Prevalent genotypes of meticillin-resistant *Staphylococcus aureus*: report from Pakistan

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Meticillin-resistant *Staphylococcus aureus* (MRSA) is a major nosocomial pathogen in Pakistan and is emerging in the community. This is one of the first reports of the prevalent genotypes of MRSA in both hospital and community settings in Pakistan. Isolates collected in 2006–2007 were characterized by PFGE, staphylococcal cassette chromosome mec (SCCmec) typing and multilocus sequence typing (MLST). PFGE identified nine pulsotypes, the majority of isolates belonging to pulsotypes A (n=70) and B (n=38), which were predominant among hospital-onset MRSA (HO-MRSA) and community-onset MRSA (CO-MRSA) isolates, respectively. Among the HO-MRSA isolates, variants of SCCmec type III were prevalent, whilst SCCmec type IV or variants were predominant in the CO-MRSA isolates. MLST identified two principal sequence types, ST8 and ST239. An association was observed between ST8, PFGE pulotyype B and SCCmec type IV in the CO-MRSA (ST8-MRSA-IV). Similarly, ST239, PFGE pulotytype A and SCCmec type III were associated with HO-MRSA (ST239-MRSA-III). Therefore, the prevalent genotypes circulating in Pakistan at the time of study were ST8-MRSA-IV and ST239-MRSA-III in the community and hospital settings, respectively. A set of HO-MRSA isolates collected in 1997 were characterized by PFGE and SCCmec typing for comparison. The isolates belonged to two PFGE pulsotypes (A, n=28; B, n=11) and contained just two SCCmec types. These results suggest that an increase in genetic diversity occurred over the period 1997–2007 as a result of either microevolution or the importation of strains from surrounding areas.

INTRODUCTION

Meticillin-resistant *Staphylococcus aureus* (MRSA) is an important global pathogen in the hospital setting that has become increasingly prevalent in community-acquired infections in recent years (Fluit et al., 2001; Chambers, 2001). There are limited data regarding the frequency of healthcare-associated infections caused by MRSA in Pakistan, but recent studies suggest that 42–51% of healthcare-associated *S. aureus* infections may be due to MRSA (Hafiz et al., 2002; Butt et al., 2004; Perwaiz et al., 2007).

Clinical *S. aureus* isolates have traditionally been tracked using phage typing and PFGE, which have proved useful in local outbreak investigations, but are less suitable for global studies (Bannerman et al., 1995; Branger et al., 2003; Ichiyama et al., 1991; Struelens et al., 1992). DNA-sequence-based methods including multilocus sequence typing (MLST) (Maiden et al., 1998), spa typing (Shopsin et al., 1999) and coa typing (Shopsin et al., 2000) have demonstrated adequacy for use in global epidemiological studies and for determining genetic relationships. Sequence-based methods are commonly supplemented by the use of staphylococcal cassette chromosome mec (SCCmec) typing of MRSA (Chongtrakool et al., 2006).

Using MLST, *S. aureus* populations have been shown to be highly clonal, with the majority of isolates belonging to a limited number of closely related genotypes, which are often globally distributed and stable over time (Feil & Enright, 2004; Enright et al., 2002). Studies have shown that epidemic MRSA (EMRSA) clones from hospitals belong to one of five clonal complexes: CC5 (New York/Japanese clone, Paediatric clone), CC8 (Iberian clone, Brazilian clone, Archaic clone), CC22 (EMRSA-15), CC30 (EMRSA-16) and CC45 (Berlin epidemic clone) (Enright et al., 2002; Aires de Sousa et al., 2000; Sá-Leão et al., 1999;
Domínguez et al., 1994; Heym et al., 2002; Teixeira et al., 1995; Crisostomo et al., 2001; Johnson et al., 2001; Witte et al., 1994). The aim of this study was to determine the prevalent MRSA genotypes circulating in the Aga Khan University Hospital (AKUH) in Karachi and the surrounding areas between June 2006 and July 2007 using PFGE, MLST, SCCmec typing and antimicrobial susceptibility testing.

METHODS

Isolates. A total of 126 consecutive, non-duplicated, clinically significant MRSA isolates were collected at the AKUH, Karachi, between June 2006 and July 2007. Of the 126 isolates, 102 were from Karachi, 12 from Sindh, 8 from Punjab and 4 from the North-West Frontier Province. To compare genotypes over time, 39 isolates collected from patients admitted to AKUH in 1997 were also investigated.

MRSA isolates from samples taken ≥48 h after hospital admission were considered to be hospital-onset (HO-MRSA, \( n = 107 \)). The 19 remaining isolates were from samples taken within 48 h of admission from patients with no previous history of hospital admission in the last 12 months. However, as it was not possible to exclude all potential risk factors, the latter isolates were referred to as community-onset (CO-MRSA) rather than community-acquired.

Bacterial identification and antimicrobial susceptibility testing. S. aureus was identified using coagulase, DNase and mannitol fermentation tests. Antimicrobial susceptibility was determined using Kirby–Bauer disc diffusion in accordance with the Clinical and Laboratory Standards Institute guidelines using oxacillin (1 \( \mu \)g) or cefoxitin (30 \( \mu \)g), erythromycin (15 \( \mu \)g), gentamicin (10 \( \mu \)g), amikacin (30 \( \mu \)g), co-trimoxazole (1.25/23.75 \( \mu \)g), chloramphenicol (30 \( \mu \)g), ofloxacin (5 \( \mu \)g), tetracycline (30 \( \mu \)g) and vancomycin (30 \( \mu \)g) (NCCLS, 2004). Susceptibility to fusidic acid (10 \( \mu \)g) was determined according to the British Society of Antimicrobial Chemotherapy guidelines (BSAC, 2008).

DNA extraction. DNA was extracted from S. aureus isolates using the Wizard Genomic DNA Purification kit according to the manufacturer’s instructions (Promega).

mecA PCR. The presence of the mecA gene was confirmed by PCR amplification as described by Murakami et al. (1991).

PFGE. PFGE was performed as described by McDougal et al. (2003). Briefly, plugs were digested with Smal restriction enzyme (Promega) and loaded into the wells of a 1 % agarose gel and run in 0.5 \( \times \) TBE using a CHEF-DR III system (Bio-Rad) according to the following parameters: 200 V (6 \( \text{V cm}^{-1} \)), temperature 14 °C, initial switch time 5 s, final switch time 40 s, included angle 120°, with a total run time of 21 h. Visual analysis of PFGE fingerprints was performed according to the criteria of Tenover et al. (1995). Similarity between banding patterns was estimated using BioNumerics software (version 4.5; Applied Maths) by performing cluster analysis using the unweighted pair group method analysis (UPGMA). Isolates that showed a coefficient of similarity ≥75 % (a difference of four bands) were grouped as one PFGE type and labelled alphabetically. Similarly, those showing a coefficient of similarity of ≥50 % (a difference of ≥seven bands) were grouped as a separate PFGE type. Isolates that showed between 50 % and 75 % similarity (a difference of five or six bands) were regarded as PFGE subtypes.

SCCmec typing. SCCmec typing was performed according to the multiplex PCR protocol of Oliveira & de Lencastre (2002). S. aureus strains COL, BK2464, ANS46 and MW2 were used as controls for SCCmec types I, II, III and IV, respectively. In instances where the SCCmec type could not be determined, the mec and ccr gene complexes were typed according to Zhang et al. (2005) and Hanssen et al. (2004), respectively.

MLST. MLST was performed according to the protocol of Enright et al. (2000).

Statistical analysis. SPSS version 16.0 was used for data analysis. Differences in the antimicrobial susceptibility of HO-MRSA and CO-MRSA isolates to the agents were compared using the chi-square test. A P-value of <0.05 was considered significant.

RESULTS AND DISCUSSION

PFGE

Two PFGE pulsotypes (A, \( n = 28 \); B, \( n = 11 \)) with eight subtypes were observed among the 39 isolates collected in 1997, in five major clusters of A1, A4, A16, A17 and B2.

The PFGE patterns of the 126 MRSA isolates collected in 2006–2007 were classified into nine pulsotypes with 33 subtypes. The predominant pulsotypes were A (\( n = 22 \)) and B (\( n = 11 \)), with multiple subtypes, A1–A15 (\( n = 48 \)) and B1–B10 (\( n = 27 \)). These two pulsotypes accounted for 108 (86 %) isolates. Other pulsotypes, C, D, E and F, were less common with fewer subtypes, C1 and C2, D1, E1–E4 and F1, respectively. Pulsotypes G–I had no subtypes.

Interestingly, subtypes A16 and A17 observed in 1997 were not observed in the 2006–2007 collection, indicating a change in the prevalence of molecular subtypes. This finding was in agreement with other studies published from Poland, Taiwan, Portugal and Spain (Tai et al., 2002; Bogut et al., 2008; Luczak-Kadłubowska et al., 2008; Aires de Sousa et al., 2008). Furthermore, persistence and overall predominance of PFGE pulsotypes A and B during both periods indicated that these were the local epidemic strains. These findings suggested their distinct origin and were in full agreement with reports published from neighbouring countries, including India, China and Taiwan (Ko et al., 2005; Shukla et al., 2004; Vandenesch et al., 2003).

CO-MRSA (\( n = 19 \)) was distributed in five PFGE pulsotypes (A, B, E, H and I), whilst the HO-MRSA (\( n = 107 \)) was distributed in six PFGE pulsotypes (A, B, C, D, F and G). These results indicated the predominance and spread of PFGE pulsotype A in the hospital setting during both study periods, which was consistent with previous reports (Wang et al., 2002; Tai et al., 2006). The results also indicated that the same genetic lineages of S. aureus had disseminated and persisted within the hospital setting and were also spreading in the community. The dispersion of CO-MRSA in multiple PFGE pulsotypes suggested their diverse origin as a result of either microevolution or the importation of strains from surrounding areas, some of which had become established in...

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the hospital setting. Nosocomial transmission of CO-MRSA and hospital outbreaks have been described in the USA and Europe (Otter & French, 2006).

**SCCmec typing**

SCCmec typing of the 2006–2007 isolates identified eight SCCmec types circulating in Pakistan (Table 1). This analysis indicated that among the 126 isolates studied, 78 contained a SCCmec type III or type III variant and 38 contained a type IV or type IV variant. Nine isolates could not be assigned to a SCCmec type due to the lack of amplification, but were subsequently found to belong to SCCmec type IV following typing of the mec and ccr gene complexes (mec gene complex B, ccr gene complex 2) and were tentatively named SCCmec type IV variant 1. A further isolate contained a unique type that was identified as SCCmec type IVA lacking a 342 bp band and was named SCCmec type IV variant 2. The distribution of the various PFGE pulsotypes in the CO-MRSA and HO-MRSA isolates and their relation with SCCmec type are shown in Table 1.

In the hospital setting, the predominant element was SCCmec type III variant 1, and in the community, the most frequent types were IVA and IV. SCCmec type IVA was found to be distributed most widely, being detected in seven of the nine PFGE pulsotypes, while SCCmec type IV was distributed in three PFGE pulsotypes (Table 1). Similarly, SCCmec type IV variant 2 was found in three different PFGE pulsotypes. These strains were isolated from different geographical regions and displayed no epidemiological linkage. This finding is similar to that of Berglund et al. (2005), who reported that the SCCmec type IV element was widely distributed in PFGE pulsotypes in Sweden, suggesting that the SCCmec type IV element was linked to a capacity to transfer between distinct clones of *S. aureus*. HO-MRSA collected during 1997 was of only two types, SCCmec type III variant 1 and IVA, while the 2006–2007 isolates demonstrated greater diversity. The results of SCCmec typing were consistent with studies from various Asian countries where SCCmec type III elements predominated, while in the USA, Japan and Korea, the most prevalent SCCmec types were I and II (Chongtrakool et al., 2006; Ito et al., 2004; Ko et al., 2005; Ma et al., 2002; Shukla et al., 2004; Vandenesch et al., 2003). Recently, Chongtrakool et al. (2006) reported that isolates containing SCCmec type III were prevalent in 9 out of 11 Asian countries. These findings illustrated the evolution of organisms under variable geographical and environmental pressures. Further understanding of endemic MRSA lineages and their correlation with regional and global strains requires further investigation.

**MLST**

Eighteen of the CO-MRSA isolates and representatives of the major HO-MRSA PFGE pulsotypes/subtypes (n=25) were further characterized by MLST. Among the CO-MRSA isolates, there was a significant association with ST8 (chi-square test, Yates’ correction, P≤0.05), which was the prevalent sequence type (n=12; 67%). In addition, ST239 was represented by three isolates and the remaining sequence types were each represented by one isolate. Among the 25 HO-MRSA isolates, only two sequence types were observed. ST239 was represented by 14 isolates and ST8 was represented by 11 isolates. No significant association was observed with a particular sequence type among the HO isolates (chi-square test, Yates’ correction, P>0.05). Robinson & Enright (2004) demonstrated that ST239 evolved from ST8 following a large-scale recombination event which led to the incorporation of ~557 kb (spanning the origin of replication, oriC) from a ST30 donor. ST239 has previously been shown to be prevalent in many other Asian countries, including China, India, Indonesia, Singapore, Sri Lanka, Taiwan, Thailand, Vietnam and Hong Kong (Chongtrakool et al., 2006; Zhang et al., 2005). Shabir et al. (2010) recently reported the prevalence of ST239 among MRSA isolates collected from Pakistan and India. Interestingly, only three SCCmec

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**Table 1. Association of CO- and HO-MRSA with SCCmec type and PFGE pulsotypes**

<table>
<thead>
<tr>
<th>SCCmec type</th>
<th>PFGE pulsotypes (no. of isolates)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO</td>
<td>HA</td>
</tr>
<tr>
<td>III variant 1</td>
<td>A (3)</td>
<td>A (63), B (4), F (1)</td>
</tr>
<tr>
<td>IIIA*</td>
<td>–</td>
<td>A (3), D (1), F (1)</td>
</tr>
<tr>
<td>IIIB*</td>
<td>–</td>
<td>C (1)</td>
</tr>
<tr>
<td>III variant 2</td>
<td>B (1)</td>
<td>–</td>
</tr>
<tr>
<td>IV*</td>
<td>B (2), E (2), I (1)</td>
<td>B (2)</td>
</tr>
<tr>
<td>IVA*</td>
<td>B (5), E (2), H (1)</td>
<td>A (1), B (18), C (1), D (2), G (1)</td>
</tr>
<tr>
<td>IV variant 1</td>
<td>B (1), E (1)</td>
<td>B (4), C (3)</td>
</tr>
<tr>
<td>IV variant 2</td>
<td>–</td>
<td>B (1)</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>107</td>
</tr>
</tbody>
</table>

*SCCmec variants previously described in the literature.*
types were detected (III, IIIa and IV) in the isolates of their collection. In contrast, the majority of clinical MRSA isolates in Korea and Japan belong to ST5 (Ko et al., 2005).

Five of the 23 isolates that belonged to ST8 contained a SCC\textit{mec} type IV element (Fig. 1a). A further 14 isolates contained a SCC\textit{mec} type IVA element, and three isolates contained the SCC\textit{mec} type IV element (variant 1) that lacked the 342 bp band as described previously by Shore et al. (2005). A further isolate was found to contain a SCC\textit{mec} type IVA variant (Ito et al., 2003). These results suggested that ST8 had been introduced into the sample population on multiple occasions rather than a single introduction followed by subsequent diversification.

Of the 17 isolates designated ST239 by MLST, 15 contained SCC\textit{mec} type III variant 1 (Fig. 1a). One isolate contained a SCC\textit{mec} type IIIA element and the remaining isolate contained a SCC\textit{mec} type IIIB element. Two of the three remaining isolates, which belonged to ST1 and ST217, contained a SCC\textit{mec} type IV element, whilst the final isolate, which belonged to ST1175, contained a SCC\textit{mec} type IV variant 1 element. Therefore, the prevalent genotypes of MRSA found in Pakistan are ST239-MRSA-III and ST8-MRSA-IV.

Okuma et al. (2002) demonstrated a significant difference in the doubling time of ST239 compared to that of its parent sequence types (ST8 and ST30). The reasons for this were unclear, but may have been the result of the acquisition of a large amount of genetic material from an unrelated background, which may have been confounded by the presence of the large (~66 kb) SCC\textit{mec} type III element, which encodes resistance to multiple antibiotics, antiseptics and heavy metals (Ito et al., 2001). The presence of the SCC\textit{mec} type III element may have conferred a selective advantage to ST239 in the hospital environment, despite the longer doubling time. In contrast, the CO-MRSA isolates in this study predominantly belonged to ST8, which, as already discussed, demonstrated a moderate...
doubling time. MRSA isolates belonging to ST8 usually carry a type IV SCCmec element, which, at ~21 kb, is the smallest of the SCCmec elements described and encodes only resistance to meticillin (Ma et al., 2002). Therefore, the small size of the SCCmec type IV element may not exert a large fitness cost on those strains carrying it, thus offering a selective advantage in the community setting. MRSA isolates belonging to ST8 and ST239 displayed heterogeneity with regard to the PFGE pulsotypes (Fig. 1b). ST239 (n=17) was found within PFGE pulsotypes A (n=15), C (n=1) and F (n=1), whilst ST8 (n=23) was found within PFGE pulsotypes B (n=15), C (n=2), D (n=1), E (n=4) and G (n=1). These results suggested that ST8 and ST239 were introduced some time ago and had since diversified as demonstrated by the presence of multiple PFGE pulsotypes within ST8 and ST239. However, in light of the number of SCCmec variants observed, it is more probable that there had been multiple introductions followed by diversification.

**Antimicrobial susceptibility**

Overall, antimicrobial resistance of the 126 isolates was high: 96% were resistant to gentamicin and ofloxacin, 84% to erythromycin, 82% to tetracycline and 79% to amikacin. In addition, 43% of isolates demonstrated resistance to co-trimoxazole, 18% to fusidic acid and 10% to chloramphenicol. All isolates demonstrated resistance to oxacillin and susceptibility to vancomycin. Resistance to ofloxacin was high in both HO-MRSA (97.2%) and CO-MRSA (89.5%) isolates. The only significant difference (P<0.05) between the HO-MRSA and CO-MRSA isolates was noted in susceptibility to gentamicin and tetracycline.

Previous studies have shown that the isolation of multiantimicrobial-susceptible CO-MRSA isolates could predict the presence of SCCmec IV and IVA and this characteristic may be used as a surrogate marker for their recognition (Huang et al., 2006; Pérez-Roth et al., 2004; Takizawa et al., 2005). However, this feature was not applicable to our study as the isolates were found to be additionally resistant to other antimicrobial agents. This may have reflected the practice of over-the-counter sale of antimicrobial agents to other antimicrobial agents. This may have reflected the study as the isolates were found to be additionally resistant to co-trimoxazole, 18% to fusidic acid and 10% to chloramphenicol. All isolates demonstrated resistance to oxacillin and susceptibility to vancomycin. Resistance to ofloxacin was high in both HO-MRSA (97.2%) and CO-MRSA (89.5%) isolates. The only significant difference (P<0.05) between the HO-MRSA and CO-MRSA isolates was noted in susceptibility to gentamicin and tetracycline.

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