have a higher mortality following lung transplantation. A. xylosoxidans is similarly classified within the Burkholderiales order, but within the Alcaligenaceae family. Although previously assigned to the Alcaligenes genus, A. xylosoxidans now remains the type species within the Achromobacter genus, together with six other named species and multiple genogroups.

Epidemiology, Transmission, and Clinical Significance

Stenotrophomonas, Burkholderia, and Achromobacter species are all ubiquitous environmental organisms found in water, soil, the rhizosphere, and in and on plants. They have a worldwide distribution. SENTRY data from 1997 to 2003 identified 221,084 bacterial isolates, including 11.5% that were nonenteric GNB, of which Stenotrophomonas and Achromobacter species accounted for the majority (82.7%). Of the remaining nonenteric GNB isolated, 3,509 isolates were analyzed, of which S. maltophilia accounted for 59.2%, B. cepacia complex 7.7%, and Achromobacter species 6.7%. Amongst cancer patients at the MD Anderson Cancer Centre, the incidence of S. maltophilia had increased over time, accounting for the 5th most common Gram-negative bacterial isolate. In tropical Australia, bacteremia cases from 2000 to 2010 (over 4,500 cases), S. maltophilia accounted for 1.6% of cases; Achromobacter species 0.2%; and B. cepacia complex was not identified.

The proportion of CF patients colonized with traditional pathogens has largely remained stable over time, with P. aeruginosa isolated in 60 to 80% of patients, and methicillin-sensitive Staphylococcus aureus in 30 to 60%, while the prevalence of B. cepacia complex remains low (3–5%) with a declining incidence. There is, however, an increasing prevalence of S. maltophilia (4–15%), A. xylosoxidans (3–8%), nontuberculous mycobacteria (5–13%), and methicillin-resistant S. aureus (17.2%). In a French regional CF center, over 5,000 sputa were collected from 300 CF patients. The incidence of Pseudomonas was 59%, S. maltophilia 18.9%, B. cenocepacia 13.8%, and A. xylosoxidans 6.9%. Coinfection with two or more of these pathogens was noted to be common. In a multicenter study from Australia and New Zealand, CF patients colonized with B. cepacia complex were investigated. The authors identified B. multivorans in 29.3% and B. cenocepacia in 45.7%, with some geographic variability. Some CF centers in Australia are dominated instead by B. multivorans (A.Y. Peleg, written personal communication, July 2014). Multilocus sequence typing scheme has demonstrated that several different Achromobacter species and genogroups can infect patients with CF, although less is known about the possible differences in tropism and pathogenicity between the different species.

Person-to-person transmission of these multidrug-resistant pathogens, especially among CF patients, remains a concern. Unlike B. cepacia complex, where evidence for cross-transmission is well reported, less is known for S. maltophilia and A. xylosoxidans. However, case reports have documented incidences of patient cross-transmission.

All three organisms are capable of causing a variety of infections, including bacteremia, pneumonia, meningitis, urinary tract infections, and nosocomial infections from contaminated environmental sources (e.g., medications, nebulizers, dialysis fluids, saline solution, disinfectants, and contact lens fluid) have been reported. A major virulence factor of these organisms is their ability to produce and survive within biofilms. Biofilm production is associated with resistance to environmental factors by promoting intimate attachment to surfaces, resistance to phagocytic activity and other host immune factors, shielding from antimicrobial activity and enhanced spread across surfaces via bacterial motility. In polymicrobial infections, interspecies interactions have been demonstrated such that different species within the same biofilm can respond to each other’s signaling systems and provide survival advantages to the entire polymicrobial community.

Beyond Human Pathogens

B. cepacia complex, S. maltophilia, and A. xylosoxidans share many beneficial environmental effects (see Fig. 2), although B. cepacia complex is recognized as a pathogen of onions. These organisms produce antimicrobial compounds that protect plants, cause disease in nematodes, and generate factors that promote plant growth. They also have the ability to degrade a wide variety of compounds, including pollutants and heavy metals, enabling these organisms to be effective
agents of soil bioremediation and phytoremediation. Howev

However, the concern to human health is whether the agri
gucultural use of these organisms may present a risk as re"o"vsitories for antibiotic resistance genes. Their ability to multiply in the soil and rhizosphere of plants may be reason enough to consider restricting plants from high-risk patient groups within hospitals (e.g., immunocompromised or CF wards).34–36

**Identification and Antibiotic Susceptibility Testing**

All three organisms have similar growth requirements, can have a similar appearance on standard media, and all can be potentially misidentified as each other and as *Pseudomonas* species. Table 2 outlines the basic microbiological characteristics of these organisms. Automated identification using

<table>
<thead>
<tr>
<th>Species</th>
<th>Former designation</th>
<th>Reported sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>B. cepacia</em></td>
<td>Genomovar I</td>
<td>Infections in CF and non-CF patients Environment: soil, rhizosphere, plant, and river water Bioremediation and biocontrol agent</td>
</tr>
<tr>
<td><em>B. multivorans</em></td>
<td>Genomovar II</td>
<td>Infections in CF and non-CF patients Environment: soil, rhizosphere, plant, and contaminant</td>
</tr>
<tr>
<td><em>B. cenocepacia</em></td>
<td>Genomovar III (four lineages, A–D)</td>
<td>Infections in CF and non-CF patients Environment: soil, rhizosphere, plant, river water, and industrial contaminant Biocontrol agent</td>
</tr>
<tr>
<td><em>B. stabiliz</em></td>
<td>Genomovar IV</td>
<td>Infections in CF and non-CF patients Environment: plant, hospital contaminant</td>
</tr>
<tr>
<td><em>B. vietnamiensis</em></td>
<td>Genomovar V</td>
<td>Infections in CF and non-CF patients Environment: soil, rhizosphere, plant, river water, and industrial contaminant Biocontrol agent</td>
</tr>
<tr>
<td><em>B. dolosa</em></td>
<td>Genomovar VI</td>
<td>Infections in CF patients only Environment: rhizosphere, plant</td>
</tr>
<tr>
<td><em>B. ambifaria</em></td>
<td>Genomovar VII</td>
<td>Infections in CF and non-CF patients Environment: soil, rhizosphere Biocontrol agent</td>
</tr>
<tr>
<td><em>B. anthina</em></td>
<td>Genomovar VIII</td>
<td>Infections in CF, non-CF patients and turtles Environment: soil, rhizosphere, river water, and hospital contaminant</td>
</tr>
<tr>
<td><em>B. pyrrocinia</em></td>
<td>Genomovar IX</td>
<td>Infections in CF patients only Environment: soil, rhizosphere, and river water Biocontrol agent</td>
</tr>
<tr>
<td><em>B. ubonensis</em></td>
<td>Genomovar X</td>
<td>Infections in non-CF patients only Environment: soil</td>
</tr>
<tr>
<td><em>B. latens</em></td>
<td>BCC1</td>
<td>Infections in CF patients only</td>
</tr>
<tr>
<td><em>B. diffusa</em></td>
<td>BCC2</td>
<td>Infections in CF and non-CF patients Environment: soil and water</td>
</tr>
<tr>
<td><em>B. arboris</em></td>
<td>BCC3</td>
<td>Infections in CF and non-CF patients Environment: soil rhizosphere, plant, river water, and industrial contaminant</td>
</tr>
<tr>
<td><em>B. seminalis</em></td>
<td>BCC7</td>
<td>Infections in CF and non-CF patients Environment: soil rhizosphere, plant</td>
</tr>
<tr>
<td><em>B. metallica</em></td>
<td>BCC8</td>
<td>Infections in CF patients only</td>
</tr>
<tr>
<td><em>B. contaminans</em></td>
<td>Group K (BCC AT)</td>
<td>Infections in CF patients and sheep Environment: plant</td>
</tr>
<tr>
<td><em>B. lata</em></td>
<td>Group K</td>
<td>Infections in CF and non-CF patients Environment: forest soil, rhizosphere, plant, river water, and contaminant</td>
</tr>
</tbody>
</table>

Abbreviation: CF, cystic fibrosis.

*Adapted with permission from Sousa et al.3 Vandamme and Dawyndt,78 and Drevinek and Mahenthiralingam.79*

Infections in non-CF patients include reports in immunocompromised patients (malignancy, HIV, and chronic granulomatous disease), immunocompetent individuals (chronic suppurative otitis media, pharyngeal infections, and pediatric neck infections), and hospital-acquired infections in patients with comorbidities (chronic hemodialysis, diabetes mellitus, and congestive heart failure) or those undergoing interventions (prolonged stay in intensive care units, use of central venous catheters, indwelling urinary catheters, and endotracheal tubes) or in the setting of a nosocomial outbreak.

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biochemical differentiation (such as API 20 NE [bioMérieux, Marcy l’Etoile, France] and Vitek-2 [bioMérieux, Marcy l’Etoile, France]) can demonstrate low discrimination and misidentifications, especially with CF patient samples. Modern laboratory identification techniques, such as matrix-assisted laser desorption ionization, time-of-flight mass spectrometry (MALDI-TOF MS) appears to identify and discriminate these organisms well, even with specimens from CF patients. The ability for current versions of MALDI-TOF MS instruments to routinely discriminate between the species within the B. cepacia complex requires further work, but importantly does appear to accurately identify B. cenocepacia. When compared with polymerase chain reaction–restriction fragment length polymorphism (PCR-RFLP) analysis of the recA gene, the Microflex LT MALDI-TOF (Bruker Daltonics GmbH, Leipzig, Germany), under the control of the FlexControl 3.0 software (Bruker Daltonics GmbH) and analyzed by Biotyper 2.0 software (Bruker Daltronics GmbH), produced corresponding discriminating results, although only the PCR-RFLP method provided a fine discrimination into two lineages (IIIA and IIIB).

A remarkable feature common to these three organisms is the vast array of intrinsic and acquired mechanisms of antibiotic resistance. Intrinsic β-lactamases, a wide range of efflux pump systems, enzymatic modifications, changes in the outer membrane and target site modification are just several of the mechanisms harbored by these organisms. Table 3 outlines these mechanisms in more detail, which may or may not be present in every isolate. Importantly, however, is the ability of these organisms to acquire new resistance determinants (e.g., Sul1 integron that causes trimethoprim–sulfamethoxazole resistance in S. maltophilia) and to rapidly induce resistance (e.g., with the use of fluoroquinolones).

Intrinsic antibiotic resistance patterns in S. maltophilia, B. cepacia complex, and A. xylosoxidans are important for physicians to consider when deciding on empiric therapy. Furthermore, this information assists clinical microbiology laboratories with antibiotic susceptibility testing and the

Table 2 Microbiology characteristics of Stenotrophomonas maltophilia, Burkholderia cepacia complex, and Achromobacter xylosoxidans

<table>
<thead>
<tr>
<th>Aerobic</th>
<th>Nonfermenting gram-negative rod</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Appears as a nonlactose fermenting organism on MacConkey agar</td>
</tr>
<tr>
<td>Motile</td>
<td></td>
</tr>
<tr>
<td>Catalase positive</td>
<td></td>
</tr>
<tr>
<td>Oxidase positive</td>
<td>• Except S. maltophilia which is most often oxidase negative (although reported to be oxidase positive in 20%)</td>
</tr>
<tr>
<td>Indole negative</td>
<td></td>
</tr>
<tr>
<td>H₂S negative</td>
<td></td>
</tr>
<tr>
<td>Urease negative</td>
<td></td>
</tr>
<tr>
<td>Organism</td>
<td>Category</td>
</tr>
<tr>
<td>----------------------------</td>
<td>----------------</td>
</tr>
</tbody>
</table>
| *S. maltophilia*<sup>1,80</sup> | β-lactamases  | Two chromosomal inducible β-lactamases  
  - L1 (class B) MBL; L2 (class A) serine  
  - Plasmid ESBL  
  - TEM-2 penicillinase; CTX-M | Hydrolyses all β-lactams |
|                           | Efflux systems | Multidrug efflux systems  
  - SmeDEF; SmeABC; SmrA | Resistance to tetracycline class, chloramphenicol, erythromycin and fluoroquinolone class |
|                           | Enzymatic modification | Aminoglycoside-modifying enzymes  
  Smqr topoisomerase enzyme | Resistance to aminoglycylsides and low level intrinsic quinolones |
|                           | Changes in the outer membrane | Phosphoglucomutase (SpgM) | Aminoglycosides, polymyxin B and fluoroquinolones |
|                           | Target site modification | Protect DNA gyrase and topoisomerases (Smqr); Class 1 integrons (Su1 and Su2) | Resistance to fluoroquinolones; resistance to TMP-SMX |
| *B. cepacia* complex<sup>9,32,81–84</sup> | β-lactamases  | Chromosomal, inducible Ambler class C (PenA); plus others (Ambler class A + D) | β-lactams |
|                           | Efflux systems | RND family efflux transporter | Aminoglycosides, ciprofloxacin, trimethoprim, chloramphenicol |
|                           | Enzymatic modification | Aminoglycoside-modifying enzymes; Dihydrofolate reductase | Resistance to aminoglycylsides, trimethoprim |
|                           | Changes in outer membrane | Lack of binding sites on the lipopolysaccharide layer | Intrinsic resistance to the cationic antimicrobials, polymyxins, and aminoglycosides |
|                           | Altered target site | Change in penicillin binding proteins; Mutations in the quinolone resistance-determining region, QRDR (gyrA and parC) | β-lactams; fluoroquinolones |
| *A. xylosoxidans*<sup>73,85–88</sup> | β-lactamases  | Intrinsic OXA114, OXA243, and OXA2; Cephalosporinase, bla<sub>ampC</sub>; Acquired carbapenemases (bla<sub>nnm</sub>) | β-lactams |
|                           | Efflux systems | RNA-type multidrug efflux pumps; AxyABM and AxyXY-OpBRZ | Decreased MICs of cephalosporins (except cefepime), aztreonam, fluoroquinolones, chloramphenicol. Innate aminoglycoside resistance and extrudes cefepime, carbapenems, some fluoroquinolones, tetracyclines, and erythromycin |
|                           | Enzymatic modification | Aminoglycoside modifying enzymes, AAC(6')-Ib and aadA1 | Aminoglycosides |

Abbreviations: ESBL, extended spectrum β-lactamase; MBL, metallo β-lactamase; RND, resistance nodulation division; TMP-SMX, trimethoprim-sulfamethoxazole.
Table 4 Intrinsic antibiotic resistance

<table>
<thead>
<tr>
<th></th>
<th>S. maltophilia</th>
<th>B. cepacia complex</th>
<th>A. xylosoxidans</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUCAST</td>
<td>CLSI</td>
<td>EUCAST</td>
<td>CLSI</td>
</tr>
<tr>
<td>Amoxicillin-clavulanate</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Ticarcillin-clavulanate</td>
<td>–</td>
<td>–</td>
<td>R</td>
</tr>
<tr>
<td>Piperacillin-tazobactam</td>
<td>R</td>
<td>R</td>
<td>–</td>
</tr>
<tr>
<td>Ceftriaxone</td>
<td>R</td>
<td>R</td>
<td>–</td>
</tr>
<tr>
<td>Ceftazidine</td>
<td>R</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Cefepime</td>
<td>R</td>
<td>–</td>
<td>n/r</td>
</tr>
<tr>
<td>Aztreonam</td>
<td>R</td>
<td>R</td>
<td>n/r</td>
</tr>
<tr>
<td>Erpatenem</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Imipenem</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Meropenem</td>
<td>R</td>
<td>R</td>
<td>–</td>
</tr>
<tr>
<td>Ciprofloxacin</td>
<td>–</td>
<td>n/r</td>
<td>R</td>
</tr>
<tr>
<td>Aminoglycoside</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Trimethoprim</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Trimethoprim-sulfamethoxazole</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Fosfomycin</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Minocycline/Tigecycline</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Colistin</td>
<td>–</td>
<td>–</td>
<td>R</td>
</tr>
<tr>
<td>Chloramphenicol</td>
<td>–</td>
<td>–</td>
<td>R</td>
</tr>
</tbody>
</table>

Abbreviations: CLSI, Clinical and Laboratory Standards Institute46; EUCAST, European Committee on Antimicrobial Susceptibility Testing47; n/r, not reported.

*Intrinsic resistance patterns for A. xylosoxidans gathered from other reports in the literature.27,70,71,73,88-90

reporting of results (see Table 4). There are subtle differences between intrinsic resistance reports by Clinical and Laboratory Standards Institute (CLSI; M100-S24, appendixB.2)48 and European Committee on Antimicrobial Susceptibility Testing (EUCAST)47 and for A. xylosoxidans there is only limited guidance from EUCAST alone, with additional information gathered from other reports in the literature.

Clinical breakpoints are limited for these three organisms. It should also be noted that clinical breakpoints provided are based on achievable blood levels of antimicrobials, which may not reflect what can be achieved in lung, especially in the setting of aerosolized antimicrobials.48 EUCAST provides clinical breakpoints only for S. maltophilia and only for trimethoprim–sulfamethoxazole. Caution is required in the interpretation of trimethoprim–sulfamethoxazole susceptibility testing by disc diffusion or by a gradient strip method (e.g., Etest [bioMérieux, Marcy l’Etoile, France]) as results should be read at 80% inhibition given the bacteriostatic action of the antibiotic causing a leading edge of growth. EUCAST state that results for other agents should be treated with caution given the lack of data to support a relationship between susceptibility and clinical outcome. CLSI recommends first-line reporting of trimethoprim–sulfamethoxazole, and second line reporting of ticarcillin–clavulanate, ceftazidime, minocycline, levofloxacin, and chloramphenicol. It should be noted that EUCAST considers S. maltophilia to be intrinsically resistant to ceftazidime.

CLSI provides clinical breakpoints for B. cepacia complex and recommends first-line testing of trimethoprim–sulfamethoxazole, and second line testing of ticarcillin–clavulanate, ceftazidime, meropenem, minocycline, levofloxacin, and chloramphenicol. In contrast, EUCAST recently tried to address their lack of clinical breakpoints for B. cepacia complex, however, determined that there was no evidence to describe a relationship for minimum inhibitory concentration (MIC) and outcome, and were unable to provide guidance. They describe the MIC distributions for relevant antimicrobials to be wide and that susceptibility testing was not reproducible using a routine methodology (i.e., MIC determination by the gradient strip method). A Cochrane review49 in September 2012 also concluded with similar findings, highlighting that they did not find any randomized controlled trials that compared treatments for exacerbations in CF patients who were infected with B. cepacia complex. They concluded that no conclusions could be drawn from their review and clinicians should continue to assess each patient individually, taking into account in vitro antibiotic susceptibility data, previous clinical responses and their own experience. It should be noted that EUCAST consider B. cepacia complex to be intrinsically resistant to ticarcillin–clavulanate but not piperacillin–tazobactam, while in comparison, CLSI reports intrinsic resistance to piperacillin–tazobactam, do not list ticarcillin–clavulanate in their intrinsic resistance appendix, and do provide clinical breakpoints.
<table>
<thead>
<tr>
<th></th>
<th>S. maltophilia</th>
<th>B. cepacia complex</th>
<th>A. xylosoxidans</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sens.</strong> Details</td>
<td>3.4 to &gt;90%</td>
<td>Increased resistance in CF population.</td>
<td>0–92% Increased resistance in CF population.</td>
</tr>
<tr>
<td>Trimethoprim–sulfamethoxazole</td>
<td>Bacteriostatic. High doses req. (TMP &gt; 15mg/kg). Lower susceptibility rates in CF patients.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ticarcillin–clavulanate/</td>
<td>11.5 to &gt;70%</td>
<td>Bacteriostatic. Clavulanate inhibits L2 β-lactamase. Piperacillin–tazobactam is not effective.</td>
<td>40–100% Both ticarcillin–clavulanate and piperacillin–tazobactam are reported to have variable activity.</td>
</tr>
<tr>
<td>Ceftazidime</td>
<td>0–53%</td>
<td>Other cephalosporins resistant.</td>
<td>45–84.7% Other cephalosporins resistant.</td>
</tr>
<tr>
<td>Meropenem</td>
<td>–</td>
<td>Minimal activity of imipenem or doripenem. Ertapenem not active.</td>
<td>52–100% All carbapenems appear active, except ertapenem.</td>
</tr>
<tr>
<td>Fluoroquinolone class</td>
<td>45–95%</td>
<td>Variable activity; resistance can be readily induced. EUCAST report intrinsic resistance to ciprofloxacin.</td>
<td>Intrinsic resistance reported. Greater invitro activity of newer fluoroquinolones (moxifloxacin, gatifloxacin, and levofloxacin).</td>
</tr>
<tr>
<td>Minocycline/Tigecycline</td>
<td>66.7–100%</td>
<td>Tigecycline has poor activity due to drug efflux.</td>
<td>44–51% Efflux pumps may limit the use of tetracyclines. Tigecycline MIC$_{90}$ 4 mg/L suggests Achromobacter to be a poor target for therapy with tigecycline.</td>
</tr>
<tr>
<td>Colistin</td>
<td>37.5–79%</td>
<td>Intrinsic resistance reported</td>
<td>28–70.1% Higher invitro susceptibility rates when tested against higher concentrations achievable by aerosolization.</td>
</tr>
<tr>
<td>Chloramphenicol</td>
<td>11.5–82%</td>
<td>Intrinsic resistance reported</td>
<td>22–81.2% Variable activity.</td>
</tr>
</tbody>
</table>

**Abbreviations:** CF, cystic fibrosis; CLSI, Clinical and Laboratory Standards Institute; EUCAST, European Committee on Antimicrobial Susceptibility Testing; TMP, trimethoprim.
Management of Infections

The first challenge regarding management is to establish the clinical significance of culturing one of these nonfermenters from a clinical specimen. This question is largely irrelevant if these organisms are identified from sterile sites (e.g., cerebrospinal fluid, blood, and joint aspiration), but when they are identified either alone or with other organisms from nonsterile sites (e.g., sputum, wound swabs, and urine cultures), their role in disease may be difficult to ascertain. However, the repeated isolation of these organisms in the context of clinical disease or in unwell patients, antimicrobial therapy directed against these nonfermenters is often warranted. For example, A. xylosoxidans can cause a level of inflammation similar to P. aeruginosa in chronically infected CF patients and therefore should be treated accordingly.\textsuperscript{50}

Recommendations on specific antibiotic agents for treatment are difficult given the lack of reproducible susceptibility results and minimal clinical data. The fact that these organisms are also frequently part of a mixed infection, especially when it comes to pulmonary involvement, adds to the complexity of management. Reported rates of in vitro antibiotic resistance are very broad depending on patient type and location (see \textit{Table 5}). In general, isolates from CF patients demonstrate higher rates of resistance than those found in other patient groups.

The suggested first- and second-line agents for treatment, as well as combination therapy options are outlined in \textit{Table 6}). Individual susceptibility results, patient allergy, and other concurrent conditions will also influence the choice of agent.

\textbf{S. maltophilia}

Trimethoprim–sulfamethoxazole remains the first-line therapy for \textit{S. maltophilia}. On the basis of in vitro pharmacodynamics modelling and the bacteriostatic action of trimethoprim–sulfamethoxazole, it is recommended that a higher dose be used (daily dose of 15 mg per kg of the trimethoprim component, split 6 to 8 hourly),\textsuperscript{51,52} which is more similar to the dose chosen for the treatment of \textit{Pneumocystis jirovecii} pneumonia. In the setting of trimethoprim–sulfamethoxazole resistance, second line agents are available and are often used in combination (see \textit{Table 6}).\textsuperscript{53} \textit{S. maltophilia} is inherently resistant to carbapenems, and in fact, use of this class of antibiotic often selects for \textit{S. maltophilia} in patients who are heavily immunosuppressed (e.g.,

\textbf{A. xylosoxidans}

Piperacillin–tazobactam, Meropenem, and Trimethoprim–sulfamethoxazole are often used in combination (see \textit{Table 6]).

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|l|l|}
\hline
Organism & First line & Second line & Combination & Alternative combination \\
\hline
\textit{S. maltophilia} & Trimethoprim–sulfamethoxazole & Moxifloxacin/levofloxacin, Tetracycline–clavulanate & Trimethoprim–sulfamethoxazole PLUS Any 2nd line agent, or ciprofloxacin & Ticarcillin–clavulanate PLUS Aztreonam PLUS Moxifloxacin/levofloxacin \\
\hline
\textit{B. cepacia complex} & Trimethoprim–sulfamethoxazole & Moxifloxacin/levofloxacin, Tetracycline–clavulanate & Meropenem PLUS Ceftriaxone PLUS Ciprofloxacin PLUS Tobramycin (inhaled) & Meropenem PLUS Ceftriaxone PLUS Ciprofloxacin PLUS Minocycline, or amikacin PLUS Tobramycin (inhaled) \\
\hline
\textit{A. xylosoxidans} & Piperacillin–tazobactam & Ceftriaxone PLUS Meropenem PLUS Ciprofloxacin & Meropenem PLUS Ceftriaxone PLUS Tobramycin (inhaled) & Meropenem PLUS Ceftriaxone PLUS Ciprofloxacin PLUS Tobramycin (inhaled) \\
\hline
\end{tabular}
\end{table}

\textsuperscript{a}Caution should be applied with the use of tigecycline given the 2010 and 2013 US FDA drug safety communications warning not to use tigecycline in pulmonary infections, especially hospital-acquired and ventilator-associated pneumonia, because of increased mortality risk.\textsuperscript{57,58}

\textsuperscript{b}EUCAST report B. cepacia complex to be intrinsically resistance to ciprofloxacin.

\textsuperscript{c}Inhaled antibiotics have been recommended primarily in pulmonary exacerbations of CF.

\textsuperscript{d}Use of newer fluoroquinolones are preferred when used in combination, in preference to ciprofloxacin, given the greater invitro activity,\textsuperscript{13} although intrinsic resistance and poor activity is widely reported across the class.\textsuperscript{29}
neutropenic patients). The inclusion of a specific biofilm active agent, such as moxifloxacin or levofloxacin has also been shown to be of benefit, although caution should be applied when used as monotherapy because of the risk of rapid induction of resistance. Minocycline and tigecycline have also shown some promise to assist with the treatment of *S. maltophilia*. The evidence for combination therapy often comes from in vitro synergy testing data, and highlights the need for further research into optimal therapy for this troublesome organism. The combinations are often reported involving trimethoprim–sulfamethoxazole, ticarcillin–clavulanate, moxifloxacin, levofloxacin, aztreonam, ceftazidime, colistin, rifampicin, tigecycline, and minocycline.

**B. cepacia Complex**

Similar principles apply as for treatment of *S. maltophilia*. Trimethoprim–sulfamethoxazole remains a recommended first-line therapy. Higher dosing schedules (15 mg per kg of the trimethoprim component, split 6 to 8 hourly) has again been recommended based on pharmacokinetic and pharmacodynamics data in the critically ill as well as extrapolated data from *B. pseudomallei*, the pathogen causing melioidosis. In contrast to *S. maltophilia*, *B. cepacia* complex are often sensitive to meropenem, which is another first-line therapy, but are inherently resistant to polymyxin and colistin. Tigecycline demonstrates poor activity against *B. cepacia* complex owing to drug efflux, although minocycline maintains activity. Combination therapy is often used for patients who are more severely unwell, and includes double and triple combinations of first- and second-line agents (see Table 6). The main alternative therapeutic agents beyond trimethoprim–sulfamethoxazole include ceftazidime and meropenem, either alone or in combination, or with other antimicrobial agents. The role of penicillins, namely, piperacillin–tazobactam and ticarcillin–clavulanate remains controversial given the different intrinsic resistance reports between EUCAST and CLSI, as previously mentioned. Inhaled tobramycin has the potential to achieve high pulmonary concentrations to inhibit *B. cepacia* isolates, despite widespread resistance reported. As mentioned, CF patients proceeding to lung transplantation, who are colonized or infected with *B. cepacia* complex (particularly with *B. cenocepacia*) are at high risk for a poor outcome, manifested by an overwhelming “cepacia syndrome.” The highest risk for this is within 3 months following transplant and many lung transplant centers around the world have *B. cenocepacia* as an absolute contraindication to transplant. If transplantation is performed in the setting of *B. cepacia* complex colonization or infection, aggressive combination (double and triple) therapy is often used perioperatively.

**A. xylosoxidans**

Less is known about the optimal therapy for *Achromobacter* spp. In addition to the recognized intrinsic antibiotic resistance patterns, acquired resistance is also widely reported. Given the limitations of the clinical microbiology laboratory to interpret antimicrobial susceptibility results, close communication between the treating doctors and the laboratory is required. The most active agents are piperacillin–tazobactam, meropenem, and trimethoprim–sulfamethoxazole, whereas ceftazidime is more active than cefepime. Tetracyclines (e.g., minocycline) have variable activity and may be vulnerable to a multidrug efflux pump. Although specifically for tigecycline, an MIC90 of 4 mg/L has been reported in CF patients, suggesting *Achromobacter* to be a poor target for therapy with tigecycline. Aminoglycosides, fluoroquinolones, fosfomycin, and aztreonam all have poor activity. Multidrug-resistant phenotypes and carbapenemase-producing isolates have been reported, especially for the CF patient population, further complicating therapeutic options. Combination therapy has been recommended for the treatment of *A. xylosoxidans* pulmonary exacerbations in CF. Although the use of concurrent inhaled antibiotics, such as inhaled colistin, could also be considered.

**Conclusions**

*S. maltophilia*, *B. cepacia* complex, and *A. xylosoxidans* are remarkable organisms with the ability to live and thrive in hostile environments, including withstanding antibiotic treatment. The widespread use of fluoroquinolones, aminoglycosides, and broad-spectrum β-lactam antimicrobials has created the perfect niche for these opportunistic pathogens. Infection with *Pseudomonas* species, interspecies quorum-sensing and survival within biofilms create unique therapeutic challenges. Successful treatment requires a greater understanding of the clinical consequences of infections with these organisms, together with their innate microbiological characteristics and antimicrobial resistance patterns. At this stage, more clinical data are required to assist with treatment recommendations, and future research should focus on the role of combination therapy.

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