Telithromycin post-antibiotic and post-antibiotic sub-MIC effects for 10 Gram-positive cocci

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Post-antibiotic effects (PAEs) and post-antibiotic sub-MIC effects (PA-SME) of the ketolide telithromycin (HMR 3647) were determined for 10 Gram-positive cocci with various macrolide resistance mechanisms, including inducible and constitutive ribosomal methylase and macrolide efflux resistance genes. Strains tested included four Streptococcus pneumoniae, three Streptococcus pyogenes and three Staphylococcus aureus. Telithromycin MICs were 0.008–0.015 mg/L for pneumococci, 0.015–4.0 mg/L for S. pyogenes and 0.03 mg/L for staphylococci. PAEs were determined after exposure of strains at 10× MIC for 1 h. PA-SME were determined in the presence of 0.12×, 0.25× and 0.5× MIC of the agent after the initial 1 h exposure period. The PAE of telithromycin varied from 0.3 to 3.8 h; the PA-SME varied from 0.8 to 4.6 h, with maximal PA-SME varying from 1.5 to 4.6 h. PAE tended to be shortest for S. pyogenes (0.4–2.7 h) and S. aureus (0.3–2.4 h), compared to 1.5–3.8 h for S. pneumoniae. The duration of the PA-SME was similar for the three species tested. The low MICs for many strains as well as the PAE and PA-SME demonstrated in this study for telithromycin show promise for increasing the dosing interval of this ketolide, but will need verification by pharmacokinetic/pharmacodynamic and clinical studies.

Keywords: post-antibiotic effects, PAEs, ketolides, streptococci, staphylococci

Introduction

Whereas macrolides have been in use for several decades for a wide variety of infections, their use has become increasingly limited by the development of resistance to these and the related agents of the macrolide–lincosamide–streptogramin B (MLS) group.1-3 Macrolide resistance in staphylococci and streptococci is usually a result of ribosomal methylases coded for by erm(A) or erm(B) determinants and results in resistance to macrolides and lincosamides, but not to streptogramins.4 This resistance mechanism is constitutively expressed against macrolides, but may be either constitutively or inducibly expressed against lincosamides. A second macrolide common resistance mechanism is mediated by a macrolide efflux pump coded for by mef(E) or mef(E) determinants in streptococci and msr(A) determinants in staphylococci.5,6 This latter resistance mechanism has no effect on susceptibility of strains to lincosamides or streptogramins. Many other macrolide resistance mechanisms have also been described, including 23S rRNA and L4 and L22 ribosomal protein mutations in pneumococci.6 However, isolates with these resistance mechanisms are rarely detected.

Telithromycin is a recently developed member of the ketolide family, a new class of semi-synthetic 14-membered ring macrolides derived from erythromycin A, with human pharmacokinetic properties similar to erythromycin A.5-12 Previous studies have documented in vitro activity of ketolides against Streptococcus pneumoniae regardless of macrolide or lincosamide susceptibility.1,7,9,10 Ketolides are active against macrolide-susceptible staphylococci and strains with inducible macrolide resistance and do not induce resistance in the latter group.1 However, these agents are inactive against staphylococci and Streptococcus pneumoniae with constitutive macrolide resistance.10

Post-antibiotic effect (PAE) is the term used to describe suppression of bacterial growth that persists after short exposure of organisms to antibacterials.13-15 This effect is the result of the prior antibiotic exposure rather than to persisting subinhibitory concentrations of the compound. PAE is one of the factors that has a clinical impact on antibiotic dosing regimens, allowing less frequent dosing than with agents with no PAE.13 The post-antibiotic subinhibitory effect (PA-SME), on the other hand, is used to determine the additional effect of subinhibitory concentrations of the agent, which will again increase the effect of the agent and further decrease the dosing frequency.13,16-19

This study examined the PAE and PA-SME of the new ketolide, telithromycin, against selected strains of Gram-positive cocci.
including strains with no macrolide resistance, as well as macrolide-resistant strains with constitutively and inducibly expressed \( \text{erm(A)} \) or \( \text{erm(B)} \) determinants, and streptococci with macrolide efflux mediated resistance associated with \( \text{mef(A)} \) or \( \text{mef(E)} \) determinants.

**Materials and methods**

Bacterial strains selected for the study included four \( \text{S. pneumoniae} \) (macrolide-susceptible; macrolide-resistant-lincosamide-susceptible; and inducible and constitutive macrolide-lincosamide-resistant strains), three \( \text{S. pyogenes} \) (macrolide-resistant-lincosamide-susceptible; and inducible and constitutive macrolide-lincosamide-resistant strains), and three \( \text{Staphylococcus aureus} \) (one macrolide susceptible and two inducible macrolide-lincosamide-resistant strains). Resistance phenotypes were identified by disc diffusion methodology, determined with erythromycin A and clindamycin discs applied 15 mm apart, with strains defined as inducibly resistant if they became clindamycin-resistant only in the presence of erythromycin A and as constitutively resistant if they were resistant to both compounds.\(^5,20\)

Genotypes of macrolide-resistant strains were determined by PCR using primers for the presence of \( \text{erm(A)}, \text{erm(A)} \) subclass \( \text{erm(TRA)} \), \( \text{erm(B)}, \text{erm(C)} \) and \( \text{mef(A)} \) as shown in Table 1.\(^3,5,6\)

MICs were determined by the NCCLS broth microdilution method using Mueller–Hinton broth with 5% lysed blood added for streptococci.\(^21\) Inocula were prepared to a concentration of \( 5 \times 10^5 \) cfu/well and MICs read after overnight incubation of trays in ambient air. Standard quality control strains, including \( \text{S. pneumoniae ATCC 49619} \) and \( \text{S. aureus ATCC 29212} \), were included in each run.

PAE was determined by the viable plate count method.\(^13,17\) For experiments with staphylococci, Mueller–Hinton broth (Difco Laboratories, Detroit, MI, USA) (MHB) was used. MHB supplemented with 5% lysed horse blood was used for testing streptococci. Inocula were prepared by suspending growth from an overnight trypticase soy blood agar plate in broth. The broth was incubated at 35°C for 2–4 h in a shaking water bath until turbidity matched a 2 McFarland standard (approximately \( 10^9 \) cfu/mL). Glass tubes containing 5 mL of broth with antibiotic at 10×MIC were inoculated with 50 µL of the above suspension to produce inocula of \( 10^5–10^4 \) cfu/mL. Tubes were mixed well by vortexing and viability counts determined. Growth controls with inculum but no antibiotic were included with each experiment. Inoculated tubes were then placed in a shaking water bath at 35°C for an exposure period of 1 h. At the end of the exposure period, cultures were diluted 1:1000 in pre-warmed broth to remove the antibiotic. An additional control culture was diluted in broth containing the antibiotic at a concentration of 0.01×MIC to confirm that after dilution the activity of the antibiotic had been effectively eliminated.

Viability counts were determined initially, before and immediately after dilution (0 h), and then every 2 h until the turbidity of the tube reached that of a 1 McFarland standard. Recovery plates were inoculated for at least 72 h and colony counts carried out on plates yielding 30–300 colonies.

The PAE was defined, according to Craig & Gudmundsson,\(^13\) as PAE = \( T - C \), where \( T \) = time required for viability counts of an antibiotic-exposed culture to increase by \( 1 \log_{10} \) above the counts observed immediately after dilution, and \( C \) = corresponding time for the antibiotic-free growth control. Viability counts, expressed as \( \log_{10} \) cfu/mL, were plotted against time.

For PA-SME determination, the PAE was induced as described above.\(^15,16,19\) Following the 1:1000 dilution in broth to remove the antibiotic, three additional tubes were prepared containing subinhibitory concentrations of the compound at 0.125, 0.25%, and 0.5% the MIC of the compound for that strain. Tubes were then handled as for PAE determination above. The PA-SME was defined according to Odenholt-Tornqvist et al.\(^17,19\) as PA-SME = \( T_{pa} - C \), where \( T_{pa} \) is the time for cultures previously exposed to antibiotic and then re-exposed to different subinhibitory concentrations to increase by \( 1 \log_{10} \) above the counts observed immediately after dilution, and \( C \) = corresponding time for the antibiotic-free control.

**Results**

Strains selected for this study and their susceptibility phenotypes and genotypes are shown in Table 2. Ketolide activity was related to macrolide susceptibility, with telithromycin being highly active against the erythromycin A-resistant, clindamycin-susceptible isolates of \( \text{S. pneumoniae} \) and \( \text{S. pyogenes} \) (MICs 0.015–0.125 mg/L) and the erythromycin A-resistant, inducibly clindamycin-resistant isolates (MICs 0.008–0.015 mg/L), but variably active against the erythromycin A-resistant and constitutively clindamycin-resistant isolates (MICs 0.008–4 mg/L). Telithromycin was active against the erythromycin A-susceptible strain of \( \text{S. aureus} \), as well as against the two erythromycin A-resistant isolates with inducible clindamycin resistance (MICs 0.03 mg/L).

Results of the PAE and PA-SME experiments are shown in Table 2. Regrowth rates of controls exposed to 0.01×MICs were identical to those of antimicrobial-free controls, indicating that the 1:1000 dilution step removed all detectable antimicrobial activity and that any residual antimicrobial did not interfere with PAE or PA-SME measurements. The length of the PAE varied from 0.3 to 3.8 h, and was not related to resistance phenotype or species. PAE for the \( \text{S. pneumoniae} \)
Strains ranged from 1.5 to 3.8 h, whereas values for *S. pyogenes* varied from 0.4 to 2.7 h, and values for *S. aureus* varied from 0.3 to 2.4 h. The length of the PA-SME varied from 0.8 to 5.2 h, and was not related to resistance phenotype or species. However, duration of PA-SME exceeded that of the PAE for all strains except for two of the *S. pneumoniae* strains, where durations were similar. PA-SME for the *S. pneumoniae* strains ranged from 1.5 to 5.2 h, whereas values for *S. pyogenes* varied from 0.8 to 4.5 h, and values for *S. aureus* varied from 1.9 to 3.5 h. PA-SME effects were longest at 0.5 × MICs for seven of the 10 strains; the three strains not showing this effect were all *S. pneumoniae*. These *S. pneumoniae* strains included the two strains with similar PAE and PA-SME effects, and one strain with similar PA-SME effects at all three subinhibitory concentrations.

### Discussion

MIC results for the ketolide telithromycin against *S. pneumoniae*, *S. pyogenes* and *S. aureus* were comparable to those described previously for another ketolide, HMR 3004, as well as this compound. Activity against *S. pneumoniae* was not affected by the presence of either *erm* (B) or *mef* (A) genes. However, activity against *S. pyogenes* showed more variability, with the MIC for the strain containing the *mef* (A) gene measuring 0.125 mg/L, and that for one strain with an inducibly expressed *erm* (B) gene measuring 0.015 mg/L, whereas the other strain with a constitutively expressed *erm* (B) gene had an MIC of 4 mg/L. Activity was the same against the two *S. aureus* strains with inducibly expressed *erm* (B) genes as against the macro-lide-susceptible strain (MICs 0.03 mg/L), although telithromycin is generally inactive against strains of staphylococci with constitutively expressed *erm* (B) resistance genes (MICs > 32 mg/L). Ketolides are less active against *S. pyogenes* containing the *erm* (B) gene, either constitutively or inducibly expressed. Inducibly erythromycin A-resistant strains of this species containing *erm* (A) genes are susceptible to ketolides and 16-membered macrolides such as josamycin, although inducible resistance to both groups of agents occurs with some strains.

The PAE was short (0.3–0.9 h) for three of the strains, and longer (1.5–3.8 h) for the remaining strains, with the four *S. pneumoniae* strains all belonging to the latter group. PA-SME values were most consistent for the *S. aureus* strains, but were either the same as or slightly higher than PAE values for two of the strains. PA-SME values for *S. pyogenes* were generally one- to almost five-fold longer than PAE values. For *S. pneumoniae*, PA-SME values were similar to the PAE values for macrolide-resistant strains, and were prolonged by up to two-fold only for the macrolide-susceptible strain.

These results indicate potential benefits of these PAE and PA-SME effects against all three species. For *S. pneumoniae*, the benefit was demonstrated in this study from both effects for macro-lide-susceptible strains, and from the PAE for macrolide-resistant strains. Both effects were significant for *S. pyogenes* and *S. aureus* strains with all three common macrolide-resistance determinants, although they were more modest for the latter group. The concentrations used to document PAE and PAE-SME effects were within achievable concentrations of telithromycin for all experiments except for those using the constitutively macrolide-resistant strain of *S. pyogenes*, which had a telithromycin MIC of 4 mg/L.

These results indicate that the dosage regimen of telithromycin might be affected by the combination of its serum half-life and the length of the PAE and/or PA-SME, as these represent the total period of time during which regrowth does not occur. Additional pharmacokinetic/pharmacodynamic and clinical studies will be necessary to validate this hypothesis.

### Acknowledgements

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### Table 2. Results of MIC, PAE and PA-SME experiments with telithromycin against 10 Gram-positive cocci

<table>
<thead>
<tr>
<th>Strain</th>
<th>Resistance phenotype [genotypea]</th>
<th>MIC (mg/L)</th>
<th>PAE (h)</th>
<th>PA-SME (h) at exposure to the subinhibitory concentration indicated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.12 × MIC</td>
</tr>
<tr>
<td><em>Streptococcus pneumoniae</em> ATCC 49619</td>
<td>eryR, cliR</td>
<td>0.008</td>
<td>2.7</td>
<td>3.9</td>
</tr>
<tr>
<td><em>Streptococcus pneumoniae</em> 5179936</td>
<td>eryR, cliR {mef(A)}</td>
<td>0.015</td>
<td>2.5</td>
<td>1.6</td>
</tr>
<tr>
<td><em>Streptococcus pneumoniae</em> 60067</td>
<td>eryR, cliR {erm(B)}</td>
<td>0.008</td>
<td>3.8</td>
<td>4.4</td>
</tr>
<tr>
<td><em>Streptococcus pneumoniae</em> 95333</td>
<td>eryR, cliR constconst const</td>
<td>0.015</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td><em>Streptococcus pyogenes</em> 20</td>
<td>eryR, cliR constconst const</td>
<td>0.015</td>
<td>2.7</td>
<td>3.3</td>
</tr>
<tr>
<td><em>Streptococcus pyogenes</em> 73</td>
<td>eryR, cliR {mef(A)}</td>
<td>0.125</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td><em>Streptococcus pyogenes</em> 27</td>
<td>eryR, cliR constconst const</td>
<td>4.0</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em> 5175400</td>
<td>eryR, cliR constconst const</td>
<td>0.03</td>
<td>1.9</td>
<td>2.2</td>
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<tr>
<td><em>Staphylococcus aureus</em> 65271903</td>
<td>eryR, cliR constconst const</td>
<td>0.03</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em> 5179936</td>
<td>eryR, cliR constconst const</td>
<td>0.03</td>
<td>0.3</td>
<td>1.9</td>
</tr>
</tbody>
</table>

a Macrolide resistance gene present in strain.
References


