Distribution of *erm* genes and low prevalence of inducible resistance to clindamycin among *staphylococci* isolates

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**ABSTRACT**

Introduction: Resistance to macrolides, lincosamides and streptogramins B (MLS) antibiotics in *staphylococci* may be due to modification in ribosomal target methylase encoded by *erm* genes. The expression of MLS resistance lead to three phenotypes, namely constitutive resistance (*cMLS*), inducible resistance (*iMLS*), and resistance only to macrolides and streptogramins B (MS). The *iMLS* resistance is the most difficult to detect in the clinical laboratory. Objective: This study investigated the expression of MLS resistance and the prevalence of the *erm* genes among 152 clinical isolates of *Staphylococcus aureus* and coagulase-negative *Staphylococcus* (CNS) from Hospital de Clínicas de Porto Alegre. Methods: Primary MLS resistance was detected by the disk diffusion method. Isolates with *iMLS* phenotype were tested by double-disc induction method. All isolates were tested by a genotypic assay, PCR with specific primers. Results: A total of 46.7% of *staphylococci* were positive for *cMLS*; 3.3% for *iMLS* and 3.3% for MS. One or more *erm* genes were present in 50.1% of isolates. The gene *ermA* was detected in 49 isolates, *ermC* in 29 and *ermB* in 3. Conclusion: The prevalence of the *ermA*, *ermB* and *ermC* genes were 29.6%, 17.1% and 0.66% respectively, and constitutive resistance was the most frequent as compared to the other two phenotypes.

Keywords: *Staphylococcus*; resistance; *erm* genes; macrolides.

**INTRODUCTION**

*Staphylococcus aureus* and coagulase-negative *staphylococci* (CNS) are recognized to be causing nosocomial and community-acquired infections worldwide. A great concern related to these microorganisms is their ability to develop resistance to antibiotics which originally were active against these species. Although β-lactam antibiotics are the main compounds used to treat infections due to *staphylococci*, macrolides, lincosamides and streptogramins type B (MLS) antibiotics are also widely used to treat *staphylococcal* infections. These antibiotics exert similar inhibitory effects on bacterial protein synthesis, but they are chemically distinct. MLS resistance can be caused by several mechanisms, but the predominant form is target modification mediated by *ermA*, *ermB* and *ermC* (erythromycin ribosome methylase) genes. The *erm* genes encode enzymes that confer inducible or constitutive resistance to MLS agents via methylation of the 23S rRNA, thereby reducing binding by MLS agents to the ribosome. Constitutive MLS resistance can be detected by the disk diffusion test in laboratorial routine.

Strains with constitutive MLS resistance show high-level *in vitro* cross resistance among MLS drugs. However, *staphylococci* isolates with inducible MLS resistance demonstrate clear *in vitro* resistance to 14 and 15-member macrolides (e.g., erythromycin), while they seem to be susceptible to 16-member macrolides, lincosamides and streptogramins type B. Therefore, strains can show *in vitro* erythromycin resistance and false clindamycin susceptibility, because the conventional disk-diffusion may fail to detect inducible MLS resistance. The Clinical and Laboratory Standards Institute (CLSI) developed a phenotypic method (the double-disc diffusion test (D test) to screen for inducible resistance. However, the polymerase chain
reaction (PCR) with specific primers is a genotypic method used to confirm the presence of the MLSB genes, \( \text{ermA} \), \( \text{ermB} \) and \( \text{ermC} \). The risk for therapeutic failure is increased as constitutive resistance may raise from iMLSb during the course of clindamycin therapy in patients with severe staphylococci infections.11

The objective of this study was to determine the prevalence of the MLSB genes in \( \text{Staphylococcus aureus} \) and coagulase negative \( \text{staphylococci} \) from patients attending the Hospital de Clínicas de Porto Alegre (HCPA).

**MATERIALS AND METHODS**

**Bacterial isolates**

Isolates of \( \text{S. aureus} \) and of CNS were collected from consecutive clinical specimens sent to the microbiology laboratory of the HCPA. The period of the study was between September and October 2007. The bacterial identification was performed through Gram’s technique and catalase and coagulase tests. Isolates were stored in glycerol broth at -20°C until use.

**Susceptibility tests**

The antimicrobial susceptibility test was performed by the disk diffusion method on Mueller Hinton Agar (bioMérieux, Marcy L’Etoile, France), according to the Clinical and Laboratory Standards Institute (CLSI 2008), with the following antibiotic (Oxoid®): oxacillin (1 µg), cefoxitin (30 µg), vancomycin (10 µg), clindamycin (2 µg), chloramphenicol (30 µg), doxycycline (30 µg), erythromycin (15 µg), levofloxacin (5 µg), rifampin (5 µg) and trimethoprim-sulfamethoxazole (25 µg). \( \text{S. aureus} \) ATCC 25923 was used for quality control.

The standard CLSI double-disk diffusion (D test) was performed using Mueller Hinton agar (bioMérieux, Marcy L’Etoile, France) with a 15 µg erythromycin disk and 2 µg clindamycin disk (Oxoid®) placed at distances of 15 and 26 mm and incubated for 24 h at 35°C.11

The inducible phenotype was characterized by a positive D test, a flattening of the inhibition zone around the clindamycin disk near to the erythromycin disk and indicates that erythromycin has induced clindamycin resistance (iMLSb). The phenotype cMLSb was characterized by erythromycin and clindamycin resistance. Finally, the phenotype (MSb) was characterized by clindamycin susceptibility and erythromycin resistance, with negative D test.

**ermA, ermB and ermC gene detection**

A direct colony suspension of the culture equivalent to a 1.0 McFarland standard was prepared in 500 µL of 10 mM Tris-1 mM EDTA (pH 8.0), vortexed, and boiled for 10 min and an aliquot of 5 µL of the suspension was used for each 25 µL reaction mixture.13

PCR assays and primers specific from the \( \text{ermA} \), \( \text{ermB} \) and \( \text{ermC} \) resistance genes used in this study have been previously described by Gerard, Lina et al. (Table 1).14 Each reaction was carried out in a final volume of 25 µL and included 10 x PCR buffer (pht®); 3 mM of MgCl₂ (pht®); 5 µM of each \( \text{ermA} \), \( \text{ermB} \) and \( \text{ermC} \) forward and reverse primers (Invitrogen®); RNAse and DNAse free water; 1.25 U of \( \text{Taq} \) DNA polymerase (pht®); 2.5 mM of each dATP, dTTP, dCTP, and dGTP (ABgene®); and 5 µL of DNA. The PCR mixture was subjected to thermal cycle (30 cycles of 30 s at 94°C as the denaturation step, 30 s at 57°C as the annealing step, and of 5 min at 72°C as the extension step) with a JMR® PTC-100. The PCR-amplified reaction mixture was resolved by electrophoresis through a 2% agarose gel containing ethidium bromide in Tris-borate-EDTA buffer at 12 V/cm for 30 min. The gel was visualized under UV light and the sizes of the amplification products were estimated by comparison with 100 bp molecular size standard ladder.

Three clinical samples with positives results for each of the three genes were submitted to sequencing and analyzed by BLAST and Chromas and DDBJ/EMBL/GenBank. These isolates were used as positive control in all experiments.

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<th>Table 1. Correlation between ( \text{erm} ) genes and MLSB resistance phenotypes</th>
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<td><strong>Isolate</strong></td>
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RESULTS

A total of 152 strains including 94 S. aureus and 58 CNS were included in this study. Eighty-one (53.3%) exhibited erythromycin resistance and were considered for evaluation of the three distinct MLSB resistance phenotypes (cMLS B, iMLS B, MSB). Among these 81 erythromycin-resistant strains, 10 showed clindamycin susceptibility and were tested by double-disk diffusion method. We found only five (6.2%) isolates with iMLS B resistance phenotype (three S. aureus and two CNS) and five (6.2%) with MSB resistance phenotype (two S. aureus and three CNS). The remaining 71 (87.7%) isolates were considered as cMLS B resistance phenotype (46 S. aureus and 25 CNS).

All the 152 strains were tested for the presence of MLSB resistance genes and 77 (50.1%) contained one or more erm genes (Figure 1). The erm A gene was detected in 44 isolates (41 S. aureus and three CNS), the erm B gene was found in only one isolate of S. aureus and the erm C gene was detected in 28 isolates (four S. aureus and 24 CNS). Combination of erm genes was detected in 4 CNS isolates (Graphics 1 and 2). For S. aureus isolates with cMLS B resistance phenotype, 36 presented the erm A gene, only one exhibited the erm B gene and three had the erm C gene. Moreover, in three of the S. aureus isolates with iMLS B resistance phenotype, two isolates were erm A positive and one was erm C positive. The erm C gene was identified in 20 isolates of CNS with cMLS B resistance phenotype and in two isolates of CNS with iMLS B resistance phenotype. Seven (six S. aureus and one CNS) isolates with cMLS B resistance phenotype did not present any of the three erm genes (Table 1). Resistance to non-MLS B antibiotics in S. aureus and CNS isolates with erm genes was higher in relation to the isolates without the erm genes: chloramphenicol (p = 0.004), doxycycline (p < 0.001), gentamicin (p < 0.001), levofloxacin (p < 0.001), oxacillin (p < 0.001), rifampin (p < 0.001) and, trimethoprim-sulfamethoxazole (p < 0.001). Of the 77 isolates who harbored erm genes, 65 (40 S. aureus and 25 CNS) were multidrug resistant (resistant to five or more antimicrobial class). The overall range of multiresistance among the staphylococci strains studied was 48.2%.

DISCUSSION

The incidence of constitutive and inducible MLSB resistance may vary according to different geographic region and even from hospital to hospital or patient group. This variability is usually associated with the inconsistent use of erythromycin in different institutions; the origin of the isolate (nosocomial versus community acquired); patient age and clinical samples. In our study 53.3% of staphylococci presented one of three MLS B resistance phenotypes. In fact, cMLS B resistance phenotype was the most common (46.7%) and iMLS B and MSB phenotype were each detected in only 3.3% of the staphylococci.

In a study conducted in Texas by Fiebelkorn et al. the cMLS B resistance phenotype was also the most prevalent phenotype (41.7% of staphylococci) but the iMLS B was found in 25.2% of the isolates, indicating a difference in relation to iMLS B data of the present study. In Europe where the MLS B resistance phenotype prevalence are somehow variable, in London Hamilton-Miller et al. detected staphylococci with iMLS B as the predominant phenotype (43% of isolates) and the cMLS B resistance phenotype was detected in only 24% of isolates. The D test is critical, in this scenario, to avoid therapeutic failure. On the other hand, CNS isolates studied in Sevilla demonstrated that the MSB resistance phenotype was more common (11.2%) in relation to the other phenotypes (iMLS B,
7.4% and cMLS\textsubscript{B} 3.2%). In contrast, the cMLS\textsubscript{B} resistance phenotype was most frequent (46.9%) as compared to iMLS\textsubscript{B} (30.2%) in France.\textsuperscript{14}

In Turkey it was demonstrated that the prevalence of the cMLS\textsubscript{B} phenotype is higher than that of the iMLS\textsubscript{B} phenotype and the MS\textsubscript{B} phenotype is low, data similar to our study.\textsuperscript{15,18-20}

A previous study conducted in our city evaluated 200 CNS and showed that only 2.5% of isolates presented the iMLS\textsubscript{B} resistance phenotype.\textsuperscript{21} Therefore, one could speculate that the prevalence of the inducible phenotype is low in our city.

Despite the fact that there is geographic variability among MLS\textsubscript{B} resistance phenotypes, the prevalence of \textit{erm} genes has been reported to be similar in various countries. According to our findings, the \textit{erm}\textsubscript{A} gene was the most prevalent among the \textit{S. aureus} isolates (43.6%) and the \textit{erm}\textsubscript{C} gene was the most prevalent among the SCN isolates (37.9%). Only three isolates of \textit{staphylococci} presented the \textit{erm}\textsubscript{B} gene (2.0%). The presence of more than one \textit{erm} gene was not detected in \textit{S. aureus} but it was observed in four SCN isolates. According to Martineau et al., in Canada, 20.9% of the \textit{S. aureus} were positive for the \textit{erm}\textsubscript{A} gene and 66% of CNS were positive for the \textit{erm}\textsubscript{C} gene, demonstrating that the prevalence of the \textit{erm}\textsubscript{A} gene in \textit{S. aureus} is slightly lower in comparison to other studies.\textsuperscript{21} A multicenter study in 24 European university hospitals confirmed the high prevalence of \textit{erm}\textsubscript{A} gene and the low prevalence of \textit{erm}\textsubscript{C} and \textit{erm}\textsubscript{B} genes among 851 \textit{S. aureus}.\textsuperscript{21} Lina et al. found 63.2% of \textit{S. aureus} with \textit{erm}\textsubscript{A} gene positive and 44% of CNS strains \textit{erm}\textsubscript{C} gene positive, while the \textit{erm}\textsubscript{B} gene was present in only 1% of \textit{staphylococci}.\textsuperscript{19} The results reported by Westh et al. in Denmark, also showed a high prevalence of the \textit{erm}\textsubscript{A} gene in \textit{S. aureus} isolates and the \textit{erm}\textsubscript{C} gene in CNS strains, as well as a low prevalence for the \textit{erm}\textsubscript{B} gene.\textsuperscript{20} In our study, the \textit{erm}\textsubscript{B} gene was also detected in a small percentage of \textit{staphylococci} isolates. This gene is generally found in animal \textit{staphylococci} strains.\textsuperscript{6,14,17}

In the present study, eight isolates (three \textit{S. aureus} and five SCN) susceptible to erythromycin proved to carry \textit{erm} genes (seven \textit{erm}\textsubscript{A} and one \textit{erm}\textsubscript{C}). The presence of \textit{erm} genes among isolates of \textit{staphylococci} susceptible to erythromycin had already been demonstrated in another study.\textsuperscript{21} This may be due to the lack of expression of \textit{erm} genes due to factors which down regulate the expression of this gene.\textsuperscript{22,23}

In our study we found six \textit{S. aureus} isolates and one CNS resistant to erythromycin and clindamycin but with negative genotypic test. These results were probably associated with the presence of other genes, such as \textit{msr}\textsubscript{A} and \textit{msr}\textsubscript{B}, with low frequency in \textit{Staphylococci} species isolated form humans,\textsuperscript{21} which were not evaluated in this study.

We detected three \textit{S. aureus} resistant to clindamycin and susceptible to erythromycin, which did not harbor \textit{erm} genes. In a study conducted by Lina and \textit{et al.}, the only SCN sample that presented this susceptibility profile was positive for the genes \textit{lin}\textsubscript{A} and \textit{lin}\textsubscript{A}$.\textsuperscript{14} These genes confer lincosamides resistance only in \textit{S. hemolyticus} and \textit{S. aureus}. Incidence of \textit{staphylococci} with lincosamide resistance but without resistance to macrolides and streptogramins is usually very low.\textsuperscript{14,26}

\section*{CONCLUSION}

The aim of this study was to determine the prevalence of the MLS\textsubscript{B} phenotypes and genes in \textit{Staphylococcus aureus} and coagulase-negative \textit{staphylococci} from patients receiving care at our hospital. We found that constitutive MLS\textsubscript{B} resistance was the most prevalent phenotype in \textit{staphylococci}; \textit{erm}\textsubscript{A} was the most prevalent gene in \textit{S. aureus} strains, whereas \textit{erm}\textsubscript{C} was the most frequent gene in CNS isolates. Therefore, \textit{staphylococci} with resistance to MLS\textsubscript{B} are usually detected directly in routine susceptibility test and the “D test” is not required to be performed in most of our isolates. However, other regions in our country may not present the same resistance profile as ours and, therefore, surveillance studies are warranted in different institutions.

\section*{REFERENCES}


