Investigation of toxin genes among methicillin-resistant Staphylococcus aureus strains isolated from a tertiary hospital in Malaysia

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Abstract. Staphylococcus aureus is a persistent human pathogen responsible for a variety of infections ranging from soft-tissue infections to bacteremia. It produces a variety of virulence factors which are responsible for specific acute staphylococcal toxaemia syndromes. The objective of this study was to determine the prevalence of a repertoire of toxin genes among Malaysian MRSA strains and their genetic diversity by PCR-RFLP of coa gene. One hundred eighty-eight strains (2003, 2004, 2007 and 2008) of methicillin-resistant S. aureus (MRSA) were screened for 20 genes encoding for extracellular virulence determinant (sea, seb, sec, sed, see, seh, sei, sej, tst, eta, etb, etd) and adhesins (cna, etb, fnbA, fnbB, hlg, ica, sdrE). The genetic relatedness of these strains was determined by PCR-RFLP of coa gene and agr grouping. Majority of the strains were tested positive for efb and fnbA (90% each), ica (78%) and hlg (50%) genes. A total of 101 strains were positive for at least one type of staphylococcal enterotoxin genes with sea being the predominant. Genes for seb, sed, see, seh, sej, eta and etb were not detected in any of the MRSA strains. The prevalence of sea, sec and ica among strains isolated in 2008 was increased significantly (p< 0.05) compared to 2003. Most of the strains were of agr type I (97.5%) followed by agr type II (1.2%) and agr type III (0.6%). All sea, sei and tst gene-positive strains were of agr type I. The only etd positive strain was agr type III. PCR-RFLP of coa produced 47 different patterns. The number of strains with virulence factors (sea, sec and ica) had increased over the years. No direct correlation between PCR-RFLP-coa profiles and virulotypes was observed.

INTRODUCTION

Methicillin-resistant Staphylococcus aureus (MRSA) is an important bacterial pathogen responsible for suppurative and toxins-mediated disease (Ferry et al., 2005). Staphylococcus aureus is known to produce a variety of virulence factors such as the staphylococcal enterotoxins (SEs), exfoliative toxins (Ets) and toxic shock syndrome toxin (TSST) which are responsible for specific acute staphylococcal toxaemia syndromes, including staphylococcal food poisoning and scalded skin syndrome (Mohamad Adwan et al., 2006; Udo et al., 2009).

Both SEs and TSST are members of the superantigenic toxin family that stimulate nonspecific T-cell proliferation (Ferry et al., 2005; Ortega et al., 2010; Demir et al., 2011). A total of 18 different types of enterotoxins such as SEA-SED, SEE, SEG-SER and SEU encoded by sea-sed, see, seg-ser and seu genes, respectively have been reported (Ferry et al., 2005). Among them, enterotoxin genes seg, sei, sem, sen, seo are located at enterotoxin gene cluster (egc) (Ferry et al., 2005).
An accessory gene regulator (agr) is known to be a global regulator of the staphylococcal virulon which coordinates the expression of secreted and cell-associated virulence factors (Traber et al., 2008). There are four major agr types (designated agr type 1 to agr type 4) in S. aureus (Lina et al., 2003).

Molecular subtyping methods such as pulsed-field gel electrophoresis (PFGE) and multilocus sequence typing are considered as ‘gold standard’ in typing MRSA strains, although these typing methods are often time-consuming, expensive and laborious (Ishino et al., 2006). An alternative simpler typing method, PCR-restriction fragment length polymorphism (RFLP) typing of the coagulase gene (coa) has been used in subtyping of MRSA strains as it is simple, rapid and inexpensive (Himabindu et al., 2009).

The objective of this study was to determine the prevalence of a repertoire of toxin genes among 188 Malaysian MRSA strains isolated in 2003, 2004, 2007 and 2008. The genetic relatedness of these strains was determined by PCR-RFLP of coa gene and agr grouping.

MATERIALS AND METHODS

Bacterial strains
A total of 188 non-repeat S. aureus strains from different patients admitted to University Malaya Medical Centre, Malaysia, in years 2003, 2004, 2007 and 2008 were studied. The organisms were isolated from respiratory samples [such as nasal swabs (n = 43; 22.9%), sputum (n = 23; 12.2%) and nasopharyngeal secretion (n = 9; 4.8%)], tissue (n = 16; 8.5%), wound swabs (n = 34; 18.1%), urine (n = 6; 3.2%), pus (n = 12; 6.4%), body fluids (n = 24; 12.8%), catheter tip (n = 3; 1.6%), bone (n = 4; 2.1%), blood (n = 13; 6.9%), chest tube “drainage” (n = 1; 0.5%).

All the strains were cultured in Luria-Bertani broth and stored in cryovials with 50% glycerol (Invitrogen, USA) at -20°C and -85°C.

PCR detection of virulence genes
Detection of 20 virulence genes (sea, seb, sec, sed, see, seg, seh, sei, sej, eta, etb, etd, tst, efb, fnbA, fnbB, cna, hlg, ica and sdrE) were performed by PCR using primers and cycling conditions as described earlier by Jarraud et al. (2002), Hisata et al. (2005), Arciola et al. (2005), Kumar et al. (2009), and Moore & Lindsay (2011). Genomic DNA from MRSA extracted by using Wizard Genomic DNA purification kit (Promega Madison Wis, USA) was used as DNA template.

Representative amplicons of sea, sec, seg, seh, sei, etd, tst, efb, fnbA, ica, hlg and sdrE were purified by using Qiagen DNA purification kit (Qiagen GmBH, Germany) and sequenced to validate their identities. All experiments were repeated once to confirm their reproducibility.

agr genotyping by multiplex PCR
Multiplex PCR for agr types was performed by using specific primers (agr type 1 to agr type 4) using conditions as described by Lina et al. (2003). Selected amplified products obtained were sequenced to validate their identity.

PCR-Restriction Fragment Length Polymorphism (RFLP) of coa gene
PCR amplification of coa gene was performed as previously described by Hookey et al. (1998) with minor modification. Briefly, PCR was carried out in a final volume of 25 µL containing 0.4 µM of each primer pair (Operon Biotechnologies GmbH, Germany), 35 µM of each deoxynucleoside triphosphate, 1.5 mM MgCl2 and 0.5 U Taq DNA polymerase (Promega, Madison, Wis., USA).

The amplicon of coa was digested with AluI enzyme (Promega Madison Wis, USA) as described by Hookey et al. (1998). Digested products were separated in 1.5% agarose gel at 90V for 3 hours. Gels were photographed under UV light after staining with ethidium bromide (0.5 µg/ml).

The banding patterns generated were analyzed using BioNumerics Version 6.0 (Applied Maths, Kortrijk, Belgium) and cluster analysis based on the unweighted pair group method with arithmetic averages (UPGMA) with a position tolerance of 0.15 was carried out. All DNA profiles were assigned arbitrary designation
and analyzed by defining a similarity (Dice) coefficient, $F$.

**Statistical Analysis**

Statistical software (version 8.0) was used for data analysis. Comparison of certain variables was determined by Fisher’s exact test. The associations between different virulence factors were determined by Spearman’s rank order correlation coefficient test. The $P$-value $<0.05$ (two-tailed) was taken as the level of significance for Fisher’s exact test whereas $R$-value was taken as the type of association between the variables. The breakpoints for the association of virulence factors are defined as follows: perfect association with $R = 1$, no association with $R = 0$ and invert correlation with $R = -1$.

**RESULTS**

**Prevalence of virulence genes in MRSA strains**

Majority of the strains were positive for the adhesion genes such as extracellular fibrinogen binding protein ($efb$) (96%), fibrinogen binding protein ($fnbA$) (96%), intracellular adhesion ($ica$) (78%) while hemolysin ($hlg$) and putative adhesin ($sdrE$) were amplified in 59% and 27%, respectively. No collagen adhesin ($cna$) gene was detected. Based on Spearman’s rank correlation coefficient test, correlation between $efb$ and $fnbA$ ($R = 1$, $p < 0.05$), $hlg$ and $ica$ ($R = 0.326$, $p < 0.05$) were observed.

A total of 101 strains were tested positive for at least one type of staphylococcal enterotoxin (SEs) while one strain was positive for exfoliative toxin ($etd$). No enterotoxins ($seb, sed, see$ and $seh$) or exfoliative toxins ($eta, etb$) gene was detected. Two strains harboured three SEs genes simultaneously whereas 30 strains harboured two SEs genes (Table 1). The distribution of virulence genes is summarized in Table 1.

The occurrence of SEs and exfoliative genes had significantly increased between years 2003 and 2008 ($p = 0.001$). There was a significant increase in the prevalence of virulence genes, $sea$ ($p = 0.003$), $sec$ ($p = 0.006$) and $ica$ ($p = 0.010$) in 2008 strains compared with 2003 strains. However, no significant difference in the prevalence of virulence genes in 2003 and 2008 strains for the following genes: $efb, fnbA, hlg, sdrE, seg, sei, etd$ and $tst$.

$sea$ and $sec$ genes were detected in 17.5% and 6.9% MRSA strains and these strains were isolated from invasive samples (tissue, tissue, tissue)

<table>
<thead>
<tr>
<th>Gene</th>
<th>No of strains</th>
<th>$p$ value</th>
<th>Gene combination</th>
<th>No of strains</th>
</tr>
</thead>
<tbody>
<tr>
<td>sea</td>
<td>19</td>
<td>54</td>
<td>0.152</td>
<td>$sea + sec + sei$</td>
</tr>
<tr>
<td>sec</td>
<td>4</td>
<td>32</td>
<td>0.003</td>
<td>$sec + seg + sei$</td>
</tr>
<tr>
<td>seg</td>
<td>1</td>
<td>11</td>
<td>0.107</td>
<td>$sec + sei$</td>
</tr>
<tr>
<td>sei</td>
<td>0</td>
<td>14</td>
<td>0.006</td>
<td>$sec + seg$</td>
</tr>
<tr>
<td>etd</td>
<td>0</td>
<td>1</td>
<td>1.000</td>
<td>$sea + sei$</td>
</tr>
<tr>
<td>tst</td>
<td>0</td>
<td>1</td>
<td>1.000</td>
<td>$sea + seg$</td>
</tr>
<tr>
<td>$efb$</td>
<td>59</td>
<td>121</td>
<td>1.000</td>
<td>$sea + sec$</td>
</tr>
<tr>
<td>$fnbA$</td>
<td>50</td>
<td>121</td>
<td>1.000</td>
<td>$sea$</td>
</tr>
<tr>
<td>$hlg$</td>
<td>34</td>
<td>75</td>
<td>0.753</td>
<td>$sec$</td>
</tr>
<tr>
<td>$ica$</td>
<td>39</td>
<td>104</td>
<td>0.010</td>
<td>$seg$</td>
</tr>
<tr>
<td>$sdrE$</td>
<td>14</td>
<td>37</td>
<td>0.484</td>
<td>$sei$</td>
</tr>
</tbody>
</table>

Total 22 (36%) 80 (64%)


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wound, blood, bone and pus) (Table 2). On the other hand, eight (67%) and ten (71%) MRSA strains isolated from colonization samples (sputum, nasal swabs and body fluids) were tested positive for \( \text{seg} \) and \( \text{sei} \) genes, respectively (Table 2).

Based on Spearman's rank correlation coefficient test, correlation between intercellular adhesion (ica) and SEs (\( R=0.046, p < 0.05 \)), hemolysin (hlg) and SEs (\( R=0.007, p < 0.05 \)) were observed.

**agr genotyping**

Three \( \text{agr} \) genotypes were observed: \( \text{agr} \) type I (97%; 51 strains from 2003, 9 from 2004, 15 from 2007 and 108 from 2008), \( \text{agr} \) type II (1.6%; 1 from 2007 and 2 from 2008) and \( \text{agr} \) type III (0.5%; 1 from year 2008). No \( \text{agr} \) type IV was observed. One strain (MRSA0312-35) did not belong to any \( \text{agr} \) group.

All three \( \text{agr} \) type II (MRSA0701-15, MRSA0806-14 and MRSA0812-36) strains harboured \( \text{seg} \) genes, and they were cultured from different sites and wards. The only \( \text{agr} \) type III strain (MRSA0806-13) which harboured \( \text{etd} \) gene was cultured from the nasal swab of a patient in the dialysis ward.

**PCR-RFLP analysis of coa gene**

Digestion of \( \text{coa} \) positive PCR products with AluI enzyme yielded 47 different restriction profiles (\( F=0.24-1.0 \)) (Figure 1). Four strains (MRSA0312-35, MRSA0704-15, MRSA0707-26 and MRSA0802-14) could not be typed by \( \text{coa} \)-RFLP typing despite, repeated attempts. Reproducible results were obtained in separate experiments using the same set of strains.

Seventy two MRSA strains were found to be clonally related as they shared more than 80% similarity. Among them, 37 strains shared identical PCR-RFLP profiles, even though they were cultured from different occasions and sources (Figure 1). Some strains from six years apart shared similar PCR-RFLP profiles. Further analysis showed that 31 out of these 72 MRSA strains (42.5%) harboured \( \text{sea} \) gene.

On the other hand, 33 strains were indistinguishable by \( \text{coa} \)-RFLP typing, although they were cultured from different sources and time periods (2003, 2004, 2007, 2008). Among them, 12 harboured \( \text{sea} \) genes, six had \( \text{sec} \) gene and one harboured \( \text{seg} \) gene.

**DISCUSSION**

*Staphylococcus aureus* is known to be responsible for a variety of toxins-mediated diseases (Ferry *et al.*, 2005). Although several studies have reported the incidence of selected virulence genes in MRSA in Malaysia (Ghaznavi-Rad *et al.*, 2010; Ghasemzadeh-Moghaddam *et al.*, 2011), reports comparing prevalence of virulence genes between two periods of times in Malaysia are scanty. This report shows detailed prevalence of virulence genes of MRSA isolated in a tertiary hospital in 2003, 2004, 2007 and 2008.

<table>
<thead>
<tr>
<th>Gene</th>
<th>Respiratory (n=75)</th>
<th>Tissue (n=16)</th>
<th>Wound (n=34)</th>
<th>Urine (n=6)</th>
<th>Pus (n=12)</th>
<th>Chest fluid drainage (n=1)</th>
<th>Body fluid (n=24)</th>
<th>Catheter tip (n=3)</th>
<th>Bone (n=4)</th>
<th>Blood (n=13)</th>
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<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td></td>
</tr>
<tr>
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<td>21</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>2</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>( \text{sei} )</td>
<td>12</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
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</tr>
<tr>
<td>( \text{etd} )</td>
<td>1</td>
<td>1</td>
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<td>1</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>( \text{efB} )</td>
<td>70</td>
<td>16</td>
<td>33</td>
<td>6</td>
<td>11</td>
<td>24</td>
<td>3</td>
<td>4</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>( \text{hlg} )</td>
<td>36</td>
<td>13</td>
<td>19</td>
<td>2</td>
<td>8</td>
<td>0</td>
<td>21</td>
<td>1</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>( \text{ica} )</td>
<td>52</td>
<td>14</td>
<td>27</td>
<td>4</td>
<td>10</td>
<td>0</td>
<td>22</td>
<td>3</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>( \text{sdrE} )</td>
<td>30</td>
<td>2</td>
<td>7</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
Figure 1. Dendrogram of PCR-RFLP of coa gene of MRSA strains. The dotted vertical line indicates 80% similarity level.

Spearman’s rank correlation analysis showed that there was a positive correlation between strains harbouring efb and fnb genes. Similarly, correlation between hlg and ica gene was observed. This is important as both efb and fnb genes are involved in the adherence of S. aureus strains while ica and hlg genes are involved in biofilm formation.
and promotes host cell lysis, respectively (Ferry et al., 2005).

Overall, 54% of the MRSA strains harboured at least one type of SEs gene with the percentage of 2007 and 2008 strains harbouring SEs (62%) higher than 2003 and 2004 strains (36%). This increase might be caused by horizontal gene transfer among the strains as SEs genes are carried by mobile genetic elements such as plasmids, pathogenicity islands, SCCmec and prophages (Hu et al., 2008). This is of public health concern as SEs genes are often associated with food borne poisoning, toxic shock syndrome and other toxin mediated disease (Ferry et al., 2005; Ortega et al., 2010).

Sea gene was the most common SEs gene present among Malaysian MRSA strains and this concurred with the finding reported from another tertiary hospital in Kuala Lumpur (Ghaznavi-Rad et al., 2010). However, this differed from a report by Sauer et al. (2008) where seg and sej genes were predominant in the MRSA strains in a University Hospital, Czech Republic. Although both seg and sei genes are located in the same egc operon (Sauer et al., 2008), most of the strains (99%) did not harbour these genes simultaneously (R= -0.923, p < 0.05) and this concurred with the result reported by Collery et al. (2008). Only one invasive strain (MRSA0805-10) harboured sec, seg and sei genes simultaneously.

Exfoliative toxin (encoded by etd) that can cause an inflammatory response of the skin was detected in a MRSA0806-13 strain which belong to the agr type III. No eta, etb or seb genes were present in the UMMC strains and other Malaysian MRSA strains (Ghaznavi-Rad et al., 2010).

Although Sabat et al. (2006) reported that the absence of sdrE and sdrD genes in S. aureus might decrease its invasive potential in bone tissues, our result showed that indigenous S. aureus in this tertiary hospital can cause bone infections even without the presence of sdrE gene. This infection could have involved other alleles of the sdr gene.

Fifty (27%) invasive strains were found to harbour hemolysin gene (hlg). This is not surprising as the previous report by Peacock et al. (2002) indicated that virulence factors such as fnbA, cna, sdrE, hlg, sej, eta and ica were significantly more common in invasive strains, and they contributed independently to virulence.

Significant increase in the occurrence of ica, sec and sei genes among 2008 strains when compared to 2003 strains was observed. Furthermore, Spearman’s rank correlation tests also showed that MRSA strains with ica and hlg genes showed higher virulence potential as these strains also harboured SEs, exfoliative toxin and tst genes. This is a cause for concern as the biofilm-associated bacteria is normally resistant to host immune systems and antimicrobial, and the presence of SEs will further weaken the host immune systems (Plata et al., 2009).

Majority (97%) of the strains were of agr type I and this is consistent with previous report by Peerayeh et al. (2009). Although Collery et al. (2008) reported that strains possessing tst gene are often associated with agr type III, our only tst positive strain (MRSA0802-19) was associated with agr type I.

Genotyping by PCR-RFLP of coa gene using AluI enzyme showed that most of the MRSA strains were clonally related although they were cultured from different time periods. Our previous study (Lim et al., in press) on UMMC strains also indicated that most of the MRSA strains were clonally related by PFGE with five different MLST types (ST239, ST772, ST22, ST6 and ST1178). This suggests that some MRSA clones were found to be predominant in this tertiary hospital. Some other strains obtained from years 2003, 2004 and 2007 also shared similar patterns with 2008 strains, indicating the persistence of particular PCR-RFLP types in UMMC hospital. These strains were cultured from different patients’ wards, and harboured different type of virulence genes (i.e different type of SEs) showing that MRSA strains in this study are able to acquire or lose SEs genes as these genes are carried by mobile genetic elements such as plasmids, pathogenicity islands, SCCmec and prophages (Hu et al., 2008).

In general, no direct correlation between PCR-RFLP profiles and virulotypes was
observed. Strains with identical PCR-RFLP profiles frequently belonged to different virulence patterns. Increase of MRSA strains with virulence factors over the years signal the potential loss of the usage of antimicrobial agents in treating MRSA infections as MRSA strains with virulence factors is normally resistant to host immune systems and other antimicrobial agents. The MRSA clinical strains from UMMC were mostly genetically related, suggesting that few predominant clones of the species are involved in infection. The data from this current study may act as reference for monitoring the prevalence of virulence among Malaysian MRSA strains over a longer period of times.

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