New antibiotics for paediatric use: A review of a decade of regulatory trials submitted to the European Medicines Agency from 2000-Why aren’t we doing better?

This is the author’s manuscript

Original Citation:

Availability:

Published version:
DOI:10.1016/j.ijantimicag.2013.05.001

Terms of use:
Open Access
Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)
New antibiotics for paediatric use: A review of a decade of regulatory trials submitted to the European Medicines Agency from 2000—Why aren’t we doing better?

Silvia Garazzino
Irja Lutsarb,
Chiara Bertainaa,
Pier-Angelo Tovo
Mike Sharlandc

Abstract

New initiatives have been introduced in Europe and the USA to encourage more rapid development of antibiotics. The need to ensure these new antibiotics can be safely used in children, and especially neonates, is important owing to high antimicrobial resistance in these patient groups. This review aims to determine what lessons can be learnt from the recent regulatory processes to speed up access to new medicines for children, focusing on antibiotics licensed for adults by the EMA since 2000. For the 11 newly approved antibiotics, 31 clinical trials enrolling children in Europe were identified. However, many of these trials included both adults and children but did not provide a subset analysis for paediatrics, limiting the relevance of their findings. Some studies have been prematurely terminated and others are apparently active but are still not yet recruiting patients. Among paediatric-specific studies, 18 evaluate safety and efficacy of new compounds, 4 are pharmacokinetic studies, but only 2 focus on neonates. Nearly all studies with an agreed Paediatric Investigation Plan have just started or are not yet recruiting. For most antibiotics, despite adult phase 3 studies being completed, with specific concerns for particular drugs already noted, it will take another 3–5 years before adequate prescribing information becomes available for paediatricians. Evidence from this review suggests that we could do better. Lessons should be learnt from paediatric antiretroviral development, with neonatal and paediatric pharmacokinetic, clinical trial and pharmacovigilance drug development programmes being run directly in parallel with adult studies—not a decade behind.
1. Introduction

The development of novel antibiotics is a key priority of antibacterial therapy in the 21st century. The US Food and Drug Administration (FDA) in the USA and the European Medicines Agency (EMA) in Europe are responsible for the scientific evaluation of applications for marketing authorisation of medicinal products and for the approval of specific proposed clinical indications for each compound.

Appropriate use of antibiotic agents may minimise selective pressure on the emergence of drug-resistant strains [1] and [2]. The licensing and marketing of a drug occur at the end of a long development process, in which clinical trials represent the final critical stage [3].

In the paediatric setting, the number of clinical trials is very low compared with the adult population: both economic and ethical factors can discourage pharmaceutical companies in conducting trials on children [4]. The result is a potential delay in the authorisation of antibiotics for children and a consequent increase in off-label prescribing [5]. Moreover, given the paucity of information of new antibiotics in children, data on drug safety and tolerability are often extrapolated from adult studies, with the consequent risks of underestimating toxicity, inadequate dosages and clinical failures [6].

Important new initiatives have recently been introduced both in the USA and Europe to encourage earlier and more complete evaluation of new drug products in paediatrics. The ‘Paediatric Regulation’ is a new legislation governing the development and authorisation of medicines in children that was introduced in the European Union (EU) in 2007 [7]. It brought in the creation of a Paediatric Committee, within the EMA, that provides objective scientific opinions on required drug development plans submitted by pharmaceutical companies. Such Paediatric Investigation Plans (PIPs) are aimed at ensuring that the necessary data to support authorisation of the medicine for paediatric use are obtained through targeted studies [8]. Further initiatives are now proposed to enhance the more rapid development of antibiotics. This study therefore aimed to see what lessons can be learnt from the recent regulatory processes to speed up access to new medicines for children, focusing on antibiotics licensed for adults by the EMA since 2000.

2. Materials and methods

The Medline, EMBASE and Cochrane library databases were systematically searched from January 2000 to December 2012 to identify all published papers regarding prospective clinical trials on the use of new antibiotics in infants and children aged 0–17 years and involving European countries. Only new antibiotics that have been licensed in the EU for adult use were
considered. A cross-check on references of major articles reporting adult data was also performed. To identify ongoing trials or recently completed trials, a search of the World Health Organization (WHO), US National Institutes of Health and EU clinical trials registers was performed (last accessed 31 January 2013) [9], [10] and [11]. PIPs were systematically searched through the EMA database [8].

3. Results

Eleven antibiotics approved in the EU since 2000 were identified (Table 1). A total of 31 clinical trials were found. A brief summary of completed and ongoing trials, as well as PIPs, for each drug is given.

Table 1.

Antimicrobials licensed for the adult population in the European Union (EU) since 2000.

<table>
<thead>
<tr>
<th>Drug</th>
<th>EU approved indications in adults</th>
<th>EU approved indications in children</th>
<th>Paediatric Investigation Plans (EU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aztreonam lysine</td>
<td>Pseudomonas aeruginosainfection in patients with cystic fibrosis</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Ceftaroline fosamil</td>
<td>cSSTI, CAP</td>
<td>None</td>
<td>cSSTIs, CAP (0–18 years)</td>
</tr>
<tr>
<td>Daptomycin</td>
<td>cSSTI, Staphylococcus aureusbacteraemia, S. aureus right-sided endocarditis</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Doripenem monohydrate</td>
<td>cIAI, cUTI, HAP</td>
<td>None</td>
<td>HAP/VAP, cIAI, UTI (0–18 years)</td>
</tr>
<tr>
<td>Ertapenem sodium</td>
<td>cIAI, CAP, cSSTI (diabetic foot), acute pelvic infection, surgical-site infection</td>
<td>cIAI, CAP, cSSTI (diabetic foot), acute pelvic infection</td>
<td>None</td>
</tr>
<tr>
<td>Drug</td>
<td>EU approved indications in adults</td>
<td>EU approved indications in children</td>
<td>Paediatric Investigation Plans (EU)</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------</td>
<td>------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Fidaxomicin</td>
<td>prophylaxis in elective colorectal surgery</td>
<td>in children aged ≥3 months of age</td>
<td>Safety and pharmacokinetics (2–17 years) Development of an age-appropriate oral suspension formulation (0–18 years)</td>
</tr>
<tr>
<td>Linezolid</td>
<td>CDAD</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Moxifloxacin</td>
<td>HAP, CAP, cSSTI by Gram-negative bacteria</td>
<td>None</td>
<td>PID (12–18 years) cIAI (3 months to 18 years)</td>
</tr>
<tr>
<td>Retapamulin</td>
<td>Superficial SSTI (impetigo, infected small lacerations, abrasions or sutured wounds)</td>
<td>Superficial SSTI (impetigo, infected small lacerations, abrasions or sutured wounds) in children ≥9 months of age</td>
<td>None</td>
</tr>
<tr>
<td>Telithromycin</td>
<td>CAP (mild to moderate)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Tigecycline</td>
<td>cSSTI, cIAI</td>
<td>None</td>
<td>cSSTIs, cIAIs (8–18 years)</td>
</tr>
</tbody>
</table>

cSSTI, complicated skin and soft-tissue infection; CAP, community-acquired pneumonia; cIAI, complicated intra-abdominal infection; cUTI, complicated urinary tract infection; HAP, hospital-acquired pneumonia; VAP, ventilator-associated
pneumonia; CDAD, Clostridium difficile-associated diarrhoea; AECB, acute exacerbations of chronic bronchitis; PID, pelvic inflammatory disease.

Table options

3.1. Aztreonam lysine

Aztreonam is a synthetic monobactam that has been available intravenously for many decades. It displays a mechanism of action similar to penicillin and has selective bactericidal activity against susceptible Gram-negative bacteria, including Pseudomonas aeruginosa and most clinically relevant Enterobacteriaceae. Aztreonam is inactivated by extended-spectrum β-lactamases (ESBLs) and has no activity against Gram-positive bacteria or anaerobes.

An inhaled formulation, aztreonam lysine (AZLI), administered using an ultrasonic nebuliser, was recently developed. It received conditional approval by the EMA in 2009 for the treatment of P. aeruginosa infections in adults with cystic fibrosis and was also approved by the FDA in 2010, although not in children [12] and [13]. Three clinical trials enrolling children with cystic fibrosis and lower respiratory tract infections with P. aeruginosa are registered in Europe (Table 2). AZLI demonstrated superiority in lung function and a reduction in acute pulmonary exacerbations compared with tobramycin inhalation solution in adult and paediatric patients with pulmonary P. aeruginosacolonisation. However, only a small number of children were enrolled (n = 58; 22%) and no separate analysis for the paediatric population was performed [14] and [15]. Two studies evaluating the safety and efficacy of AZLI are active but are not yet recruiting patients [16] and [17].

Table 2.

European clinical trials on aztreonam lysine involving paediatric patients.
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint</th>
<th>Secondary endpoint</th>
<th>Main exclusion criteria</th>
<th>Comparator</th>
<th>Aztreonam dose/duration</th>
<th>Status</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT00757237[14] and [15]</td>
<td>Phase 3, RCT, OLT</td>
<td>USA, Europe</td>
<td>268 (58 aged &lt;18 years)</td>
<td>≥6 years</td>
<td>Pulmonary infection by Pseudomonas aeruginosa in pts with CF</td>
<td>Comparative safety and efficacy</td>
<td>–</td>
<td>Previous antipseudomonal treatment; lung transplantation; colonisation by Burkholderiaspp.; continuous oxygen supplementation; high-dose steroids</td>
<td>TNS 300 mg q12h as intermittent 28-day courses</td>
<td>Inhalation solution 75 mg q8h as intermittent 28-day courses</td>
<td>Completed</td>
<td>Mean relative changes after one course: AZLI, 8.35%; TNS, 0.55% (P &lt; 0.001). Mean actual changes across three courses: AZLI, 2.05%; TNS, –0.66% (P = 0.002).</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint</td>
<td>Main exclusion criteria</td>
<td>Comparator</td>
<td>Aztreonam dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>-------------------</td>
<td>------------------</td>
<td>---------------------</td>
<td>------------------------</td>
<td>------------</td>
<td>------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fewer respiratory hospitalisations (P = 0.044) and respiratory events requiring additional antipseudomonal antibiotics (P = 0.004) in AZLI-treated pts</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint</td>
<td>Main exclusion criteria</td>
<td>Comparator</td>
<td>Aztreonam dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>----------------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>-------------------</td>
<td>------------------</td>
<td>--------------------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>------------</td>
<td>------------------------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>NCT01375049[16]</td>
<td>Phase 2, O L</td>
<td>USA, Europe</td>
<td>80</td>
<td>3 months to 17 years</td>
<td>Lower respiratory tract infection by <em>P. aeruginosa</em> in pts with CF</td>
<td>Microbiological response</td>
<td>–</td>
<td>Previous antipseudomonal treatment; lung transplantation; colonization by Burkholderiaspp.; continuous oxygen supplementation</td>
<td>None</td>
<td>Inhalation solution 75 mg q8h for 28 days</td>
<td>Active but not recruiting</td>
<td>NA</td>
</tr>
<tr>
<td>NCT01404234[17]</td>
<td>Phase 3, O L</td>
<td>USA, Europe</td>
<td>60</td>
<td>Up to 12 years</td>
<td>Chronic lower respiratory tract infection by <em>P. aeruginosa</em> in</td>
<td>Safety</td>
<td>Efficacy: improvement of respiratory functionalit and changes in P.</td>
<td>Previous antipseudomonal treatment; lung transplantation; colonization</td>
<td>None</td>
<td>Inhalation solution 75 mg q8h as three interm</td>
<td>Active but not recruiting</td>
<td>NA</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint</td>
<td>Main exclusion criteria</td>
<td>Comparator</td>
<td>Aztreonam dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>-------------------</td>
<td>------------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>------------</td>
<td>------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pts with CF</td>
<td></td>
<td>aeruginosae xacerbations and sputum density</td>
<td>on by Burkholderiaspp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

pts, patients; RCT, randomised controlled trial; OL, open label; CF, cystic fibrosis; TNS, tobramycin nebuliser solution; q12h, every 12 h; q8h, every 8 h; AZLI, aztreonam for inhalation solution; NA, not available.

Table options

No PIP is currently agreed on AZLI.

3.2. Ceftaroline fosamil

Ceftaroline fosamil is a novel broad-spectrum cephalosporin approved by the EMA in 2012 for the treatment of adults with complicated skin and soft-tissue infections (cSSTIs) and community-acquired pneumonia (CAP) [18].

Ceftaroline inhibits bacterial cell wall synthesis by binding penicillin-binding proteins (PBPs), including PBP2a produced by meticillin-resistant Staphylococcus aureus (MRSA). It has activity against a wide spectrum of Gram-negative and Gram-positive pathogens, such as MRSA (including vancomycin- and daptomycin-resistant strains), penicillin-resistant Streptococcus pneumoniae (PRSP), meticillin-resistant Staphylococcus epidermidis (MRSE) and Enterococcus faecalis. It is not active against P. aeruginosa and ESBL-producing strains [19].

Although clinical data are still limited, ceftaroline displays a good safety and tolerability profile. The paediatric dosage is yet to be determined. In addition to the approved indications, a potential promising role for ceftaroline is empirical monotherapy when an MRSA or MRSE infection is suspected.
Two randomised controlled trials (RCTs) are recruiting paediatric patients in Europe (Table 3): they will assess the safety, efficacy, tolerability and pharmacokinetics of ceftaroline versus comparators in children aged 2 months to 18 years with CAP and cSSTIs [20] and [21].

Table 3.
European clinical trials on ceftaroline fosamil involving paediatric patients.

<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint</th>
<th>Secondary endpoint(s)</th>
<th>Main exclusion criteria</th>
<th>Comparator(s)</th>
<th>Ceftaroline fosamil dose</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT01530763[20]</td>
<td>Phase 2–3, RCT, SB</td>
<td>USA, Europe</td>
<td>160 (estimated)</td>
<td>2 months to 18 years</td>
<td>CAP</td>
<td>Comparative efficacy; pharmacokinetics of ceftaroline fosamil in plasma and CSF</td>
<td>Hypersensitivity to β-lactams; infection with a pathogen resistant to ceftriaxone; sources of infection other than CAP; non-infectious causes of pulmonary infiltrates</td>
<td>Ceftriaxone i.v. 75 mg/kg/day (up to 4 g/day) divided q12h</td>
<td>≥6 months: i.v. ceftaroline fosamil 12 mg/kg (if ≤33 kg body weight) or 400 mg (if &gt;33 kg body weight) q8h &lt;6</td>
<td>Recruiting</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NCT01400867[21]</td>
<td>Phase 2–3, RCT, SB</td>
<td>USA, Europe, South America, Asia, South Africa</td>
<td>270 (estimated)</td>
<td>2 months to 18 years</td>
<td>cSSTI</td>
<td>Comparative safety and tolerability</td>
<td>Comparative efficacy; pharmacokinetics of ceftaroline fosamil in plasma</td>
<td>Hypersensitivity to vancomycin, aztreonam or β-lactams; requirement for concomitant systemic antimicrobial therapy; history of seizures, excluding febrile seizure of childhood; signs or suspicion of meningitis</td>
<td>Vancomycin i.v. 15 mg/kg q6h or cefazolin i.v. 75 mg/kg/day divided q8h ± aztreonam i.v. 30 mg/kg q8h</td>
<td>≥6 months: ceftaroline fosamil i.v. 12 mg/kg (if ≤33 kg body weight) or 400 mg (if &gt;33 kg body weight) q8h</td>
<td>&lt;6 months: 8 mg/kg q8h</td>
</tr>
</tbody>
</table>
pts, patients; RCT, randomised controlled trial; SB, single blind; CAP, community-acquired pneumonia; CSF, cerebrospinal fluid; i.v., intravenous; q12h, every 12 h; q8h, every 8 h; cSSTI, complicated skin and soft-tissue infection; q6h, every 6 h.

Table options

A PIP for treatment of cSSTI and CAP has been agreed [22].

3.3. Daptomycin

Daptomycin is a cyclic lipopeptide that was approved by the FDA in 2003 for the treatment of adults with SSTIs caused by Gram-positive bacteria as well as S. aureusbacteraemia or right-sided endocarditis. It is inactivated by pulmonary surfactants and therefore should not be used for non-haematogenous pneumonia [23] and [24].

Daptomycin binds to the bacterial cell membrane in a calcium-dependent manner, causing rapid membrane depolarisation and bacterial death. It has selective activity against Gram-positive bacteria, including glycopeptide-resistant enterococci, MRSA, MRSE, streptococci and corynebacteria. In adults, daptomycin is given intravenously at 4 mg/kg or 6 mg/kg once daily, respectively, for SSTIs and S. aureusbacteraemia/endocarditis. Safety and tolerability of higher dosages have been reported both in adults and children [25], [26] and [27]. Daptomycin is generally well tolerated. As its most relevant side effect is muscular toxicity, regular monitoring of creatine kinase levels is recommended [28]. A warning that daptomycin could cause life-threatening eosinophilic pneumonia has recently been issued [29].

The experience of daptomycin in children is very limited and the paediatric dosing regimen remains to be determined [30], [31], [32], [33], [34] and [35]. According to the latest Infectious Diseases Society of America (IDSA) guidelines on the management of MRSA infections, daptomycin should be administered at 6–10 mg/kg every 24 h in children with bacteraemia, osteomyelitis and septic arthritis [36].

The pharmacokinetic (PK) profile, efficacy and safety of daptomycin in infants and children are under evaluation in several trials. Among these, only two are recruiting children in the EU. One study aims at characterising the peak concentration of daptomycin in cerebrospinal fluid of children aged 3 months to 16 years with acute Gram-positive meningitis (Table 4); daptomycin will be given as single-dose add-on therapy [37]. The second study will describe the safety and efficacy of daptomycin versus standard of care in children aged 2–17 years with S. aureus bacteraemia [38].
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint</th>
<th>Secondary endpoint</th>
<th>Main exclusion criteria</th>
<th>Daptomycin dose/duration</th>
<th>Comparators</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT01522105[37]</td>
<td>OL, SG, phase I</td>
<td>Europe</td>
<td>5 (estimated)</td>
<td>3 months to 16 years</td>
<td>Gram-positive meningitis</td>
<td>Characterisation of peak concentration of DAP in the CSF</td>
<td>Evaluating possible side effects of DAP</td>
<td>Gram-negative bacteria in the CSF; renal impairment; CK level &gt;2× upper age-related norm or muscular disease/weakness; allergy or hypersensitivity to DAP; known significant chronic</td>
<td>One i.v. dose (3–24 months, 6 mg/kg; 2–6 years, 10 mg/kg; 7–11 years, 8 mg/kg; 12–16 years, 6 mg/kg) given 24 h after first</td>
<td>None</td>
<td>Recruiting</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint</td>
<td>Main exclusion criteria</td>
<td>Daptomycin dose/duration</td>
<td>Comparators</td>
<td>Status</td>
</tr>
<tr>
<td>------------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>-------------------</td>
<td>------------------</td>
<td>---------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>-------------</td>
<td>------------</td>
</tr>
<tr>
<td>NCT01728376[38]</td>
<td>RCT, SB, phase 4</td>
<td>USA, Europe, South America, Asia</td>
<td>75 (estimated)</td>
<td>2–17 years</td>
<td>Staphylococcus aureus bacteraemia</td>
<td>Comparative safety</td>
<td>Comparative efficacy</td>
<td>Shock or hypotension unresponsive to standard therapy; intolerance</td>
<td>DAP i.v. at 7 mg/kg (age 12–17 years), 9 mg/kg (age</td>
<td>Vancomycin, semisynthetic penicillin, first-generation</td>
<td>Recruiting</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint</td>
<td>Main exclusion criteria</td>
<td>Daptomycin dose/duration</td>
<td>Comparators</td>
<td>Status</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>------------------</td>
<td>------------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>-------------------------</td>
<td>-------------</td>
<td>--------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>e or hypersensitivity to DAP; renal insufficiency; rhabdomyolysis; or significant CK elevation; history of clinically significant muscular disease, nervous system or seizure disorder; S. aureus pneumonia, cephalosporin, clindamycin</td>
<td>7–11 years, 12 mg/kg (ages 2–6 years)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
At present, the lack of adequate safety data does not allow daptomycin to be routinely used in children. Potential uses in selected cases include right-sided endocarditis with or without bacteraemia, infection of intravascular devices, and osteoarticular infections caused by MRSA, MRSE and vancomycin-resistant enterococci (VRE) [39].

No PIP is currently agreed on daptomycin.

### 3.4. Doripenem monohydrate

Doripenem monohydrate is the most recently developed carbapenem [40] and [41]. It was approved by the EMA in 2008 for the treatment of nosocomial pneumonia (NP) [including ventilator-associated pneumonia (VAP)], complicated intra-abdominal infections (cIAIs) and complicated urinary tract infections (cUTIs) including pyelonephritis.

When compared with imipenem/cilastatin and meropenem, doripenem had enhanced in vitro activity against *P. aeruginosa* and Acinetobacter spp. It is also active against most β-lactam-susceptible Gram-positive bacteria, Gram-negative bacteria (including ESBL-producing strains) and anaerobes. As with other carbapenems, it inhibits synthesis of the bacterial

<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint</th>
<th>Secondary endpoint</th>
<th>Main exclusion criteria</th>
<th>Daptomycin dose/duration</th>
<th>Comparators</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>empyema, meningitis or endocarditis</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

pts, patients; OL, open label; SGA, single group assignment; CSF, cerebrospinal fluid; CK, creatine kinase; i.v., intravenous; RCT, randomised controlled trial; SB, single blind.
cell wall by attaching to PBPs and has no activity against Stenotrophomonas maltophilia. Adverse effects of doripenem are similar to those of other carbapenems [40], [41], [42], [43] and [44].

In phase 3 studies, doripenem was non-inferior to comparators in the treatment of NP and cIAIs [45], [46] and [47]. However, a recent trial evaluating its safety and efficacy in severely ill patients with VAP was terminated prematurely due to excess mortality and poorer clinical cure rates in the doripenem group [48]: in that study, doripenem was administered at a higher dose [1 g every 8 h (q8h)] and for a shorter treatment period (7 days) than currently authorised (500 mg q8h for 10–14 days) and was compared with 1 g q8h of imipenem/cilastatin for 10 days. Following these preliminary results, the EMA's Committee for Medicinal Products for Human Use (CHMP) recommended updating the prescribing information allowing higher doses (1 g q8h for 10–14 days) in patients with NP caused by non-fermenting Gram-negative bacteria [49].

PK and pharmacovigilance studies of doripenem in children have been started in Europe (Table 5).

Table 5.
European clinical trials on doripenem monohydrate involving paediatric patients.

<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint</th>
<th>Secondary endpoint(s)</th>
<th>Main exclusion criteria</th>
<th>Comparator(s)</th>
<th>Doripenem dose/duration</th>
<th>Status</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT01381848, EudraCT2009-014387-20 [50] and [51]</td>
<td>Phase I, O &amp; L</td>
<td>USA, Europe</td>
<td>48</td>
<td>0–12 weeks</td>
<td>Bacterial infection</td>
<td>PK study (doripenem concentrations in blood)</td>
<td>Safety of single-dose doripenem</td>
<td>Clinically significant abnormal physical examination, vital signs or laboratory</td>
<td>None</td>
<td>Single i.v. dose: 5 mg/kg in pts &lt;8 weeks; 8 mg/kg in</td>
<td>Completed</td>
<td>NA</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Doripenem dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>-------------------</td>
<td>------------------</td>
<td>----------------------</td>
<td>-------------------------</td>
<td>---------------</td>
<td>-------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>NCT01110421, EudraCT 2009-016069-27 [52] and [53]</td>
<td>Phase 3, RCT, DB</td>
<td>South and Central America, USA, Europe, Asia</td>
<td>140</td>
<td>3 months to 18 years</td>
<td>CAP</td>
<td>Comparative safety</td>
<td>Clinical cure at TOC and EOT; relapse at LTFU; population PK analysis</td>
<td>Suspected or proven study drug-resistant organisms (e.g. Staphylococcus aureus, Stenotrophomonas, etc.); immunosuppression (ANC &lt;500 cells/μL); epilepsy</td>
<td>Cefepime i.v. (50 mg/kg up to 2 g/dose q8h) for ≥3 days, followed by PO amoxicillin/clavulanate potassium or other PO antibiotics (total 10–14 days)</td>
<td>20 mg/kg i.v. up to 500 mg/dose q8h for ≥3 days, followed by PO amoxicillin/clavulanate potassium or alternative PO antibiotic therapy (total 10–14 days)</td>
<td>Suspended</td>
<td>NA</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infec.</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Doripenem dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>---------------</td>
<td>------------------</td>
<td>----------------------</td>
<td>------------------------</td>
<td>--------------</td>
<td>-------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>NCT01110408, EudraCT2009-015953-18 [54] and [55]</td>
<td>Phase 3, RCT, DB</td>
<td>USA, Europe, Asia, South America, Africa</td>
<td>140</td>
<td>3 months to 18 years</td>
<td>cUTI</td>
<td>Comparative safety</td>
<td>Clinical cure and microbiological response at TOC and LTFU; clinical improvement and microbiological response at EOT; population PK analysis</td>
<td>Concomitant infections; diagnosis of intractable UTI, permanent urinary catheter, abscesses; suspected or proven study drug-resistant organisms; ANC &lt;500 cells/μL; epilepsy</td>
<td>Cefepime i.v. (50 mg/kg up to 2 g/dose q8h) for 3–14 days. Pts may be discharged with PO antibiotic therapy</td>
<td>20 mg/kg i.v. up to 500 mg/dose q8h for 3–14 days. Pts may be discharged with PO antibiotic therapy</td>
<td>Recruiting</td>
<td>NA</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Doripenem dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------------</td>
<td>------------------------------------</td>
<td>------------</td>
<td>-----</td>
<td>-------------------</td>
<td>-------------------</td>
<td>-----------------------</td>
<td>-----------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------</td>
<td>--------------</td>
<td>---------</td>
</tr>
<tr>
<td>NCT01110382, EudraCT 2009-015864-32 [56] and [57]</td>
<td>Phase 3, RCT, DB</td>
<td>USA, Europe, South America</td>
<td>140</td>
<td>3 months to 18 years</td>
<td>cIAI</td>
<td>Comparative safety</td>
<td>Clinical cure and microbiological response at TOC and LTFU; clinical improvement at EOT; population PK analysis</td>
<td>Meropenem 20 mg/kg i.v. up to 1 g/dose q8h for 3–14 days. i.v. drugs may be switched to an oral antibiotic to complete the 5–14-day course of treatment</td>
<td>20 mg/kg i.v. up to 500 mg/dose q8h for 3–14 days. i.v. drugs may be switched to an oral antibiotic to complete the 5–14-day course of treatment</td>
<td>Recruiting</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>NCT01366651[58]</td>
<td>Phase 1</td>
<td>Europe</td>
<td>10</td>
<td>0–1 year</td>
<td>Meningitis</td>
<td>Safety of doripenem</td>
<td>Any condition that may interfere with the assessment,</td>
<td>None</td>
<td>Pts &lt;12 weeks, 10 mg/kg i.v. q8h for 5 doses; pts</td>
<td>Recruiting</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Doripenem dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>----------</td>
<td>-----------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>-------------------</td>
<td>------------------</td>
<td>------------------------</td>
<td>-------------------------</td>
<td>---------------</td>
<td>------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>OL</td>
<td>OL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Trations in CSF</td>
<td></td>
<td>According to investigator</td>
<td>≥12 weeks to &lt;1 year, 30 mg/kg i.v. q8h for 5 doses</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

pts, patients; OL, open label; PK, pharmacokinetic; i.v., intravenous; NA, not available; RCT, randomised controlled trial; DB, double blind; CAP, community-acquired pneumonia; TOC, test of cure; EOT, end of i.v. therapy; LTFU, long-term follow-up; ANC, absolute neutrophil count; q8h, every 8 h; PO, per os; cUTI, complicated urinary tract infection; cIAI, complicated intra-abdominal infection; CSF, cerebrospinal fluid.

Table options

The pharmacokinetics, safety and tolerability of single-dose doripenem have been studied in hospitalised neonates (both term and preterm) and in infants <12 weeks of age with, or at risk for, bacterial infections under treatment with other intravenous (i.v.) antibiotics [50] and [51]. In that study, doripenem was given as add-on therapy. The study was completed in April 2012 but results are not available at present. One study comparing the safety and tolerability of doripenem with cefepime in children with bacterial pneumonia was suspended following premature discontinuation of the adult VAP study [52] and [53]. Three randomised controlled paediatric studies are currently ongoing. Doripenem is compared with i.v. cefepime for safety and efficacy in the treatment of cUTIs in children aged 3 months to 18 years; sampling for PK investigation is scheduled in doripenem-treated subjects [54] and [55]. A second study is evaluating doripenem versus meropenem in hospitalised children with cIAIs; a PK subanalysis for the doripenem group is also planned [56] and [57]. Another study plans to assess the penetration of doripenem (given as add-on therapy) into the cerebrospinal fluid of hospitalised children aged <1 year with meningitis [58].
Following the limited data on the safety of doripenem and its limited potential advantages over older carbapenems, its role in paediatrics remains to be established. Given its broad spectrum of activity, it might be useful for treating children with nosocomial infections or with infections caused by enteric or non-fermentative Gram-negative bacteria [41].

A PIP for treatment of hospital-acquired pneumonia (HAP)/VAP, cIAIs and UTIs including complicated and uncomplicated pyelonephritis and cases with concurrent bacteraemia has been agreed [59].

3.5. Ertapenem sodium

Ertapenem is a carbapenem with broad-spectrum antibacterial activity against aerobic and anaerobic pathogens, including ESBL- and AmpC-producing Gram-negatives [60] and [61]. In contrast to other carbapenems, it is not active against P. aeruginosa and Acinetobacter baumannii. Ertapenem is approved in Europe for the treatment of adults and children aged ≥3 months with cIAIs, CAP, diabetic foot infections and acute pelvic infection. It is also licensed for surgical-site infection prophylaxis in elective colorectal surgery in adults. Further indications in the USA include cSSTIs and UTIs [62]. Paediatric dosing is 15 mg/kg i.v. every 12 h (q12h) in children aged 3 months to 12 years (maximum 1 g/daily) and 1 g once daily in older children [60]. The intramuscular route has been licensed in the USA but not in Europe. The safety profile in children was comparable with that found in adults [60]. Use of ertapenem was associated with neutropenia, diarrhoea and mild-to-moderate elevation of liver function tests; seizures were identified with comparable frequency to comparators [63].

Arguedas et al. investigated the safety, tolerability and efficacy of ertapenem versus ceftriaxone in children aged 3 months to 17 years with cUTIs, SSTIs or CAP (Table 6) [64] and [65]. The overall incidence of clinical adverse events (AEs) was comparable between the two groups. The most common drug-related AEs were diarrhoea, vomiting, infusion-site pain and erythema. In general, the clinical response to ertapenem was similar to that found in adults for similar infections.

Table 6.

European clinical trials on ertapenem sodium involving paediatric patients.
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint</th>
<th>Secondary endpoint(s)</th>
<th>Main exclusion criteria</th>
<th>Comparator</th>
<th>Ertapenem dose/duration</th>
<th>Status</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT00451386 [64] and [65]</td>
<td>Phase 3, RCT</td>
<td>Europe, USA, South America</td>
<td>403</td>
<td>3 months to 17 years</td>
<td>cUTI, CAP, SSTI</td>
<td>Comparative safety (incidence of clinical and laboratory drug-related serious AEs)</td>
<td>Comparative tolerability and efficacy</td>
<td>Infected burn wounds; necrotising fasciitis; osteomyelitis or septic arthritis; mechanical ventilation; cystic fibrosis; chronic lung disease or empyema; significant renal impairment</td>
<td>Ceftriaxone</td>
<td>13–17 years, 1 g i.v. OD; 3 months–12 years, 15 mg/kg BID (maximum 1 g daily) for a mean of 4 days</td>
<td>Completed</td>
<td>Most common drug-related clinical AEs: diarrhoea (5.9% ertapenem, 10% ceftriaxone), infusion-site erythema (3% ertapenem),</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator</td>
<td>Ertapenem dose/duration</td>
<td>Status</td>
<td>Result</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>-------------------</td>
<td>------------------</td>
<td>-----------------------</td>
<td>------------------------</td>
<td>------------</td>
<td>--------------------------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2% ceftriaxone), infusion-site pain (5% ertapenem, 1% ceftriaxone). Serious drug-related clinical AE: 1 pt each. No serious

<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint</th>
<th>Secondary endpoint(s)</th>
<th>Main exclusion criteria</th>
<th>Comparator</th>
<th>Ertapenem dose/duration</th>
<th>Status</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>N. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator</td>
<td>Ertapenem dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----</td>
<td>-------------------</td>
<td>------------------</td>
<td>------------------------</td>
<td>------------------------</td>
<td>------------</td>
<td>------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

s drug-related laboratory AEs. Overall clinical response to ertapenem similar to larger clinical trials in adults
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>N. o. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint</th>
<th>Secondary endpoint(s)</th>
<th>Main exclusion criteria</th>
<th>Comparator</th>
<th>Ertapenem dose/ duration</th>
<th>Status</th>
<th>Results</th>
</tr>
</thead>
</table>
| NCT01069900, EudraCT 2009-015578-37 [66] and [67] | RCT, DB, phase 3 | Europe, South America, USA, South /East Asia | 300 | 3 months to 17 years | IAI | Comparative safety with a special focus on cardiac and musculoskeletal events | Evaluatio
<p>| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint</th>
<th>Secondary endpoint(s)</th>
<th>Main exclusion criteria</th>
<th>Comparator</th>
<th>Ertapenem dose/ duration</th>
<th>Status</th>
<th>Results</th>
</tr>
</thead>
</table>

- **ogical response at Days 3–5 and EOT**
- concomitant treatment with QT prolonging drugs; history of tendon disease/disorder related to quinolone treatment; abnormal musculoskeletal findings at baseline

pts, patients; RCT, randomised controlled trial; cUTI, complicated urinary tract infection; CAP, community-acquired pneumonia; SSTI, skin and soft-tissue infection; AE, adverse event; i.v., intravenous; OD, once daily; BID, twice daily; DB, double blind; IAI, intra-abdominal infection; TOC, test of cure; EOT, end of therapy; q12h, every 12 h; NA, not available.
In a separate RCT, ertapenem was the comparator drug to moxifloxacin in children aged 3 months to 17 years with cIAIs [66] and [67].

A potential advantage of ertapenem compared with other carbapenems is the spectrum of activity sparing P. aeruginosa: ertapenem does not adversely affect carbapenem resistance among these bacteria, and improved P. aeruginosa susceptibilities have been reported after years of its use [61] and [68]. Ertapenem's prolonged half-life with once-daily dosing facilitates its use in outpatient parenteral antibiotic therapy (OPAT) for children older than 12 years.

No PIP is currently available on ertapenem.

3.6. Fidaxomicin

Fidaxomicin is the first in a new class of narrow-spectrum 18-ring macrolide antibiotics. Produced by an actinomycete, it has selective bactericidal activity against pathogenic Clostridium difficile, with minimal effects on the normal intestinal microflora. Its mechanism of action consists in inhibition of bacterial RNA polymerase [69] and [70].

Fidaxomicin is approved in the EU and USA for the treatment of adults with C. difficile-associated diarrhoea (CDAD). In pre-marketing studies, fidaxomicin was non-inferior to oral vancomycin in achieving clinical cure of CDAD (92.1% vs. 89.8%) and was associated with fewer recurrences [71]. In the USA, a study on the safety, tolerability and pharmacokinetics of fidaxomicin in children (6 months to 18 years) with CDAD is currently in progress [72]. In the EU, a prospective observational study in children has recently started (Table 7), aiming to determine the incidence and clinical outcomes of C. difficile infection in 60 term neonates and to investigate the feasibility of a potential interventional study [73].

Table 7.

European clinical trial on fidaxomicin involving paediatric patients.
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Location</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoints</th>
<th>Secondary endpoint</th>
<th>Main exclusion criteria</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT01533844</td>
<td>Observational, non-interventional</td>
<td>Europe</td>
<td>60 (estimated)</td>
<td>0–27 days</td>
<td>CDAD</td>
<td>To determine the feasibility of a potential interventional study with fidaxomycin; to determine the incidence and clinical aspects of CDI in neonates and whether a subgroup can be identified</td>
<td>–</td>
<td>Preterm neonates; negative Clostridium difficiletoxin test</td>
<td>Recruiting</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Location</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoints</td>
<td>Secondary endpoint</td>
<td>Main exclusion criteria</td>
<td>Status</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>----------</td>
<td>------------</td>
<td>-----</td>
<td>-------------------</td>
<td>-------------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>--------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>where treatment with fidaxomicin therapy might improve outcome</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

pts, patients; CDAD, Clostridium difficile-associated disease; CDI, C. difficile infection.

Table options

A PIP for treatment of CDAD in children has been agreed [74].

3.7. Linezolid

Linezolid is the first member of the oxazolidinones [75]. It exhibits a selective spectrum of activity against Gram-positive bacteria, including MRSA, MRSE, VRE and PRSP. Linezolid inhibits bacterial protein synthesis through blocking the initiation process.

In Europe, approved indications for its use in adults are CAP, HAP and cSSTIs caused by Gram-positive bacteria. The FDA labelled linezolid for paediatric use in 2002 at doses of 10 mg/kg q8h in children aged 0–11 years and 10 mg/kg q12h (maximum 600 mg q12h) in older children. Conversely, in most European countries it remains off-label in the paediatric setting, although recent reports note that it is occasionally prescribed in children [76] and [77]. Neonatal dosing of linezolid has been poorly studied. PK data suggest that linezolid clearance is decreased in preterm and in term neonates <7 days of age; therefore, all neonates should be treated with 10 mg/kg q12h during their first week of life [78]. The main side effects in
children are gastrointestinal disturbances. Peripheral and optic neuropathy and myelotoxicity seem less frequent than in adults, however the risk of these severe complications should be considered and careful monitoring is recommended [77]. Linezolid has several advantages over glycopeptides. The high and rapid tissue penetration supports its use for central nervous system or osteoarticular infections. The oral formulation, with excellent bioavailability, can be useful in step-down therapy and in outpatients. Its activity against mycobacteria justifies its potential role in treating drug-resistant tuberculosis [79].

Five clinical trials enrolling adults and children (aged 13–17 years) treated with linezolid have been completed in the EU (Table 8). In three trials, linezolid was administered to treat CAP caused by PRSP, cSSTIs and catheter-related bloodstream infections due to Gram-positive organisms, or febrile neutropenia in oncological patients [80], [81], [82], [83] and [84]. In all these studies the number of enrolled children was limited and a stratified analysis for the paediatric population was not given. Therefore, no definite conclusions can be drawn. For the remaining two trials, evaluating children aged 0–17 years with haemato-oncological disease or undergoing haematopoietic stem cell transplantation, results are not yet available. The first study evaluated the efficacy and safety of rescue therapy with antibiotic-lock technique with either linezolid, vancomycin or amikacin for the treatment of indwelling central venous catheter (CVC)-related bacteraemia in retained CVC [85]. The second study evaluated continuous infusion with either linezolid, vancomycin, ceftazidime or meropenem as salvage therapy of tunnel/pocket infections of an indwelling CVC [86].

Table 8.

European clinical trials on linezolid (LNZ) involving paediatric patients.
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations (ITT)</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoints</th>
<th>Secondary endpoint</th>
<th>Main exclusion criteria</th>
<th>Comparator(s)</th>
<th>Linezolid dose/duration</th>
<th>Status</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olled, OL</td>
<td>, Asia</td>
<td>54.5 years</td>
<td></td>
<td></td>
<td></td>
<td>Efficacy</td>
<td>safety</td>
<td>&gt;24 h with another antibiotic; HIV-positive subjects; low CD4 count</td>
<td>O for 10–21 days</td>
<td></td>
<td></td>
<td>77.3%. Microbiological eradication, 84.3%. Main AEs, abdominal pain (3.5%), headache (3.9%), diarrhoea (4.4%), nausea (5.7%), anaemia</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts (ITT)</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoints</td>
<td>Secondary endpoint</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Linezolid dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
<td>-----------</td>
<td>-----------------</td>
<td>-----</td>
<td>------------------</td>
<td>------------------</td>
<td>-------------------</td>
<td>----------------------</td>
<td>--------------</td>
<td>------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>NCT00037050, EudraCT: 2004-001511-54 [81], [82] and [83]</td>
<td>Phase 3, RCT, OL</td>
<td>Europe, USA, Latin America, South America, Asia, Russian Federation, South</td>
<td>363</td>
<td>LNZ, 16–92 years (mean 53.7)</td>
<td>Comparator, 14–94 years (mean 53.8)</td>
<td>Central indwelling catheter-related cSSTI or bacteraemia by Staphylococcus aureus, CoNS, Entrococcus spp.</td>
<td>Evaluative empirical treatment</td>
<td>Comparative efficacy of LNZ; incidence of late metastatic sequelae in patients treated with LNZ</td>
<td>Tunnelled catheter that cannot be removed; endocarditis; infection of permanent intravascular device</td>
<td>Vancomycin i.v. 1 g q12h; oxacillin i.v. 2 g q6h; dicloxacin PO 500 mg q6h</td>
<td>600 mg q12h i.v./P O for 10–28 days</td>
<td>Completed</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts (ITT)</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoints</td>
<td>Secondary endpoint</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Linezolid dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>-----------------</td>
<td>-----</td>
<td>-------------------</td>
<td>-------------------</td>
<td>--------------------</td>
<td>------------------------</td>
<td>---------------</td>
<td>--------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>NCT00035425 [84]</td>
<td>Phase 3, RCT, DB</td>
<td>Europe, USA, Latin</td>
<td>61 LNZ, 57 com</td>
<td>LNZ, 15–80 years (mea)</td>
<td>Suspected or proven Gram-positive (S. aureus,</td>
<td>Comparative clinical</td>
<td>Microbiologic</td>
<td>Fever due to known causes</td>
<td>LNZ, 89.9% comparator; bacteraemia, 86.3% LNZ, 90.5% comparator</td>
<td>600 mg q 12 h i.v. for</td>
<td>Completed</td>
<td>Clinical success: 82.9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts (ITT)</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoints</td>
<td>Secondary endpoint</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Linezolid dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
<td>-----------</td>
<td>-----------------</td>
<td>-----</td>
<td>------------------</td>
<td>------------------</td>
<td>-------------------</td>
<td>----------------------</td>
<td>--------------</td>
<td>-----------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>America, paratractor</td>
<td>n 45.2 years</td>
<td>CoNS, Streptococcus sp.) infection in febrile, neutropenic cancer pts</td>
<td>45.2 years</td>
<td></td>
<td></td>
<td></td>
<td>q12h i.v.</td>
<td>10–28 days</td>
<td>LNZ, 80.0% vancomycin</td>
<td>Microbiological success: 81.8%</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts (ITT)</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoints</td>
<td>Secondary endpoint</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Linezolid dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>-----------------</td>
<td>-----</td>
<td>-------------------</td>
<td>-------------------</td>
<td>------------------</td>
<td>------------------------</td>
<td>---------------</td>
<td>-----------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>EudraCT: 2006-000595-32 [85]</td>
<td>Phase 2, not controlled, OL</td>
<td>Europe</td>
<td>12</td>
<td>&lt;18 years</td>
<td>Central indwelling catheter-related bacteraemia in haematological pts</td>
<td>Safety and efficacy</td>
<td>New metastatic infections during treatment; lack of response within 7 days of treatment;</td>
<td>None</td>
<td>NA</td>
<td>Completed</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts (ITT)</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoints</td>
<td>Secondary endpoint</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Linezolid dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
<td>-----------</td>
<td>-----------------</td>
<td>-----</td>
<td>------------------</td>
<td>-------------------</td>
<td>-------------------</td>
<td>----------------------</td>
<td>---------------</td>
<td>--------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>EudraCT: 2006-002146-10 [86]</td>
<td>Not controlled, phase 2, OL</td>
<td>Europe</td>
<td>12</td>
<td>&lt;18 years</td>
<td>Tunnel/pocket infections (cellulitis) of central indwelling catheters in haematological pts</td>
<td>Tolera bility of antibiotic lock; feasibility of outpatient therapy</td>
<td>New metastatic infections during treatment; lack of response within 7 days of treatment</td>
<td>None</td>
<td>NA</td>
<td>Completed</td>
<td>NA</td>
<td>advers e reactions to the drug used</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts (ITT)</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primar y endpoints</td>
<td>Second ary endpoint</td>
<td>Main exclus ion criteria</td>
<td>Comparator(s)</td>
<td>Linezolid dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
<td>-----------</td>
<td>-----------------</td>
<td>-----</td>
<td>-------------------</td>
<td>-------------------</td>
<td>-------------------</td>
<td>-----------------------</td>
<td>--------------</td>
<td>------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
</tbody>
</table>

pts, patients; ITT, intention to treat; OL, open label; CAP, community-acquired pneumonia; HIV, human immunodeficiency virus; q12h, every 12 h; i.v., intravenous; PO, per os; AE, adverse event; RCT, randomised controlled trial; cSSTI, complicated skin and soft-tissue infection; CoNS, coagulase-negative staphylococci; q6h, every 6 h; DB, double blind; CNS, central nervous system; NA, not available.

Table options

In two previously cited RCTs, linezolid is one of the comparators for ceftaroline [20] and [21].

No PIP is currently available on linezolid.

3.8. Moxifloxacin

Moxifloxacin is a fourth-generation fluoroquinolone with a rapid bactericidal effect [87]. It acts by interfering with topoisomerase II and IV, which are essential enzymes for the replication, transcription and repair of bacterial DNA. Its spectrum of activity covers Gram-positive bacteria (including S. pneumoniae and S. aureus), Gram-negative bacteria, some
anaerobes and atypical strains. Moxifloxacin has high oral availability and rapidly distributes to extravascular spaces, with a strong affinity for alveolar tissue.

Although moxifloxacin displayed a favourable safety profile in clinical trials, the EMA-approved indications have been recently restricted due to the increased risk of adverse hepatic reactions [88]. They include second-line therapy of acute bacterial sinusitis, acute exacerbations of chronic bronchitis (AECB) and CAP. Warnings have also been raised for spontaneous tendon ruptures, worsening of myasthenia gravis symptoms and severe skin reactions. Other serious adverse effects include irreversible peripheral neuropathy and QTc prolongation [89].

The main advantages of moxifloxacin are once-daily administration, fast bactericidal action, good tissue penetration and broad spectrum of activity, including mycobacteria.

Moxifloxacin is not licensed for paediatric use, with the exception of the topical formulation, and its dosage in children is still to be determined. The WHO guidelines on the treatment of drug-resistant tuberculosis recommend a moxifloxacin dose of 7.5–10 mg/kg/day (maximum 400 mg) in children [90]. In the USA, a trial is currently investigating the pharmacokinetics of single-dose moxifloxacin in children aged 3 months to 14 years [91].

Four trials on the systemic use of moxifloxacin (hydrochloride) in children are being conducted in the EU (Table 9). Table 9.

European clinical trials on moxifloxacin involving paediatric patients.
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint(s)</th>
<th>Secondary endpoint(s)</th>
<th>Main exclusion criteria</th>
<th>Comparator(s)</th>
<th>Status</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT01069900, EudraCT 2009-015578-37 [66] and [67]</td>
<td>Phase 3, RCT, DB</td>
<td>Europe, Asia, Central and South America, USA</td>
<td>450</td>
<td>3 months to 17 years</td>
<td>IAI</td>
<td>Comparative safety</td>
<td>Evaluation of musculo skeletal AEs; electrocardiogram profiles; clinical response at TOC among subjects with a bacteriologically confirmed complicated IAI; Spontaneous bacterial peritonitis; pancreatic processes: early acute or suppurative (non-perforated) appendicitis; severe immunosuppression; congenital or</td>
<td>Ertapenem 1 g i.v. OD for a minimum of 3 days (age 13 years to &lt;18 years) or 15 mg/kg body weight i.v. BID not to exceed 1 g daily (age &lt;13 years) If switched to PO:</td>
<td>Recruitin g</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12–17 years (≥45 kg): 400 mg i.v. OD for a minimum of 3 days If switched to PO:</td>
<td>400 mg OD &lt;12 years: 4 mg/kg BID</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint(s)</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Moxifloxacin dose/duration</td>
<td>Status</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>------------------</td>
<td>---------------------</td>
<td>-----------------------</td>
<td>------------------------</td>
<td>--------------</td>
<td>--------------------------</td>
<td>--------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Clinical and bacteriological response to treatment at a ‘during therapy’ visit and at EOT.
- Acquired QT prolongation, concomitant treatment with QT-prolonging drugs; tendon disease/disorder related to quinolone treatment; pathogenic organisms resistant to study.

- 45 mg amoxicillin/kg body weight BID not to exceed 875 mg amoxicillin BID (total treatment duration 5–14 days).

- i.v. and PO (maximum 400 mg daily) for 5–14 days.
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint(s)</th>
<th>Secondary endpoint(s)</th>
<th>Main exclusion criteria</th>
<th>Comparator(s)</th>
<th>Moxifloxacin dose/duration</th>
<th>Status</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT00932802[92] and [93]</td>
<td>Phase 4, observational</td>
<td>Europe, Central and South America, Asia ,</td>
<td>500000</td>
<td>≥12 years</td>
<td>Outpatients with AECB</td>
<td>Evaluation of impact of AECB on the patient and community; effect and AEs collection; course of symptom relief; evaluation of frequency of new exacerbations;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Completed</td>
<td>No subanalysis for the paediatric cohort</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>N o. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primar y endpoint(s)</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Moxifloxacin dose/duratio n</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
<td>-----------------</td>
<td>-------------</td>
<td>-----</td>
<td>-------------------</td>
<td>----------------------</td>
<td>-----------------------</td>
<td>------------------------</td>
<td>---------------</td>
<td>-----------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>NCT00997997[94]</td>
<td>Phase 4, observational</td>
<td>Europe, Asia, Africa</td>
<td>630</td>
<td>10 years</td>
<td>cSSTI s</td>
<td>Efficacy (course of severity of infection and of AEs collection; overall assessment of tolerability by the investigator)</td>
<td>Progression of chronic respiratory disease; speed of return to normal daily life activities</td>
<td>According to local product information</td>
<td>None</td>
<td>Accordin g to investigator</td>
<td>Completed</td>
<td>No subsa nalysis for the paediatric</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>N o. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint(s)</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Moxifloxacin dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>-------------</td>
<td>-----</td>
<td>------------------</td>
<td>---------------------</td>
<td>------------------------</td>
<td>-------------------------</td>
<td>--------------</td>
<td>---------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>clinical signs and symptoms, duration until improvement, recovery, wound closure, reuse of moxifloxacin)</td>
<td>physician</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint(s)</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Status</td>
<td>Results</td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>-------------------</td>
<td>------------------------------------</td>
<td>------------</td>
<td>-----</td>
<td>-------------------</td>
<td>---------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
<td>-------------------------</td>
<td>----------------</td>
<td>--------------</td>
<td>--------------------------</td>
<td></td>
</tr>
<tr>
<td>NCT00930488[95]</td>
<td>Observational, phase 4</td>
<td>Europe, Asia, Africa</td>
<td>7 2 4 1</td>
<td>NA</td>
<td>Acute bacterial sinusitis</td>
<td>Evaluation of potential benefits of antibacterial therapy with moxifloxacin</td>
<td>Evaluation of tolerability and safety of moxifloxacin in daily practice</td>
<td>None</td>
<td>According to investigator</td>
<td>Completed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EudraCT 2009-017319-13 [96]</td>
<td>RCT</td>
<td>Europe</td>
<td>1 3 0 0</td>
<td>&lt;1 8 years</td>
<td>AOM with otorrhoea and tympanostomy</td>
<td>Safety and efficacy of topical moxifloxacin; demon</td>
<td>–</td>
<td>Tympanostomy tubes containing antimicrobial agents; current</td>
<td>Placebo</td>
<td>Ongoing in Belgium; prematurely ended</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint(s)</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator(s)</td>
<td>Moxifloxacin dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>---------</td>
<td>-----</td>
<td>-------------------</td>
<td>--------------------</td>
<td>-----------------------</td>
<td>------------------------</td>
<td>---------------</td>
<td>---------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
</tbody>
</table>
|           |            |           |         |     | tuberculosis      | stratification of the therapeutic superiority of moxifloxacin at EOT | acute or chronic non-tube otorrhoea or otitis externa or malignant otitis externa; ear infection of fungal or mycobacterial origin; herpetic infection; mastoiditis or other suppurative ear infection | Denmark and Finland | Den...
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>N o. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint(s)</th>
<th>Secondary endpoint(s)</th>
<th>Main exclusion criteria</th>
<th>Comparator(s)</th>
<th>Moxifloxacin dose/duration</th>
<th>Status</th>
<th>Results</th>
</tr>
</thead>
</table>

pts, patients; RCT, randomised controlled trial; DB, double blind; IAI, intra-abdominal infection; TOC, test of cure; EOT, end of therapy; i.v., intravenous; OD, once daily; BID, twice daily; PO, per os; AECB, acute exacerbations of chronic bronchitis; AE, adverse event; cSSTI, complicated skin and soft-tissue infection; NA, not available; AOM, acute otitis media.

Table options

A RCT is evaluating the safety and efficacy of moxifloxacin versus ertapenem in hospitalised children with cIAIs. The study is still recruiting participants. The safety endpoints focus on cardiac and musculoskeletal AEs [66] and [67].

The remaining three studies are observational phase 4 trials, but their paediatric relevance is limited as the number of enrolled children is not reported and no paediatric subanalysis is available. The first study enrolled outpatients aged ≥12 years under daily treatment with oral moxifloxacin for AECB. It aimed to determine the impact of AECB on the patient and the community and to evaluate the safety and efficacy of moxifloxacin in daily practice [92] and [93]. The second study evaluated patients aged ≥10 years with cSSTIs: moxifloxacin under daily-life treatment conditions appeared effective and the incidence of AEs was low [94]. The third study evaluated the potential benefits, tolerability and safety of moxifloxacin in patients with acute bacterial sinusitis [95].

Finally, a European trial is currently evaluating the safety and efficacy of topical moxifloxacin otic solution in children with acute otitis media with otorrhoea and tympanostomy tubes [96].
PIPs for treatment of pelvic inflammatory disease in female adolescents aged from 12 years to <18 years and cIAIs aged from 3 months to <18 years have been agreed on moxifloxacin [97], [98], [99] and [100].

3.9. Retapamulin

Retapamulin is a topical antibiotic belonging to the new class of pleuromutilins. It is approved by the EMA for bacterial superficial skin infections, such as impetigo due to meticillin-susceptible S. aureus or Streptococcus pyogenes, in patients ≥9 months of age. Retapamulin inhibits bacterial protein synthesis by interacting at a site on the 50S subunit of the bacterial ribosome through a unique mechanism. Systemic exposure following topical application through intact skin is low. The most common adverse reaction is irritation at the application site [101] and [102].

Retapamulin ointment was superior to placebo in adults and children with primary impetigo (Table 10). Pruritus at the application site was the most common AE (6%) [103] and [104]. Retapamulin and sodium fusidate had comparable clinical and bacteriological efficacy in the treatment of impetigo in adults and children aged ≥9 months; both drugs were well tolerated [105], [106] and [107]. The pharmacokinetics of retapamulin has been evaluated in 86 children (2–24 months) with secondarily infected traumatic lesions, dermatoses or impetigo. The study has been completed but the results have not been published [108] and [109]. A pharmacovigilance study will monitor the prescriptions of retapamulin across the EU in infants <9 months of age [110].

Table 10.

European clinical trials on topical retapamulin involving paediatric patients.
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint</th>
<th>Secondary endpoint(s)</th>
<th>Main exclusion criteria</th>
<th>Comparator</th>
<th>Retapamulin dose/duration</th>
<th>Status</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT00133848 [103] and [104]</td>
<td>RCT, DB, phase 3</td>
<td>Asia, Europe, Central and South America</td>
<td>210</td>
<td>≥9 months</td>
<td>Primary impetigo</td>
<td>Clinical response at EOT</td>
<td>Clinical response at FU; impetigo lesion area at EOT and FU</td>
<td>Systemic infection; serious or life-threatening underlying diseases</td>
<td>Placebo ointment</td>
<td>1% ointment BID for 5 days</td>
<td>Completed</td>
<td>Success rate: 85.6% retapamulin, 52.1% placebo</td>
</tr>
<tr>
<td>NCT00133874, EudraCT 2004-004439-70 [105], [106] and [107]</td>
<td>RCT, SB, phase 3</td>
<td>Canada, South America, Europe, Asia</td>
<td>520</td>
<td>≥9 months</td>
<td>Impetigo</td>
<td>Clinical response (no need for additional antibiotic treatment)</td>
<td>Clinical response at FU; microbiological response at</td>
<td>Systemic infection; serious or life-threatening underlying diseases</td>
<td>2% sodium fusidate ointment TID</td>
<td>1% ointment BID for 5 days</td>
<td>Completed</td>
<td>Comparrable clinical efficacy (PPP: retapamulin 99.1%)</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint(s)</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator</td>
<td>Retapamulin dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>------------------</td>
<td>---------------------</td>
<td>-----------------------</td>
<td>------------------------</td>
<td>------------</td>
<td>--------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South Africa</td>
<td></td>
<td></td>
<td></td>
<td>EOT and FU; extent of impetigo lesion area at EOT and FU</td>
<td>EOT and FU; extent of impetigo lesion area at EOT and FU</td>
<td>disease for 7 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results: vs. comparator 94.0%; ITT population: 94.8% retapamulin vs. 90.1% comparator. Similar bacteriological efficacy.
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primary endpoint</th>
<th>Secondary endpoint(s)</th>
<th>Main exclusion criteria</th>
<th>Comparator</th>
<th>Retapamulin dose/duration</th>
<th>Status</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT00555061, EudraCT 2006-003374-10 [108] and [109]</td>
<td>Non-randomised, OL, phase 4</td>
<td>South America, Europe, Central America, South Africa, USA</td>
<td>87 (1 pt did not receive study medication)</td>
<td>2–24 months</td>
<td>Seco ndarily infected traumatic lesions and dermatoses; impetigo</td>
<td>Pharmacokinetics of retapamulin</td>
<td>Age-stratified clinical success at FU; bacteriological response at FU by baseline pathogen; safety of retapamulin</td>
<td>Hypersensitivity to pleuromutilin or components of the ointment; prematurity; animal/human bites, puncture wounds or abscesses;</td>
<td>None</td>
<td>1% ointment BID for 5 days</td>
<td>Completed</td>
<td>NA</td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator</td>
<td>Retapamulin dose/duration</td>
<td>Status</td>
<td>Results</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>------------------</td>
<td>------------------</td>
<td>-----------------------</td>
<td>------------------------</td>
<td>------------</td>
<td>--------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Main exclusion criteria</td>
<td>Comparator</td>
<td>Retapamulin dose/duration</td>
<td>Status</td>
<td>Result</td>
</tr>
<tr>
<td>----------</td>
<td>------------------------------------------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>-------------------</td>
<td>-------------------</td>
<td>-----------------------</td>
<td>-------------------------</td>
<td>------------</td>
<td>---------------------------</td>
<td>----------------</td>
<td>--------</td>
</tr>
<tr>
<td>NCT01153828[110]</td>
<td>Observational, pharmacovigilance study</td>
<td>Europe</td>
<td>NA</td>
<td>Any</td>
<td>Impetigo, secondarily infected traumatic lesions</td>
<td>Age-stratified monitoring of prescribed use of retapamulin</td>
<td>Co-prescription of retapamulin and topical mupirocin; co-prescription of retapamulin and topical fusidic acid</td>
<td>Enrolment in the General Practice Research Database of &lt;1 month duration</td>
<td>None</td>
<td>NA</td>
<td>Ongoing, but not recruiting</td>
<td>NA</td>
</tr>
</tbody>
</table>
3.10. Telithromycin

Telithromycin is a semisynthetic erythromycin derivative and the first member of the ketolides. It was approved in Europe in 2001 and in the USA in 2004. It acts through inhibition of bacterial protein synthesis through binding to the bacterial ribosome with higher affinity than erythromycin [111] and [112]. Following oral administration, telithromycin is rapidly absorbed and diffused into tissues and phagocytes. Telithromycin is used to treat respiratory infections as it is effective against macrolide-resistant S. pneumoniae [113]. In Europe it is marketed for the treatment of adults with mild-to-moderate CAP, AECB, acute sinusitis and tonsillitis/pharyngitis caused by Group A β-haemolytic streptococci (GAS). It is also licensed at 25 mg/kg once daily in children aged 12–18 years with GAS tonsillitis/pharyngitis when β-lactams are not appropriate [114].

The most common side effects are gastrointestinal symptoms. Prolonged QTc intervals may also be observed. Recently, serious safety concerns have been raised regarding risks for severe liver toxicity, visual disturbances, transient loss of consciousness and exacerbations of myasthenia gravis: indeed, part of the telithromycin molecule acts as an antagonist of cholinergic receptors of muscles, eye and liver. For safety reasons, in 2007 the FDA revised the labelling removing two indications (acute bacterial sinusitis and AECB), whilst the EMA has recommended to restrict the use of telithromycin to the treatment of bronchitis, sinusitis and tonsillitis/pharyngitis caused by bacterial strains that are resistant to or cannot be treated with β-lactams or macrolides [115] and [116]. Following the benefit/risk evaluation by the CHMP, the marketing authorisation holder decided to stop the paediatric development programme [117]. Therefore, three studies investigating infants and children with acute otitis media were terminated in Europe (Table 11) and no PIP has been issued [118], [119] and [120].

Table 11.

European clinical trials on telithromycin involving paediatric patients.
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts,</th>
<th>Age</th>
<th>Type of infection</th>
<th>No. of pts,</th>
<th>No. of yrs,</th>
<th>Age</th>
<th>Type of infection</th>
<th>No. of yrs,</th>
<th>Exclusion criteria</th>
<th>Comparator(s)</th>
<th>Telithromycin dose/duration</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT00174811[118]</td>
<td>RC, DB, phase 3</td>
<td>South America, Europe, Asia, USA</td>
<td>639</td>
<td>6–59 months</td>
<td>AOM</td>
<td>Clinical cure at EOT and TOC visit</td>
<td>Time to symptom resolution; clinical cure by causative pathogen; bacteriological eradication at comparative safety; PK substudy; health resource utilisation and impact on usual activities</td>
<td>Uncertain AOM not needing antibiotics; otorrhoea or tympanostomy tubes; congenital abnormalities; congenital prolonged QT syndrome, treatment with agents interfering with QT prolongation; uncorrected hypokalaemia</td>
<td>Cefuroxime 15 mg/kg BID for 10 days (PO)</td>
<td>25 mg/kg OD for 5–10 days (PO)</td>
<td>Study was terminated before enrolment was completed (no definite conclusions on efficacy available). Cure rate: telithromycin 90.0%, cefuroxime 92.7%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Exclusion criteria</td>
<td>Comparator(s)</td>
<td>Telithromycin dose/duration</td>
<td>Comments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
<td>----------------------------------</td>
<td>------------</td>
<td>-----------</td>
<td>-------------------</td>
<td>------------------</td>
<td>----------------------</td>
<td>------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NCT00315003</td>
<td>RC T, DB,</td>
<td>South America, Europe, Israel,</td>
<td>321</td>
<td>6 months</td>
<td>Suppurative AOM</td>
<td>Time to symptom resolution and clinical cure at the TOC visit</td>
<td>Safety</td>
<td>Mild-to-moderate symptoms and signs of AOM; otorrhoea or tympanostomy tube; congenital long QT syndrome; Azithromycin oral suspension 10 mg/kg OD on Day 1, followed by 5 mg/kg OD on</td>
<td>25 mg/kg OD for 5 days (PO)</td>
<td>Because of early termination of the study and limited data, no definite efficacy conclusi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts, Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Exclusion criteria</td>
<td>Comparator(s)</td>
<td>Telithromycin dose/duration</td>
<td>Comments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>-----------------</td>
<td>------------------</td>
<td>-----------------</td>
<td>------------------------</td>
<td>-------------------</td>
<td>--------------</td>
<td>----------------------------</td>
<td>----------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>known or suspected uncorrected hypokalaemia, hypomagnesaemia, bradycardia; myasthenia gravis; known impaired renal function; congenital abnormalities; immunodeficiency; hypersensitivity to macrolides</td>
<td>Days 2–5, max. 500 mg on Day 1 and 250 mg/day from Days 2–5</td>
<td>Telithromycin; known or suspected uncorrected hypokalaemia, hypomagnesaemia, bradycardia; myasthenia gravis; known impaired renal function; congenital abnormalities; immunodeficiency; hypersensitivity to macrolides</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Exclusion criteria</td>
<td>Comparator(s)</td>
<td>Telithromycin dose/duration</td>
<td>Comments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----</td>
<td>-------------------</td>
<td>------------------</td>
<td>-----------------------</td>
<td>-------------------</td>
<td>---------------</td>
<td>-----------------------------</td>
<td>----------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EudraCT: 2004-000738-34 [120]</td>
<td>RC T, DB</td>
<td>Europ and non-EU states</td>
<td>900</td>
<td>6–59 months</td>
<td>AOM</td>
<td>Non-inferiority of telithromycin vs. cefuroxime axetil</td>
<td>Comparative efficacy; safety of telithromycin; prevalence of nasopharyngeal carriage of Streptococcus pneumoniae; plasma telithromycin concentration</td>
<td>Otorrhoea or tympanostomy tube; otitis externa; chronic diseases; congenital prolonged QT syndrome; myasthenia gravis; impaired renal function, hypokalaemia,</td>
<td>Cefuroxime axetil 15 mg/kg BID for 10 days</td>
<td>25 mg/kg OD for 5–10 days</td>
<td>Prematurely ended</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>No. of pts, Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Exclusion criteria</td>
<td>Comparator(s)</td>
<td>Telithromycin dose/duration</td>
<td>Comments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>----------------</td>
<td>------------------</td>
<td>-----------------</td>
<td>----------------------</td>
<td>-------------------</td>
<td>---------------</td>
<td>-----------------------------</td>
<td>----------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>hypomagnesaemia, bradycardia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

pts, patients; RCT, randomised controlled trial; DB, double blind; AOM, acute otitis media; EOT, end of treatment; TOC, test of cure; PK, pharmacokinetic; BID, twice daily; PO, per os; OD, once daily; ITT, intention-to-treat; EU, European Union.

Table options

3.11. Tigecycline
Tigecycline is the first member of the glycylcyclines. It is structurally similar to tetracyclines and acts as a protein synthesis inhibitor by binding to the 30S ribosomal subunit of bacteria [121] and [122]. Its bacteriostatic activity is maintained in the presence of several resistance mechanisms that affect other antibiotics and it covers a variety of Gram-positive and Gram-negative bacteria (including MRSA, S. maltophilia, A. baumannii and multidrug-resistant Enterobacteriaceae), anaerobes and atypical bacteria. It is not active against P. aeruginosa, Morganella or Providencia spp.[121] and [122].

Tigecycline was given a fast-track approval by the FDA for the treatment of cSSTIs, cIAIs and CAP. It was authorised in the EU in 2006 for adults with cSSTIs (excluding diabetic foot infections) and cIAIs; a variation application to include CAP in licensed indications was withdrawn in 2008.

Tigecycline has similar side effects to the tetracyclines, such as diarrhoea, nausea and vomiting. It may also cause photosensitivity, pseudotumour cerebri and pancreatitis [121], [122] and [123]. Its use is to be avoided in young children and during pregnancy owing to its effects on teeth and bone. Recently, a warning regarding increased mortality risk associated with tigecycline use has been issued [124] and [125]. A recent meta-analysis of RCTs of tigecycline documented that septic shock and superinfections were significantly more frequent in patients treated with tigecycline than with comparators. The CHMP has recommended to restrict tigecycline use to only when other suitable alternatives are not available and to include new warnings to inform prescribers of the higher mortality recorded in tigecycline trials [126].

Two paediatric studies on tigecycline have been conducted in Europe (Table 12). A multicentre study investigated emergency use of the drug in adults and children aged ≥8 years infected by resistant bacteria where other treatments had not been successful. The study has been completed but results for the paediatric cohort are not available [127]. A phase 2 study evaluated the PK profile of multiple doses of tigecycline in children aged 8–11 years with cIAIs, cSSTIs or CAP to identify an appropriate dose regimen (0.75, 1 or 1.25 mg/kg q12h) and to assess the safety profile and efficacy of tigecycline [128] and [129]. The ca. 1.2 mg/kg q12h dosage appeared the most appropriate, to be tested in phase 3 clinical trials. In this cohort, nausea was the most frequent AE and the overall clinical cure rate was 94%.

Table 12.

European clinical trials on tigecycline involving paediatric patients.
<table>
<thead>
<tr>
<th>Study no.</th>
<th>Study type</th>
<th>Locations</th>
<th>No. of pts</th>
<th>Age</th>
<th>Type of infection</th>
<th>Primar y endpoint</th>
<th>Secondary endpoint(s)</th>
<th>Exclusion criteria</th>
<th>Comparator</th>
<th>Tigecycline dose/duration</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT00205816[127]</td>
<td>Non-randomised, uncontrolled, OL, phase 3</td>
<td>Europe, USA</td>
<td>27</td>
<td>≥8 years</td>
<td>Bacterial infections due to resistant pathogens</td>
<td>Mechanism for the emergency use of tigecycline in clinical situations</td>
<td>Safety and efficacy</td>
<td>Expected survival &lt;2 weeks; hypersensitivity to tigecycline, tetracyclines or related compounds; pregnancy or breastfeeding</td>
<td>None</td>
<td>Tigecycline, 100 mg i.v. followed by 50 mg q12h or q24h for 5–90 days</td>
<td>NA for the paediatric cohort</td>
</tr>
<tr>
<td>NCT00488345[128] and [129]</td>
<td>Randomised, OL, phase 2</td>
<td>Europe, South Africa,</td>
<td>59</td>
<td>8–11 years</td>
<td>cIAI, cSSTI, CAP</td>
<td>PK properties of ascending doses</td>
<td>Population PK model, safety, Endocarditis; artificial heart valve or infected device; hypersensitivity</td>
<td>NA</td>
<td>Tigecycline 0.75, 1 or 1.25 mg/kg</td>
<td>Mean PK values: Cmax, 1899 ng/mL; Tmax, 0.56 h; between-</td>
<td></td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>N o. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Exclusion criteria</td>
<td>Comparator</td>
<td>Tigecycline dose/duration</td>
<td>Results</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>------------</td>
<td>-----</td>
<td>------------------</td>
<td>------------------</td>
<td>----------------------</td>
<td>-------------------</td>
<td>------------</td>
<td>--------------------------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td>Asia, USA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>efficiency to tigecycline or other related compounds; immunosuppressed patients; serious infections (e.g. necrotising fasciitis, gangrene, empyema, abscess, etc.); critical conditions (sepsis and septic shock)</td>
<td>i.v. for ≥5 days</td>
<td>dose AUC, 2833 ng h/mL; weight-normalised clearance, 0.503 L/h/kg; and Vd,ss, 4.88 L/kg. Overall clinical cure rates at TOC: 94%, 76% and 75% in the 0.75, 1 and 1.25 mg/kg cohorts, respectively. Nausea in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study no.</td>
<td>Study type</td>
<td>Locations</td>
<td>N o. of pts</td>
<td>Age</td>
<td>Type of infection</td>
<td>Primary endpoint</td>
<td>Secondary endpoint(s)</td>
<td>Exclusion criteria</td>
<td>Comparator</td>
<td>Tigecycline dose/duration</td>
<td>Results</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----</td>
<td>-------------------</td>
<td>-----------------</td>
<td>----------------------</td>
<td>-------------------</td>
<td>------------</td>
<td>--------------------------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

50% of patients. PD simulations predicted that a dosage of ca. 1.2 mg/kg q12h would lead to therapeutic target attainment levels of up to 82% for the target AUC0–24/MIC ratios.

pts, patients; OL, open label; i.v., intravenous; q12h, every 12 h; q24h, every 24 h; NA, not available; cIAI, complicated intra-abdominal infection; cSSTI, complicated skin and soft-tissue infection; CAP, community-acquired pneumonia; PK, pharmacokinetic; Cmax, peak concentration of drug; Tmax, time at which Cmax is observed; AUC, area under the...
concentration–time curve; Vd,ss, volume of distribution at steady state; TOC, test of cure; PD, pharmacodynamic; MIC, minimum inhibitory concentration.

Table options

A PIP has been agreed for treatment of cSSTIs and cIAIs in children aged 8–18 years [130].

4. Discussion

The increasing problem of multidrug-resistant bacteria will encourage the development and hopefully subsequent approval of new antibiotics [2]. The need for targeted studies on antibiotics in children has been recognised as a matter of concern by the regulatory authorities. However, despite the recent efforts in implementing paediatric trials, the number of studies that have been or are being conducted in children in this area still remains strikingly low, especially in Europe. For all the different possible indications for the 11 antibiotics newly approved by the EMA (of which only 2 have paediatric labelling), 31 clinical trials enrolling children in Europe were identified. However, many of these trials were mainly focused on adults and did not provide a subset analysis for the older children recruited, limiting the relevance of their findings. Some studies have been prematurely terminated and others are active but are still not yet recruiting patients. Among paediatric-targeted studies, 18 evaluate the safety and efficacy of new compounds, 4 are PK studies, but only 2 focus on neonates, the population in which dosing is likely most different from adults or older children. We could identify only one paediatric pharmacovigilance study on antibiotics in Europe. Nearly all studies with an agreed PIP have just started or are not yet recruiting. To our knowledge, this is the first comprehensive review on clinical trials conducted in the EU on antibiotics in children. Previous reports in the USA have documented an increase in the quantity and quality of paediatric controlled trials, demonstrating a success of the FDA paediatric exclusivity programme. However, it also emerged that dissemination of trial results in the literature is limited, as barely one-half of studies were published and determined labelling changes [131], [132] and [133]. A possible bias should also be taken into account in our study: unregistered trials, as well as unpublished data retained by pharmaceutical companies, may have led to an underestimation of available results. The new interventions and legislation introduced both in the USA and Europe should further promote drug evaluation in paediatrics, but the efficacy of these processes is under review. There are a number of steps that would improve the design of new antibiotic trials in children in Europe. These include an adequate knowledge of the basic epidemiology of key clinical syndromes in children (CAP, SSTI, IAI, etc.) through prospective observational studies. Second, a closer collaboration between clinicians and the pharmaceutical industry is necessary, particularly in early study design. The EMA has created a European paediatric network of research networks, investigators and
centres with expertise in paediatric clinical studies [European Network of Paediatric Research at the European Medicines Agency (Enpr-EMA)], that supports high-quality studies in children and helps with fostering closer links between industry, the regulators, patient representatives and academic clinical trial networks [134].

The EU and the European Federation of Pharmaceutical Industries and Associations (EFPIA) have launched a public–private partnership called the Innovative Medicines Initiative (IMI), aimed at improving and speeding up the drug development process. Combating and treatment of infectious diseases is a key research priority of the IMI programme: in May 2012, the IMI launched its 6th Call on the theme ‘Combating Antibiotic Resistance’ that includes ‘innovative trial design & clinical drug development’ [135]. It was perhaps slightly disappointing that the call did not include any specific development programme for children, with the call being only on clinical trials for adults. One potential model could be based on the Paediatric European Network for Treatment of AIDS (PENTA), established in 1991 as a collaboration between paediatric human immunodeficiency virus (HIV) centres in Europe, working closely with industry and the regulator to rapidly develop appropriate studies in children in parallel with adult HIV drug development programmes [136]. These studies are often a combination of PK, safety and strategic trials, rather than expensive and often not appropriate large phase 3 efficacy studies. PENTA has now become PENTA-ID, and can work with Pharma to develop new antimicrobials in Europe. This structured approach may actually speed drug development within the current regulatory framework. This level of collaboration with baseline observational studies, linked to planned interventional studies, is now required for antibiotics under early development.

Funding: IL was partly supported by the European Union through the European Regional Development Fund, the Estonian Science Foundation and target financing of the Estonian Ministry of Education and Research (SF0180004s12).

Competing interests: None declared.

Ethical approval: Not required.

References

[1]
Collateral damage and what the future might hold. The need to balance prudent antibiotic utilization and stewardship with effective patient management.

Int J Infect Dis, 10 (Suppl 2) (2005), pp. S17–S24

[2]

[3]
Economic return of clinical trials performed under the Pediatric Exclusivity Program.
JAMA, 297 (2007), pp. 480–488

[4]
Medicines for children licensed by the European Medicines Agency (EMEA): the balance after 10 years.

Survey of unlicensed and off label drug use in paediatric wards in European countries. European Network for Drug Investigation in Children
BMJ, 320 (2000), pp. 79–82


[8]


Aztreonam lysine: a novel inhalational antibiotic for cystic fibrosis
Microbiology, safety, and pharmacokinetics of aztreonam lysinate for inhalation in patients with cystic fibrosis


Inhaled aztreonam lysine vs. inhaled tobramycin in cystic fibrosis: a comparative efficacy trial
J Cyst Fibros, 12 (2013), pp. 130–140


[23] C. Vilhena, A. Bettencourt
Daptomycin: a review of properties, clinical use, drug delivery and resistance

Daptomycin: pharmacology and clinical use
Expert Opin Pharmacother, 11 (2010), pp. 615–625
[25]
G. Wu, T. Abraham, J. Rapp, F. Vastey, N. Saad, E. Balmir
Daptomycin: evaluation of a high-dose treatment strategy

[26]
P.A. Moise, E. Hershberger, M.I. Amodio-Groton, K.C. Lamp
Safety and clinical outcomes when utilizing high-dose (≥8 mg/kg) daptomycin therapy
Ann Pharmacother, 43 (2009), pp. 1211–1219

[27]
Single-dose pharmacokinetics and tolerability of daptomycin 8 to 10 mg/kg in children aged 2 to 6 years with suspected or proved Gram-positive infections

[28]
M.J. Rybak
The efficacy and safety of daptomycin: first in a new class of antibiotics for Gram-positive bacteria

[29]

[30]
Pharmacokinetics and tolerability of single-dose daptomycin in young infants

[31]
Single-dose pharmacokinetics of daptomycin in children with suspected or proved Gram-positive infections

[32]
G. Erturan, H. Holme, R. Smith, R. Dodds, S. Iyer
Successful use of daptomycin in Panton–Valentine leucocidin positive Staphylococcus aureus paediatric osteomyelitis

[33]
Serum levels of daptomycin in pediatric patients
Infection, 40 (2012), pp. 367–371

[34]
L.M. Jacobson, A.M. Milstone, J. Zenilman, K.C. Carroll, R. Arav-Boger
Daptomycin therapy failure in an adolescent with methicillin-resistant Staphylococcus aureus bacteremia

[35]
C.A. Beneri, D.P. Nicolau, H.S. Seiden, L.G. Rubin
Successful treatment of a neonate with persistent vancomycin-resistant enterococcal bacteremia with a daptomycin-containing regimen
Infect Drug Resist, 1 (2008), pp. 9–11


Daptomycin therapy for invasive Gram-positive bacterial infections in children

[40]
S.J. Matthews, J.W. Lancaster
Doripenem monohydrate, a broad-spectrum carbapenem antibiotic
Clin Ther, 31 (2009), pp. 42–63

[41]
G.D. Overturf
Doripenem: an early look at a carbapenem not yet approved for pediatrics

[42]
S.J. Keam
Doripenem: a review of its use in the treatment of bacterial infections
Drugs, 68 (2008), pp. 2021–2057

[43]
E.B. Chahine, M.J. Ferrill, M.N. Poulakos
Doripenem: a new carbapenem antibiotic

[44]
R. Redman, T.M. File Jr.
Safety of intravenous infusion of doripenem

[45]
Efficacy and safety of doripenem versus piperacillin/tazobactam in nosocomial pneumonia: a randomized, open-label, multicenter study

[46]
C. Lucasti, A. Jasovich, O. Umeh, J. Jiang, K. Kaniga, I. Friedland
Efficacy and tolerability of IV doripenem versus meropenem in adults with complicated intra-abdominal infection: a phase III, prospective, multicenter, randomized, double-blind, noninferiority study
Efficacy and safety of intravenous infusion of doripenem versus imipenem in ventilator-associated pneumonia: a multicenter, randomized study
Crit Care Med, 36 (2008), pp. 1089–1096

A randomized trial of 7-day doripenem versus 10-day imipenem–cilastatin for ventilator-associated pneumonia
Crit Care, 16 (2012), p. R218


[50]

[51]
An open-label study to evaluate the single-dose pharmacokinetics, safety, and tolerability of doripenem in infants (term and preterm), less than 12 weeks chronological age. EudraCT Number 2009-014387-20. https://www.clinicaltrialsregister.eu/ctr-search/trial/2009-014387-20/GB or/BE.

[52]

[53]
[54]

[55]

[56]

[57]
[58]

[59]

[60]
B.L. Congeni
Ertapenem
Expert Opin Pharmacother, 11 (2010), pp. 669–672

[61]
Comparative review of the carbapenems
Drugs, 67 (2007), pp. 1027–1052
[62]

[63]
Safety and tolerability of ertapenem

[64]
Safety and tolerability of ertapenem versus ceftriaxone in a double-blind study performed in children with complicated urinary tract infection, community-acquired pneumonia or skin and soft-tissue infection

[65]
[66]

[67]
A randomized, double-blind, multicenter trial to evaluate the safety and efficacy of sequential (intravenous, oral) moxifloxacin versus comparator in pediatric subjects with complicated intraabdominal infection. EudraCT Number: 2009-015578-37. https://www.clinicaltrialsregister.eu/ctr-search/trial/2009-015578-37/DE or/LV or/LT or/IT or/CZ or/BE or/HU or/BG or/GB

[68]
Carbapenem stewardship: does ertapenem affect Pseudomonas susceptibility to other carbapenems? A review of the evidence

[69]
Y. Golan, L. Epstein
Safety and efficacy of fidaxomicin in the treatment of Clostridium difficile-associated diarrhea

[70]
T.J. Louie, J. Emery, W. Krulicki, B. Byrne, M. Mah
OPT-80 eliminates Clostridium difficile and is sparing of Bacteroides species during treatment of C. difficile infection

[71]
Fidaxomicin versus vancomycin for infection with Clostridium difficile in Europe, Canada, and the USA: a double-blind, non-inferiority, randomised controlled trial
Lancet Infect Dis, 12 (2012), pp. 281–289

[72]

[73]
To determine the feasibility of a fidaxomicin study in neonates and to assess C. difficile (Clostridium difficile) involvement in the pathogenesis (DAISY). ClinicalTrials.gov Identifier: NCT01533844. http://www.clinicaltrials.gov/ct2/show/NCT01533844

[74]

[75]
I.M. Gould
Clinical activity of anti-Gram-positive agents against methicillin-resistant Staphylococcus aureus

[76]
Off-label antibiotic use in children in three European countries

[77]
S. Garazzino, P.A. Tovo
Clinical experience with linezolid in infants and children

[78]
S. Kocher, W. Müller, B. Resch
Linezolid treatment of nosocomial bacterial infection with multiresistant Gram-positive pathogens in preterm infants: a systematic review

[79]
Efficacy, safety and tolerability of linezolid containing regimens in treating MDR-TB and XDR-TB: systematic review and meta-analysis
Eur Respir J, 40 (2012), pp. 1430–1442

[80]

[81]
Complicated skin and skin-structure infections and catheter-related bloodstream infections: noninferiority of linezolid in a phase 3 study
Clin Infect Dis, 48 (2009), pp. 203–212

[82]

[83]

[84]
Treatment of neutropenic patients with fever who are suspected to have a gram positive infection. ClinicalTrials.gov Identifier: NCT00035425. Data on file. http://www.clinicaltrials.gov/ct2/show/NCT00035425

[85]

[86]

[87]
C.H. Nightingale

Moxifloxacin, a new antibiotic designed to treat community-acquired respiratory tract infections: a review of microbiologic and pharmacokinetic–pharmacodynamic characteristics

[88]
European Medicines Agency. European Medicines Agency recommends restricting the use of oral moxifloxacin-containing medicines.

[89]
P.M. Tulkens, P. Arvis, F. Kruesmann

Moxifloxacin safety: an analysis of 14 years of clinical data
Drugs R D, 12 (2012), pp. 71–100
[90]


[91]


[92]


[93]

M. Miravitlles, A. Anzueto, S. Ewig, D. Legnani, K. Stauch
Characterization of exacerbations of chronic bronchitis and COPD in Europe: the GIANT study
Avelox in complicated skin and skin structure infections (ARTOS). ClinicalTrials.gov

Treatment of patients with acute sinusitis. ClinicalTrials.gov

L.P. Yang, S.J. Keam
Retapamulin: a review of its use in the management of impetigo and other uncomplicated superficial skin infections
Drugs, 68 (2008), pp. 855–873

[102]
R. Novak, D.M. Shlaes
The pleuromutilin antibiotics: a new class for human use
Curr Opin Investig Drugs, 11 (2010), pp. 182–191

[103]

[104]
Efficacy and safety of retapamulin ointment as treatment of impetigo: randomized double-blind multicentre placebo-controlled trial
[105]

[106]
Topical retapamulin ointment, 1%, versus sodium fusidate ointment, 2%, for impetigo: a randomized, observer-blinded, noninferiority study

[107]

[108]
An open-label, non-comparative study to assess the pharmacokinetics, safety and efficacy of topical retapamulin (SB-275833) ointment, 1%, twice daily for five days in the treatment of uncomplicated skin and skin structure infections in pediatric subjects aged 2 to 24 months. EudraCT Number: 2006-003374-10.


M. Nguyen, E.P. Chung
Telithromycin: the first ketolide antimicrobial
Clin Ther, 27 (2005), pp. 1144–1163

M. Zeitlinger, C.C. Wagner, B. Heinisch
Ketolides—the modern relatives of macrolides: the pharmacokinetic perspective
Clin Pharmacokinet, 48 (2009), pp. 23–38
[113]
Clinical and bacteriologic efficacy of telithromycin in patients with bacteremic community-acquired pneumonia
Respir Med, 100 (2006), pp. 577–585

[114]
European Medicines Agency. Ketek (telithromycin) product

[115]
US Food and Drug Administration. Ketek (telithromycin) product

[116]

[117]

[118]

[119]
Multinational, randomized, double-blind, double-dummy, comparative study to evaluate the efficacy and safety of telithromycin 25 mg/kg given once daily for 5 or 10 days depending on age and previous treatment history versus cefuroxime axetil 15 mg/kg, given twice daily for 10 days, in children with acute otitis media. EudraCT Number: 2004-000738-34. https://www.clinicaltrialsregister.eu/ctr-search/trial/2004-000738-34/DE

C.M. Slover, K.A. Rodvold, L.H. Danziger
Tigecycline: a novel broad-spectrum antimicrobial

T.L. Doan, H.B. Fung, D. Mehta, P.F. Riska
Tigecycline: a glycylcycline antimicrobial agent

S. Prot-Labarthe, R. Youdaren, M. Benkerrou, R. Basmaci, M. Lorrot
Pediatric acute pancreatitis related to tigecycline

[124]
US Food and Drug Administration. FDA Drug Safety Communication: Increased risk of death with Tygacil (tigecycline) compared to other antibiotics used to treat similar infections. http://www.fda.gov/Drugs/DrugSafety/ucm224370.htm

[125]

[126]

[127]
Study Evaluating the Pharmacokinetics (PK), Safety, and Tolerability of Tigecycline in Patients 8 to 11 Years of Age. ClinicalTrials.gov Identifier: NCT00488345. http://www.clinicaltrials.gov/ct2/show/NCT00488345

Pharmacokinetics and safety profile of tigecycline in children aged 8 to 11 years with selected serious infections: a multicenter, open-label, ascending-dose study
Clin Ther, 34 (2012), pp. 496–507


Peer-reviewed publication of clinical trials completed for pediatric exclusivity

*JAMA*, 296 (2006), pp. 1266–1273

[132]

D. Thomson, L. Hartling, E. Cohen, B. Vandermeer, L. Tjosvold, T.P. Klassen

Controlled trials in children: quantity, methodological quality and descriptive characteristics of pediatric controlled trials published 1948–2006


[133]

N. Freemantle, M. Calvert

What can we learn from observational studies of oseltamivir to treat influenza in healthy adults?

*BMJ*, 339 (2009), p. b5248


[135]

[136]