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Prevalence and Mechanisms of Erythromycin Resistance in Group A and Group B Streptococcus: Implications for Reporting Susceptibility Results

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In Canada, as in other regions of North America and Europe, the rates of erythromycin resistance among isolates of the group A Streptococcus (GAS; Streptococcus pyogenes) and the group B Streptococcus (GBS; Streptococcus agalactiae) have been increasing (1, 8, 16). In Ontario, Canada, the rate of erythromycin resistance among GBS isolates has increased from 5 to 13% over a period of 3 years (4). For GAS isolates it has increased from 2 to 14% over 4 years (12). In the United States, the rates of erythromycin resistance among GBS isolates increased from 12 to 20% between 1990 and 2000 (16). Despite these documented increases, there are geographic variations in resistance rates and the prevalence of resistance mechanisms (11). In one study, the rates of macrolide resistance among GAS isolates varied from 9% in large urban settings to 0% in rural areas, with an overall average of 4.6% (23).

Resistance to erythromycin in streptococci is mediated by two major mechanisms. Drug efflux, also referred to as the M phenotype, is encoded by the mefA gene and results in low-level resistance to erythromycin but not clindamycin. Resistance may also be due to methylation of the ribosomal drug binding site, which mediates resistance to macrolides, lincosamides, and streptogramin group B (MLSb). Methylenases are encoded by the erm genes and may be inducibly or constitutively expressed (13). Isolates with inducible MLSb resistance test resistant to erythromycin and susceptible to clindamycin (19). In contrast, constitutive MLSb resistance results in resistance to both erythromycin and clindamycin (19). At present, many laboratories report susceptibilities to erythromycin and clindamycin on the basis of in vitro test results without reference to the mechanisms of resistance. In this study, our goal was first to determine the prevalence of erythromycin and clindamycin resistance among clinical isolates of GBS and GAS from the Ottawa, Ontario, Canada, area. Second, we correlated the in vitro results with the mechanism of resistance to help guide the most appropriate approach to the reporting of clindamycin susceptibility.


MATERIALS AND METHODS

Bacterial isolates. A total of 593 consecutive clinical isolates of GAS and 338 consecutive clinical isolates of GBS were collected from an adult hospital and a pediatric hospital in Ottawa from 2002 to 2003. Among the GAS isolates, 339 (57%) were recovered from pediatric specimens, and all were pharyngeal isolates. The remaining 254 (43%) GAS isolates were from specimens recovered from throats (51%), wounds (26%), blood and sterile sites (14%), and other sources (9%) from adults. The GBS isolates were recovered from vaginal-rectal swabs (32%), wounds (25%), urine (21%), blood and sterile sites (16%), and other sources (6%).

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TABLE 1. Comparison of phenotypes and genotypes of erythromycin-resistant GAS isolates

<table>
<thead>
<tr>
<th>Mechanism of resistance</th>
<th>No. of isolates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erythromycin resistance</td>
<td>16 (6)</td>
</tr>
<tr>
<td>MLSB resistance</td>
<td>33 (10)</td>
</tr>
<tr>
<td>MLSB resistance</td>
<td>5 (17)</td>
</tr>
<tr>
<td>MLSB resistance</td>
<td>2 (13)</td>
</tr>
<tr>
<td>MLSB resistance</td>
<td>56 (20)</td>
</tr>
<tr>
<td>MLSB resistance</td>
<td>1,024</td>
</tr>
<tr>
<td>MLSB resistance</td>
<td>4–1,024</td>
</tr>
<tr>
<td>MLSB resistance</td>
<td>0.06–0.5</td>
</tr>
<tr>
<td>MLSB resistance</td>
<td>1–512</td>
</tr>
<tr>
<td>MLSB resistance</td>
<td>0.06–0.125</td>
</tr>
</tbody>
</table>

**RESULTS**

**Erythromycin and clindamycin resistance in GAS isolates.** Erythromycin resistance was detected in 49 (8%) of the 593 GAS isolates, and clindamycin resistance was detected in 6 (1%) of the 593 GAS isolates. Among the erythromycin-resistant isolates, 33 had the M phenotype, which was due to the presence of mefA in all 33 isolates; 5 isolates had constitutive MLSB resistance due to the presence of ermB; and 9 isolates had inducible MLSB resistance, which was detected in association with ermB in 1 isolate and in association with ermTR in the remaining 8 isolates. Two erythromycin-resistant isolates had undefined mechanisms of resistance (Table 1). The erythromycin and clindamycin MICs were consistent with the expected phenotypes. Isolates with mefA-mediated resistance had low-level resistance to erythromycin (MICs at which 90% of isolates are inhibited [MIC90] = 32 μg/ml), and all isolates were susceptible to clindamycin (Table 1).

**Erythromycin resistance in GAS isolates from adult and pediatric populations.** Erythromycin resistance was found in 16 of 254 (6%) adult GAS isolates, whereas it was found in 33 of 339 (10%) pediatric GAS isolates (Table 2). Efflux encoded by mefA was identified in both pediatric and adult isolates but was more prevalent among pediatric isolates (72% of pediatric isolates versus 56% of adult isolates). Among the remaining resistant isolates, inducible MLSB resistance (ermTR) was more prevalent among adult isolates (31%), whereas constitutive MLSB resistance (ermB) was found equally among adult and pediatric isolates (13%) (Table 2).

**Erythromycin and clindamycin resistance in GBS isolates.** Among the 338 GBS isolates tested, 55 (16%) and 26 (8%) were resistant to erythromycin and clindamycin, respectively. Of the 55 erythromycin-resistant isolates, 7 displayed the M phenotype, which was due to mefA in all 7 isolates; 22 had an inducible MLSB resistance phenotype, which was due to ermTR in all 22 isolates; and 26 had constitutive MLSB resistance. Of the MLSB-resistant isolates with the constitutive resistance phenotype, resistance was due to ermB in most isolates, but resistance was associated with ermTR, either alone or in combination with other mechanisms, in a small proportion of cases.
of the isolates (Table 3). Three additional isolates were found to be susceptible to erythromycin and resistant to clindamycin. Resistance was mediated by linB (L phenotype) in one isolate and was undefined in the remaining two isolates.

The distribution of clindamycin MICs for erythromycin-resistant isolates was consistent with the observed phenotype (Table 3). For isolates with the M and the inducible MLSB resistance phenotypes, the clindamycin MIC remained below the NCCLS-defined breakpoint of 1 μg/ml (MIC90s, 0.06 and 0.25 μg/ml, respectively). The MIC90s of erythromycin for these isolates were above the breakpoints consistent with low-level resistance (8 and 16 μg/ml for the M and the inducible MLSB resistance phenotypes, respectively) and were within 1 dilution of each other. Isolates with the constitutive MLSB resistance phenotype were highly resistant to both erythromycin and clindamycin (Table 3).

**DISCUSSION**

For the reporting of clindamycin susceptibility, it is important to consider the significance of inducible methylation. Treatment failures with clindamycin have previously been reported for *Staphylococcus aureus* isolates with inducible MLSB resistance encoded by *ermA* (7, 15, 20, 22). To address these concerns, NCCLS has revised its 2004 recommendations for testing and reporting of the clindamycin susceptibilities of *Staphylococcus* (17). Current recommendations are to test *S. aureus* and coagulase-negative *Staphylococcus* isolates for inducible MLSB resistance by the double-disk diffusion test, and reports of clindamycin failure during therapy have been associated with this phenotype. Unlike *Staphylococcus* species, NCCLS has no recommendations for the routine testing of erythromycin-resistant GAS or GBS isolates for inducible MLSB resistance. Concerns over the increasing incidence of macrolide resistance in GAS and GBS (13). Presumably, the failure of clindamycin treatment for infections caused by GAS and GBS isolates with inducible resistance may also be expected. Experimentally, the in vitro selection of *ermTR* GAS isolates with constitutive clindamycin resistance has been reported (10). The selection of constitutive expression was found to be due to alterations in the attenuator sequences of the *erm* gene in erythromycin-resistant isolates. Although we did not determine if similar alterations were present in our isolates, the fact that 20% of the clindamycin-resistant GAS isolates harbored the *ermTR* gene suggests that a high frequency of selection for constitutive resistance may also be expected for streptococci. These results are consistent with those of other studies that have found *ermTR* in a significant proportion of GBS isolates with constitutive resistance (4).

The implication for reporting of clindamycin resistance among GAS and GBS isolates will depend on the prevalence of erythromycin resistance and the mechanism of resistance. Assuming that inducible MLSB resistance is clinically relevant, in our region, where the prevalence of the *erm* gene among erythromycin-resistant GBS isolates is approximately 90%, clindamycin susceptibility could be reported on the basis of in vitro test results or double-disk diffusion testing with erythromycin. Taking into consideration workflow issues and knowledge of local resistance trends, at the Division of Microbiology, Department of Laboratory Medicine, The Ottawa Hospital, the clindamycin susceptibilities of GBS isolates are now reported on the basis of the results of testing with erythromycin. For GAS isolates, the use of erythromycin susceptibility as a surrogate for clindamycin susceptibility may not be appropriate, because approximately 70% of our strains were resistant because of efflux (meFA). Therefore, testing of GAS by the double-disk diffusion method would be more appropriate for the reporting of clindamycin resistance.

There is significant geographic variation in the prevalence of macrolide resistance genes, particularly for GAS (11). In southern Ontario, *meFA* accounted for resistance in 91% of the erythromycin-resistant GAS isolates, whereas the rate of resistance accounted for by *meFA* was 62% in this study (12). This may be attributed to differences in the serotypes of the strains circulating in each region (12). In some European studies, the prevalence of *meFA* among erythromycin-resistant GAS isolates has been reported to range from 32 to 64% (6, 8). For

**TABLE 3. Comparison of phenotypes and genotypes of erythromycin-resistant GBS isolates**

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Genotype</th>
<th>No. of isolates</th>
<th>Erythromycin</th>
<th>Clindamycin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>90% Range</td>
<td>90% Range</td>
</tr>
<tr>
<td>M</td>
<td>meFA</td>
<td>7</td>
<td>8</td>
<td>0.06</td>
</tr>
<tr>
<td>iMLSB</td>
<td>ermTR</td>
<td>22</td>
<td>≥1.024</td>
<td>0.25</td>
</tr>
<tr>
<td>cMLS</td>
<td>ermB</td>
<td>19</td>
<td>4–1.024</td>
<td>1.024</td>
</tr>
<tr>
<td>cMLS</td>
<td>ermTR</td>
<td>5</td>
<td>256–1.024</td>
<td>512–1.024</td>
</tr>
<tr>
<td>cMLS</td>
<td>ermTR, ermB</td>
<td>1</td>
<td>≥1.024</td>
<td>≥1.024</td>
</tr>
<tr>
<td>cMLS</td>
<td>ermTR, meFA</td>
<td>1</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>L</td>
<td>linB</td>
<td>1</td>
<td>0.06–0.125</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td></td>
<td>2</td>
<td>0.06–0.125</td>
<td>0.5–2</td>
</tr>
</tbody>
</table>

*Abbreviations: M, efflux; iMLS, inducible MLS resistance; cMLS, constitutive MLS resistance; L, lincomycin nucleotidyltransferase.*

*a* A total of 55 isolates were tested.

*b* Abbreviations: M, efflux; iMLS, inducible MLS resistance; cMLS, constitutive MLS resistance; L, lincomycin nucleotidyltransferase.
GAS, we did observe differences in the erythromycin resistance rates and the prevalence of the associated mechanism of resistance between adult and pediatric populations. Although the sample size was small, the rate of macrolide resistance was higher among pediatric isolates. Efflux (mefA) was the more common mechanism of resistance in both groups of isolates but was more predominant in pediatric isolates. Among the adult isolates, the mechanisms of resistance were more equally distributed between efflux and methylation. For GBS, the variation in resistance mechanisms was not as apparent. The prevalences of inducible and constitutive methylation and efflux in GBS were similar to those previously reported from southern Ontario (4). These differences emphasize the need for laboratories to understand the prevalence of mechanisms of macrolide resistance to determine the most appropriate approach to the reporting of clindamycin susceptibility. Although the results of disk diffusion and MIC testing correlated well with the presence of constitutive MLSB resistance (ermB), only double-disk diffusion testing accurately differentiated efflux (mefA) from inducible MLSB resistance (ermTR) for both GAS and GBS (data not shown). We did not determine the optimal separation between the erythromycin and clindamycin disks. Whether the separation obtained with regular disk dispensers would be optimal for the detection of inducible MLSB resistance remains a simple and reliable alternative method still needs to be determined. Nevertheless, double-disk diffusion testing remains a simple and reliable alternative method to PCR for deciding how to report clindamycin susceptibility results for GBS and GAS and can easily be incorporated into routine testing.

ACKNOWLEDGMENTS

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