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Reducing transmission of methicillin-resistant *Staphylococcus aureus* in a surgical ward of a resource-limited hospital in Indonesia: an intervention study

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SUMMARY

Background: Methicillin-resistant *Staphylococcus aureus* (MRSA) is endemic in healthcare settings in Indonesia.
Aim: To evaluate the effect of a bundle of preventive measures on the transmission and acquisition of MRSA in a surgical ward of a resource-limited hospital in Indonesia.
Methods: The study consisted of a pre-intervention (7 months), intervention (2 months), and post-intervention phase (5 months) and included screening for MRSA among eligible patients, healthcare workers (HCWs), and the hospital environment. In the intervention phase, a bundle of preventive actions was introduced, comprising: a hand hygiene educational program, cohorting of MRSA-positive patients, decolonization therapy for all MRSA-positive patients and HCWs, and cleaning and disinfection of the ward's innate environment. Hand hygiene compliance was assessed throughout the study period. The primary outcome was the acquisition rate of MRSA among patients per 1,000 patient-days at risk. Clonality of MRSA isolates was determined by Raman spectroscopy and multilocus sequence typing.
Findings: In total, 1,120 patients were included. Hand hygiene compliance rate rose from 15% pre-intervention to 65% post-intervention ($P<0.001$). The MRSA acquisition decreased from 9/1,000 patient-days at risk pre-intervention to 3/1,000 patient-days at risk post-

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intervention, but this difference did not reach statistical significance (P=0.08). Raman type 9 which belonged to ST239 was the single dominant MRSA clone.

Conclusion: The introduction of a bundle of preventive measures may reduce MRSA transmission and acquisition among surgery patients in a resource-limited hospital in Indonesia, but additional efforts are needed.

Introduction

Methicillin-resistant *Staphylococcus aureus* (MRSA) has emerged as a prevalent antimicrobial-resistant microorganism, causing both community- and hospital-acquired infections. Although the prevalence varies considerably between countries or regions, MRSA has been detected in most countries worldwide [1—8]. Infections caused by MRSA are associated with excess morbidity and mortality [9]. Guidelines with measures to prevent the spread of MRSA within healthcare facilities have been implemented in several developed countries. These measures focus on the three main reservoirs of MRSA in the hospital, which are healthcare workers (HCWs), the innate environment, and patients, and commonly include active surveillance cultures and screening of contacts, isolation and barrier precautions with disinfection of the environment, and selective decontamination of asymptomatic carriage. For hospitals in developing countries, where the burden of MRSA disease may be even higher, the control of MRSA transmission is challenging, since resources are limited and wards are often large and overcrowded. A set of measures for the control of MRSA that can be applied in these settings has not been developed so far, to the best of our knowledge [8,10—13].

Previously, we have shown an MRSA carriage rate of 4.3% among surgery patients at discharge from Indonesian hospitals [14]. In Dr. Saiful Anwar hospital in Malang, Indonesia, the carriage rate was the highest, 8.0%. In the present study, we aimed to design feasible actions to prevent further transmission of MRSA in the surgery ward of this resource-limited hospital, and to measure the effect of introducing these preventive measures on the transmission and acquisition of MRSA. We performed bacterial typing in order to analyze the clonal relatedness of the MRSA isolates circulating in the ward.

Methods

Setting

The study was carried out in two rooms of the surgical ward in the Dr. Saiful Anwar Hospital in Malang, Indonesia, which is an 810-bed tertiary care academic hospital. The baseline characteristics were: Room A: male general surgery room, shared by 50 adult patients, with a nurse-to-patient ratio of 1:5—10, two sinks were available; Room B: female general surgery room, for 22 adult patients, with a nurse-to-patient ratio of 1:3—6, one sink was available. In each room, two bottles of 500 mL alcohol-based liquid in wall dispensers were available located in the middle of the room. Isolation facilities were not present. The HCWs were dedicated to the study wards except doctors who rotated out of the study wards.

Study design and participants

The study was approved by the medical ethics committee of Dr. Saiful Anwar hospital, Malang, Indonesia (No.129/EC/KEPK-JK/05/2012). The study was registered to the ISRCTN registry with ID ISRCTN22906231 (http://www.isrctn.com/ISRCTN22906231). A before-and-after intervention study was conducted during a period of 14 months as described in Table 1. Culture-based screening of MRSA among patients, HCWs, and the environment was performed during each phase. Patients were screened on admission and at discharge; however, routine screening on day 5 of hospitalisation was also carried out to anticipate the missing of discharge screening. All patients admitted to the study rooms were eligible for inclusion; patients leaving the room within 48 hours of admission were excluded from the analysis. Only patients with complete culture sets, i.e. nose and throat swab taken on admission and either at day-5 hospitalisation or at discharge (or both), were included into the statistical analysis. When a subsequent MRSA screening moment (on day 5 of hospitalisation and/or at discharge) got through the phase of screening at admission, the patient was analysed within the phase at the moment of admission. Screening of HCWs (nurse, nurse assistant, cleaning staff, pharmacist, and dietician) and environment was conducted in the first week and the last week of the pre- and post-intervention phase, and in the middle of the intervention phase. Doctors on duty in both rooms were included in the screening in the pre- and post-intervention phase.

The hand hygiene compliance among HCWs was observed directly by three trained observers on various time slots during the workweek (Monday to Friday) using the hand hygiene compliance observation sheet based on the WHO tools [15].

Interventions

During the intervention phase, a bundle of preventive measures was introduced in the ward as described in Table 1 [8,16—18]. The design of the intervention was mainly based on recommendations by Calfee *et al*. and adapted to our setting [16].

Microbiological procedures

For screening of MRSA carriage among patients and HCWs, the anterior nares, throat, and skin lesions, if present, were sampled. The hospital environment was screened by taking samples from bedrails, bedside cabinets, thermometers, stethoscopes, blood pressure cuffs, nurses' tables, door handles, telephone receivers, sink handles, intravenous line stands, and trolley handles. All cultures were performed using cotton-tipped swabs and transported in Amies agar medium

Table 1
Description of the bundle of intervention measures

Preventive measures against MRSA transmission	Period		
	Pre-intervention phase (July 2012—January 2013)	Intervention phase (February 2013—March 2013)	Post-intervention phase (April 2013—August 2013)
Hand hygiene promotion	Posters of hand hygiene procedure according to the WHO guideline created by infection control team were placed on the wall near the sinks. No systematic and sustainable educational program.	The existing posters were maintained. In addition, we placed 2 bigger posters on the wall of each study ward. Reminders of "five hand hygiene opportunities" were placed on the cover of each medical record. Each healthcare worker working in the study ward was obliged to read the information sheet regarding hand hygiene procedure. Weekly presentation was delivered in the study ward attended by nurses, nurse assistants, pharmacists, and dieticians.	
Handrub solution access	Two bottles of 500 mL alcohol-based liquid were placed through wall-fixed dispensers and located in the middle of the study ward.	A bottle of 500 mL chlorhexidine-containing hand glycerin alcohol 0.5% was placed at each bedside.	
Hand hygiene compliance observation	The compliance was observed and measured on seven different days.	The compliance was observed and measured 7 times.	The compliance was observed and measured 15 times.
Screening of MRSA	Screening of patients[1], HCWs[2], and hospital environment[2]	Screening of patients[1], HCWs[3], and hospital environment[3]	Screening of patients[1], HCWs[2], and hospital environment[2]
Cohorting	Not yet implemented.	Patients with MRSA detected at admission were grouped separately from MRSA-negative patients behind a screen in a designated area (Figure 2).	
Decolonization/load reduction therapy	None.	Patients with MRSA detected at admission and MRSA-positive HCWs received decolonization therapy consisting of mupirocin dermatological cream 2% (Bactoderm cream, PT. Ikapharmindo Putramas, Indonesia) to both nares twice daily for five days plus body wash with chlorhexidine-medicated soap 4% (Hibiscrub, Astra Zeneca) for seven days. Patients and HCWs who carried MRSA in their throat were additionally offered trimethoprim/sulfamethoxazole oral therapy 960 mg twice daily for seven days.	
Cleaning and disinfection of hospital environment	Not performed.	Cleaning and disinfection of surfaces was conducted once a week using sodium hypochlorite 0.05%.	
Disinfection of instruments	Not regularly.	Disinfection of instruments was conducted using alcohol 70% regularly once a week and after use by MRSA-positive patients before being used by MRSA-negative patients.	

WHO, World Health Organization; MRSA, methicillin-resistant *Staphylococcus aureus*; HCWs, healthcare workers.
[1]At admission and either at day-5 or at discharge; [2]In the first week and at the end of the phase; [3]In the middle of the phase.

without charcoal (Copan Italia, Brescia, Italia). Swabs were directly inoculated into 5 mL phenol red mannitol broth (BBL™, Le Pont de Claix, France) for overnight incubation at 37°C and then sub-cultured onto *Staphylococcus aureus* and MRSA Chromagar medium (ITK Diagnostics, Uithoorn, the Netherlands) for 24—48 hours incubation at 37°C. Typical colonies of *S. aureus* and MRSA confirmed with Staphaurex®Plus (Remel, PT. Dipa Puspa Labsains, Indonesia) were stored into trypticase soy agar. After a subsequent identification test performed by mass spectrometry (MALDI-TOF, Bruker, the Netherlands), the colonies were stored into trypticase soy broth containing 15% glycerol at -80°C until further analysis.

DNA isolation and detection of mecA *and PVL genes*

Bacterial DNA was extracted using a MagNa Pure LC DNA system (DNA isolation kit III; Roche Molecular Biochemicals, Mannheim, Germany) [19]. *mecA* and PVL (*lukF-PV* and *lukS-PV*) genes were detected by PCR [20,21].

Raman spectroscopy

The clonal relatedness among MRSA isolates was assessed using Raman spectroscopy (SpectraCellRA Bacterial Strain Analyzer, River D international BV, Rotterdam, the Netherlands) [22,23]. Raman spectral analysis was performed using SpectraCellRA software version 1.9.0.13444:24 (RiverD international) as previously described [14]. The squared Pearson correlation coefficient (R2) determined the similarity of the sample spectra and the known R2 distribution of the identical and unrelated strains. Sixteen isolates were measured in duplicate as a reproducibility control. A two dimensional plot was created to compare the similarity of multiple isolates; the similarity of two isolates was presented by a color scale. The clonal relatedness was determined by setting the similarity threshold and cut-off value as previously described.

Multilocus sequence typing (MLST)

Ten MRSA isolates from the largest clusters of Raman spectra were selected randomly and analysed by MLST for international comparison purposes [24]. We selected isolates from both the center and the edge of the Raman cluster. The MLST sequence type was assigned through the MLST website (www.mlst.net).

Definitions

- MRSA prevalence at admission: proportion of patients screened positive for MRSA within 48 hours of admission.
- MRSA carriage prevalence among HCWs: proportion of HCWs screened positive for MRSA.
- Prevalence of environmental contamination by MRSA: the percentage of environmental samples revealing MRSA in culture.
- MRSA acquisition: an MRSA-positive screening test either at day-5 hospitalisation or at discharge that followed an initial negative test on admission [25].
- MRSA acquisition rate: the number of MRSA acquisition events divided by the number of patient-days at risk times 1,000.
- Hand hygiene compliance: percentage of correct hand hygiene actions undertaken on moments when hand hygiene was considered necessary according to the WHO "five moments" [15].
- Definitions of handwashing and handrubbing were as described in the WHO guideline [15].

Statistical analysis

Data of MRSA prevalence among patients at admission, HCWs, and environment were analysed using statistical software packages SPSS version 16.0 (SPSS Inc., Chicago, USA). Differences in prevalence between study phase were determined using chi-square tests or fisher's exact test (when numbers were small). The effect of the intervention measures (i.e. the difference of acquisition rate between the pre- and post-intervention phase) was analysed with an Exact Wilcoxon-Mann Whitney test using R version 3.3.2 (2016-10-31) statistical software. The intervention phase was not taken into account because this was when the intervention measures, especially the hand hygiene promotion, was carried out. A *P* value less than 0.05 was considered significant for all analyses.

Results

MRSA prevalence

In total, 1,937 patients were eligible during the study, however, 817 patients were excluded from data analysis because the patients moved to another room or ward within 48 hours in the pre- and post-intervention phase (3/426, 0.7%; 1/305, 0.3%), were discharged upon personal request in the pre-intervention phase (1/426, 0.2%), missed to be screened at admission (27/426, 6.3%; 9/86, 10.5%; 25/305, 8.2%) and at discharge (395/426, 92.7%; 77/86, 89.5%; 277/305, 90.8%) in all phases. Therefore, 1,120 patients were included in the statistical analysis (Figure 1).

The MRSA prevalence among patients, HCWs and the environment is presented in Table 2. The prevalence of MRSA among patients at admission in the pre-intervention phase did not differ significantly from that in the post-intervention phase. The MRSA carriage rate among HCWs in the pre-intervention phase did also not differ from that in the intervention phase (P=0.340). In the post-intervention phase, we did not find any MRSA carrier among the HCWs (compared to pre-intervention, P=0.420). In the intervention and post-intervention phase, re-screening for patients and HCWs with MRSA was carried out to evaluate the effect of decolonization therapy. All HCWs carrying Raman type (RT) 2 and RT10 had a negative MRSA screening culture after decolonization therapy, whereas 7/12 (58.3%) patients with MRSA were successfully decolonized. The five patients that were not succesfully decolonized carried either RT8, RT9, or RT11 MRSA clones.

We found the hospital environment to be contaminated with MRSA in the pre- (2 items: intravenous line stand and bedrail) and post-intervention phase (one item: patient table). We did not find MRSA contamination of the environment during the intervention phase, but the number of samples taken during this phase was lower (Table 2). The

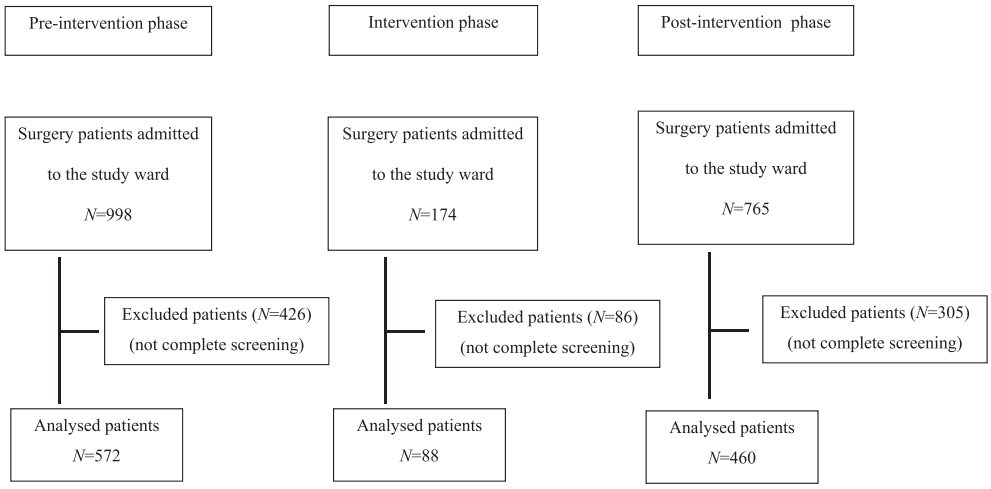

Figure 1. Flow chart of patients included in the analysis.

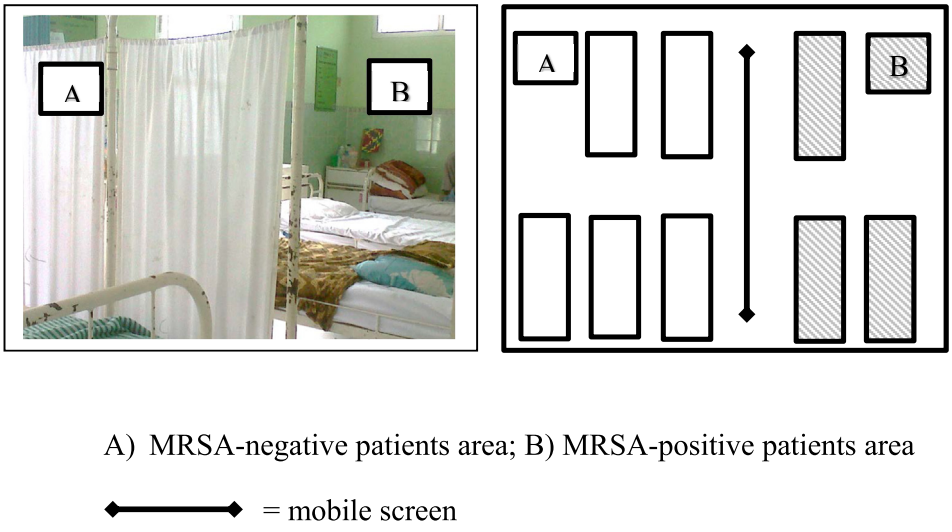

Figure 2. Cohorting procedure for MRSA-positive patients in the study ward. MRSA, methicillin-resistant *Staphylococcus aureus*. Zone A contained more beds than presented in the picture.

Table 2
The prevalence of MRSA carriage among patients, healthcare workers, and the hospital environment

Group	Phase	No. of subjects screened	No. of patients without complete screening	No. of patients analysed	No. of cultures (ENV)	Prevalence of MRSA carriage at admission (%; CI_{95})	MRSA acquisition event	Median of MRSA acquisition rate[1] (range)	Prevalence of MRSA carriage (%; CI_{95})
HCWs[3]	PI	68							1/68 (1.5; 0.1—7.9)[2]
	I	60							3/60 (5.0; 1.7—13.7)
	PoI	94							0/94[2]
Patients	PI	998	426	572		18/572 (3.1; 2.0—4.9)[4]	30	5.3 (0.0—41.0)	
	I	174	86	88		1/88 (1.1; 0.1—6.2)	2	2.8 (0.0—5.6)	
	PoI	765	305	460		11/460 (2.4; 1.3—4.2)[4]	8	1.7 (0.0—6.7)	
ENV					201				2/201 (1.0; 0.3—3.6)[5]
					100				0/100
					200				1/200 (0.5; 0.0—2.8)[5]

MRSA, methicillin-resistant *Staphylococcus aureus*; HCWs, healthcare workers; ENV, environment; PI, pre-intervention; I, intervention; PoI, post-intervention.
[1]Number of acquisition events divided by number of patient-days at risk (per 1000 patient-days); [2]P=0.420; [3]HCWs who carried MRSA and received decolonization therapy were screened before and after decolonization therapy. [4]P=0.589; [5]Contamination rate on hospital environment, P=1.000.

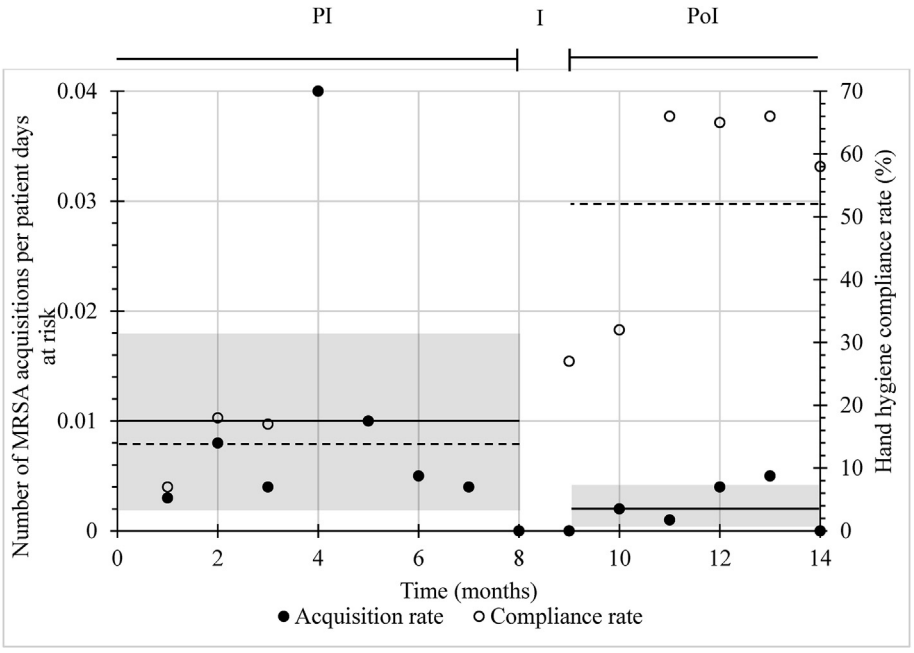

Figure 3. Methicillin-resistant *Staphylococcus aureus* acquisitions among patients versus hand hygiene compliance rate among healthcare workers. The solid horizontal line represents the average of acquisition rate, the grey area represents the 95% confidence interval around that mean. The dashed horizontal line represents the average of hand hygiene compliance. PI=pre-intervention phase; I=intervention phase; PoI=post-intervention phase.

prevalence of the PVL-genes among the 90 MRSA isolates obtained in this study was 17%.

MRSA acquisition

After implementing the bundle of preventive measures, the acquisition rate of MRSA was lower but this decrease did not reach statistical significance (9—3 per 1,000 patient-days at risk; P=0.08). The highest acquisition rate of MRSA was 41 per 1,000 patient—days at risk and occurred in the fourth month of the pre-intervention phase (Figure 3).

Patients who acquired MRSA were detected at day 5 of hospitalization in 21 (70%), 2 (100%), and 7 (87.5%) cases in the pre-intervention, intervention, and post-intervention phase, respectively. Of the nine patients who were detected as MRSA carrier at discharge in the pre-intervention phase, the average of length of stay was 6.4 days. Of these, one patient screened at discharge was detected as MRSA carrier on day 3.

Adherence to hand hygiene procedure

In general, the overall hand hygiene compliance rate increased significantly from 15% (95% confidence interval [CI_{95}], 12—19%) in the pre-, to 30% (CI_{95}, 28—33%) in the intervention, and to 64% (CI_{95}, 62—66%) in the post-intervention phase. In the pre- and intervention phase, the compliance rate of handrubbing was low, 11% (CI_{95}, 4—18%) and 25% (CI_{95}, 20—30%), respectively. However, it was much higher than handwashing (P<0.001) after implementation of

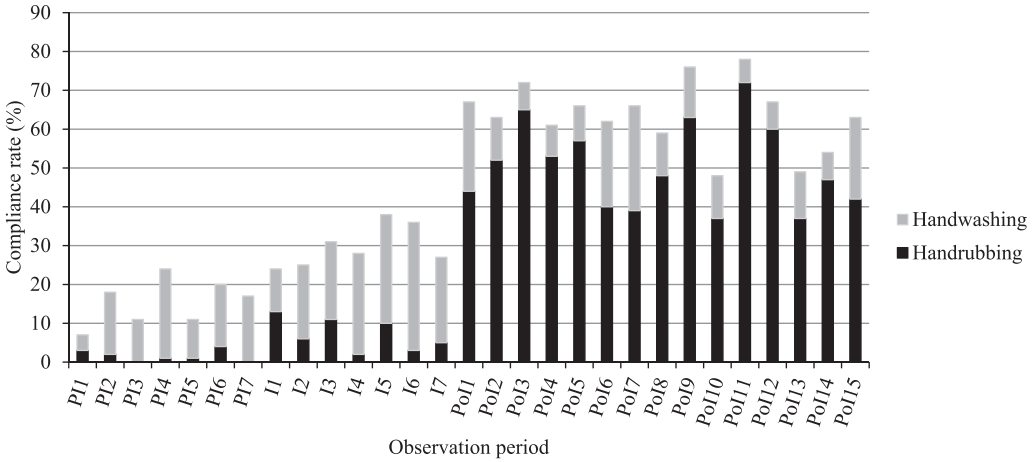

Figure 4. Trend of hand hygiene compliance during the study period. PI, pre-intervention phase; I, intervention phase; PoI, post-intervention phase.

Table 3
The compliance to the five moments of hand hygiene before/during the intervention and in the post-intervention phase

Hand hygiene moment	Total		
	Compliance (%)		OR (95% CI)
	PI and I	PoI	
1	9.5	84.7	52.8 (31.2–89.2)[a]
2	3.6	39.8	17.8 (8.6–36.7)[a]
3	36.7	70.3	4.1 (2.1–8.0)[a]
4	39.7	64.8	2.8 (2.1–3.8)[b]
5	34.9	61.8	3.0 (2.4–3.7)[a]

OR, odds ratio; PI, pre-intervention phase; I, intervention phase, PoI, post-intervention phase.
Moment 1, before touching a patient; moment 2, before clean/aseptic procedure; moment 3, after body fluid exposure risk; moment 4, after touching a patient; moment 5, after touching patient surroundings.
[a] $p<0.001$ (Fisher's exact test).
[b] $p<0.001$ (χ^2).

preventive actions (Figure 4). When comparing the five moments of hand hygiene recommended by WHO guideline, the compliance rate was significantly higher ($P<0.001$) for all five moments of hand hygiene, but this was greatest for the moment before the HCWs touched patients and performed a clean or aseptic procedure (Table 3). The improvement of hand hygiene compliance was accompanied by a decrease of the MRSA acquisition rate (Figure 3).

Raman spectroscopy

We performed Raman spectroscopy for 90 out of 93 MRSA isolates obtained in the pre- (patients: 31 isolates; HCW: 1 isolate), intervention (patients: 4 isolates; HCW: 1 isolate), and post-intervention phase (patients: 52 isolates; environment: 1 isolate). The Raman spectroscopic analysis showed 22 RTs, of which RT9 was most frequently found, followed by RT11 and RT8 (Figure 5). The two MRSA isolates from HCWs were unique.

The endemicity profile of MRSA isolates (Figure 6) showed that the dominant RT9 and its closely related RT11 were found either at admission or during admission in both the pre- and post-intervention phase of this study. The RT9 strain was isolated from both rooms, whereas the RT11 strain was only found in the male room (data not shown). Although the RT11 clone was not cultured from patients at the time of admission in the pre-intervention phase, it was found among admissions both in the intervention and post-intervention phase. Interestingly, the third most common type, RT8, was found only in the post-intervention phase of the study, suggesting a recent introduction and spread of a new MRSA clone in this setting. Other unique RTs were detected only briefly during the study period.

MLST analysis

MLST results of ten MRSA isolates are presented in Table 4. All seven MRSA isolates that belonged to RT9 and RT11 were assigned to ST239, indicating that these two clones were

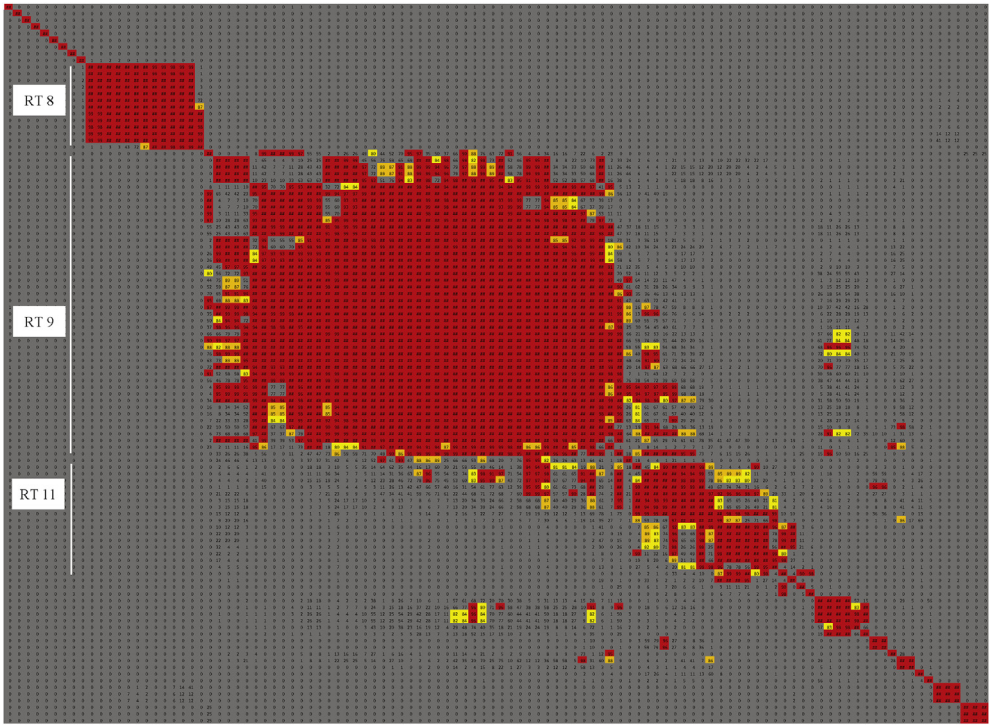

Figure 5. Raman spectra of methicillin-resistant *Staphylococcus aureus* isolates.The correlation matrix displayed is used to analyse the relatedness between isolates. Red clusters show isolates that are indistinguishable based on the cut-off value. The grey areas indicate isolates that are not related based on the similarity threshold. Yellow areas to orange areas gradually show the potentially related isolates. RT9 includes 39 MRSA isolates from patients (pre-intervention: 15 isolates and post-intervention: 24 isolates) and one MRSA isolate from the environment in the post-intervention phase. RT11 contains 15 MRSA isolates from patients (pre-intervention: 2 isolates, intervention: 3 isolates, post-intervention: 10 isolates). RT8 consists of 10 PVL-positive MRSA isolates from patients in the post-implementation phase.

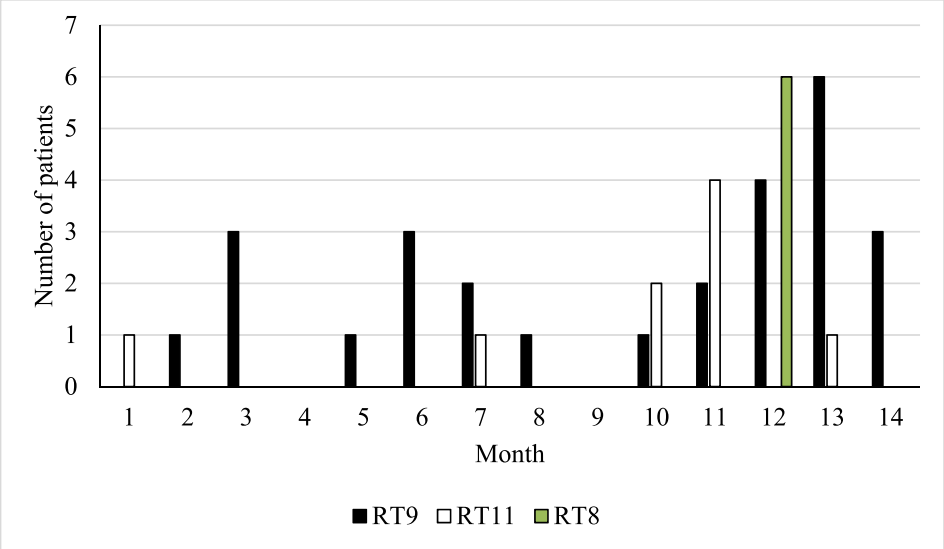

Figure 6. Endemicity profile of large clusters of MRSA assigned to RT9, RT11, and RT8. Month 1–7=pre-intervention phase; month 8–9=implementation of intervention phase; month 10–14=post-intervention phase. MRSA, methicillin-resistant *Staphylococcus aureus*; RT, Raman type.

indeed genetically closely related. One PVL-positive MRSA isolate belonging to RT8 was assigned to ST772.

Discussion

This study is the first intervention study aimed at reducing MRSA transmission in a resource-limited hospital in Indonesia. The intervention significantly improved hand hygiene compliance among HCWs and we observed a reduction in the MRSA acquisition rate after implementation of the intervention. This decline in MRSA acquisition rate, however, did not reach statistical significance, possibly due to the limited duration of the follow-up phase. Other studies regarding the impact of MRSA control programs have likewise showed varied levels of effectiveness for reducing the incidence rate of hospital-acquired MRSA [11,25–28].

Table 4
Results of Raman spectroscopy analysis and MLST of 10 selected methicillin-resistant *Staphylococcus aureus* isolates

Isolate number	Raman type	Sequence type
PPoM 10458[a]	8	772
PPiM 10293[b]	9	239
PPiM 10756[b]	9	239
PPoM 20544[a]	9	239
PPoM 20673[a]	9	239
HI 1097[c]	10	8
PPoH 10221[d]	11	239
PPoM 10212[a]	11	239
PIK 10127[e]	11	239
PPiM 10495[b]	15	789

[a]isolated from patients at admission in the post-intervention phase; [b]isolated from patients at admission in the pre-intervention phase; [c]isolated from healthcare worker in the intervention phase; [d]isolated from patients at day-5 admission in the post-intervention phase; [e]isolated from patients at discharge in the intervention phase.

The most important reservoir in our study were patients. To control this reservoir, we applied cohorting of MRSA-positive patients behind a screen and decolonization therapy. The detection of MRSA-positive patients on admission is crucial, since this determines the influx of MRSAs. The prevalence of MRSA-positive patients on admission in our study did not differ significantly before and after implementation, as shown using a universal screening approach. In low-resource settings, however, this is not feasible as part of routine patient care, and for this we propose a risk-based screening. In a previous analysis, we showed that in our setting patients referred from other hospitals, patients transferred from the surgical acute care unit, patients that had a surgical procedure within three months before admission, and immunocompromised patients were more likely to be MRSA carriers at admission to the surgery ward [29].

In settings with more resources, moving MRSA-positive patients to single-patient rooms or installing contact precautions with dedicated medical equipment can be carried out. However, this was not possible in our hospital, instead, patients were cohorted behind a screen. Also, personal protective equipment was scarce. This may well have restricted the impact of the bundle of preventive measures aimed at reducing the MRSA acquisition rate in this study.

Based on Raman spectroscopy and MLST analysis, RT9 and RT11 MRSA clones belonging to ST239 were particularly endemic in the male ward throughout the study. The number of patients already colonized on admission with either one of these two dominant MRSA clones even increased in the post-intervention phase. It is known that ST239-MRSA is the predominant MRSA sequence type in most Asian countries, highly transmissible and difficult to control in hospital settings [1,14,30,31].

Contrary to earlier studies [14,32,33], we now observed the emergence of a PVL-positive MRSA clone in the post-intervention phase of this study. The PVL-positive MRSA representing RT8 was introduced to the male surgery room by five

patients who were cultured positive at the time of admission. This PVL-positive MRSA belonged to ST772-MRSA which has been reported before as a community-associated (CA) MRSA infiltrating in hospital settings in India [34,35].

MRSA was also found among HCWs and the hospital environment, reservoirs that were not found positive in our previous study [14]. Nevertheless, MRSA carriage of HCWs was successfully eliminated whereas only one item of the hospital environment was contaminated with MRSA in the post-intervention phase.

Adherence of HCWs to hand hygiene procedures is an important factor to control MRSA transmission [36,37]. In this study, accessibility to handrub containers supported with systematic and sustainable hand hygiene education were likely instrumental in the improvement of hand hygiene compliance. However, high workload, understaffing, skin irritation and a sensation of stickiness of the handrub solution might hamper the adherence to the hand hygiene procedure [38].

This study has some limitations. First, we performed the study in a single tertiary care center and only in the surgery ward. This intervention should be implemented in some other healthcare settings or wards to assess its effectiveness. However, this was not feasible because of limited resources. To overcome this limitation, mathematical and computational modelling can be applied to evaluate hospital infection control in different settings [39]. Such mathematical modelling might also be useful to evaluate the transmission rates of MRSA strains circulating in the ward before and after the intervention. Second, HCWs may have improved their compliance with hand hygiene guidelines because they were aware of being observed (Hawthorne effect). It is known that this effect will diminish when observations take place over longer periods of time [40]. Third, the hand hygiene compliance among doctors, nurses, and students was not compared. Consequently, we could not identify the group that contributed most to the level of adherence with hand hygiene procedures. However, previous publications reported lower hand hygiene compliance rates of doctors than nurses [36,38]. Fourth, we did not take clinical cultures into account. Therefore, patients with only MRSA in a clinical culture were not included in the acquisition rate analysis as MRSA positive. The concordance of MRSA clones between screening and clinical cultures isolates would have confirmed or refuted the notion that MRSA acquisition will contribute to nosocomial MRSA infections. Last, we did not observe compliance with contact precautions by HCWs caring for MRSA-positive patients. The limited number of nurses and medical equipment including personal protective equipment and medical instruments in our hospital may well have had impact on the compliance with the measures taken for MRSA-positive patients. Adherence to cohorting, decolonization therapy, and environmental cleaning was also not systematically assessed.

Conclusions

In summary, both hospital-associated MRSA and CA-MRSA pose a threat to patients in the hospital setting in Indonesia. A bundle of intervention measures including hand hygiene, risk-based screening on admission, adapted isolation procedures, cleaning and disinfection of hospital environment, disinfection of instruments, and decolonization therapy may help to control the MRSA transmission in surgery wards in resource-limited hospitals in Indonesia, but additional efforts are probably needed. Adherence to all intervention bundle elements should be systematically assessed to evaluate the importance of each separate measure.

Abbreviations

MRSA	methicillin-resistant *Staphylococcus aureus*
HCW	healthcare worker
PVL	Panton-Valentine leukocidin
ST	sequence type
PCR	polymerase chain reaction
WHO	World Health Organization
MLST	multilocus sequence typing
CI	confidence interval
RT	Raman type
CA-MRSA	community-associated MRSA.

Declarations

Ethics approval and consent to participate: the study was approved by the medical ethics committee (No 129/EC/KEPK-JK/05/2012). Informed consent was obtained from each participant before taking the sample.

Consent for publications

Since information related to individual patients is not included in this contribution, consent for publication from individual patients is not applicable.

Availability of data and materials

Please contact author for data request.

Competing interest

The authors declare that they have no competing interests. JAS recently collaborated with employees of bioMerieux on a research project that included whole genome sequencing of bacterial isolates, which was performed by the company.

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Authors' contributions

All authors participated in conception and study design other than additional contributions. SS, MH, and KK contributed with substantive intellectual expertise in this study. DE, IAH, ALEA, and LGT were involved in data collection related to bacterial culture and hand hygiene compliance. AHS arranged the MRSA carriage screening of healthcare workers, particularly among doctors. VP and II supplied and distributed handrub bottles and medicine needed for MRSA decolonization

therapy from Pharmacy Department to the study wards. NO and DWE conducted Raman spectroscopy of MRSA isolates. SVS carried out MLST of the MRSA isolates. NSE contributed to data analysis. DS, HAV, and JAS contributed to design of the study, final data analysis, and interpretation in addition to writing and finalizing the manuscript. All authors read and approved the final manuscript.

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