High Contribution and Impact of Resistant Gram Negative Pathogens Causing Surgical Site infections at a Multi-Hospital Healthcare System in Saudi Arabia, 2007-2016

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Abstract

BACKGROUND Despite being largely preventable, surgical site infections (SSIs) is still one of the most frequent healthcare associated infections worldwide. The presence of resistant pathogens can further augment its clinical and economic impact. The objective was to estimate the prevalence and extent of resistance in SSI pathogens in a tertiary care setting in Saudi Arabia and to compare such data to US National Healthcare Safety Network (NHSN) hospitals. **METHODS** Targeted SSI surveillance was prospectively conducted on several surgical procedures done between 2007 and 2016 in four hospitals of Ministry of National Guard Health Affairs. Definitions and methodology of SSI and bacterial resistance were based on NHSN. **RESULTS** A total 492 pathogens causing 403 SSI events were included. The most frequent pathogens were *Staphylococcus aureus* (22.8%), *Pseudomonas* (20.1%), *Klebsiella* (12.2%), and *Escherichia coli* (12.2%), with marked variability between surgeries. Approximately 30.3% of *Staphylococcus aureus* were methicillin-resistant (MRSA), 13.0% of Enterococci were vancomycin-resistant (VRE), and 5.5% of Enterobacteriaceae were carbapenem resistant (CRE). The highest multidrug-resistant (MDR) GNPs were *Acinetobacter* (58.3%), *Klebsiella* (20.4%) and *Escherichia coli* (16.3%). MRSA was significantly less frequent while cephalosporin-resistant *Klebsiella*, MDR *Klebsiella*, and MDR *Escherichia coli* were significantly more frequent in our hospitals compared with NHSN hospitals. **CONCLUSION** GNPs in a tertiary care setting in Saudi Arabia are responsible for approximately 60% of SSI with more resistant patterns than Western countries. This information may be critical to secure resources and ensure support of caregivers and healthcare leaders in implementing antimicrobial stewardship programs and evidence-based SSI preventive practices. **KEYWORDS** Antimicrobial resistance, multidrug resistance, surgical site infections, surveillance, pathogens, hospital, Saudi Arabia

Background

Surgical site infection (SSI) is a global healthcare problem increasing patient morbidity, mortality, and healthcare cost [1, 2]. Despite the fact that more than 50% are preventable [3], SSI remains the most frequent healthcare-associated infections (HAIs) in low and middle income countries, affecting up to 30% of the patients undergoing surgery [1, 4]. Even in high income countries, it is still the second frequent type of HAI, accounting for more than 20% of all HAIs [5-7]. Several surgical-related practices have been linked to the development of antimicrobial resistance [8]. The presence of resistant pathogens has been shown to augment the clinical and economic impact of SSI [9-11]. Therefore, recent SSI guidelines stressed on the appropriate use of antimicrobial prophylaxis to reduce the risk of antimicrobial resistance [8, 12, 13].

Gram positive pathogens (GPPs) are traditionally the most frequently isolated SSI pathogens, with a considerable number of these pathogens are now resistant [5, 14, 15]. For example, 44% of *Staphylococcus aureus* and 20% of *Enterococcus* spp. isolated from surgical wounds in the USA are resistant [14, 15]. Unlike the prevalence of SSI in Saudi Arabia [16-19], very few studies focused on the causative pathogens and/or their resistance patterns [16-18]. Moreover, surgery-specific pathogen data in available reports were either lacking or covered a small number of patients [16-18]. Likewise, very limited data on the resistance patterns of pathogens causing SSI were reported in the Gulf Cooperation Council (GCC) [17] and the Middle Eastern countries [20, 21]. Therefore, a study that combined aggregate data from 30 developing countries including some regional ones were not able to present data on pathogen profile nor bacterial resistance [22]. The objective of the current study was to estimate the prevalence and extent of resistance of SSI pathogens identified during HAI surveillance in four tertiary care hospitals in Saudi Arabia; additionally, to compare such data to US National Healthcare Safety Network (NHSN) hospitals.

Methods

Setting: Data were collected from four Ministry of National Guard Health Affairs (MNGHA) hospitals; King Abdulaziz Medical City-Riyadh (KAMC-R), King Abdulaziz Medical City-Jeddah (KAMC-J), King Abdulaziz Hospital-Alhassa (KAH), Imam Abdulrahman Bin Faisal Hospital-Dammam (IABFH). MNGHA hospitals are governmentally funded tertiary care hospitals that provide free services for more than 1.5 million Saudi National Guard soldiers, employees and their families. The total

bed capacity is approximately 2200 beds with an average occupancy rate of 72%. Approximately 30 thousands surgical procedures are conducted in MNGHA hospitals every year.

Design: SSI surveillance was prospectively conducted on several surgical procedures done in four MNGHA hospitals between 2007 and 2016. The surveillance was performed by trained infection preventionists (IPs) using unified SSI data collection methods, similar to those of the NHSN [23]. The surveillance was targeting selected surgical procedures based on annual risk assessments, approved by the hospital infection control committee. Post-discharge surveillance data were obtained from admission and readmission records as well as surgical follow-up, outpatient clinics, and emergency visits.

Event eligibility: All surgeries performed on adult patients and was part of the targeted surveillance plan during the study period were initially included. SSI events diagnosed clinically without laboratory confirmation were then excluded. Only surgeries done among admitted patients were included.

Infection and resistance definitions: The surveillance definitions and data collection methods followed a locally generated GCC surveillance manual [24] that was based on the NHSN definitions [23], including the changes introduced in 2013 [25]. While rare, more than one pathogen was allowed for a single SSI event. Multidrug resistance (MDR) definitions were retrospectively calculated as per the current NHSN definitions [26] and recent NHSN reports [14, 15]. Cephalosporin-resistant was defined as *Klebsiella* testing non-susceptible (resistant or intermediate) to at least one cephalosporin agent (ceftazidime, cefotaxime, ceftriaxone or cefepime) [26]. Carbapenem-resistant *Enterobacteriaceae* (CRE) was defined as *Klebsiella*, *Escherichia coli*, or *Enterobacter* testing resistant to imipenem [26]. MDR Gram negative pathogens (GNPs) were defined as pathogens testing non-susceptible (resistant or intermediate) to at least one agent in at least 3 out of 5 antimicrobial classes; aminoglycosides (amikacin or gentamicin), cephalosporins (ceftazidime, cefotaxime, ceftriaxone, or cefepime), fluoroquinolones (ciprofloxacin or levofloxacin), carbapenems (imipenem or meropenem), β -lactamase inhibitor (piperacillin or piperacillin/tazobactam) [14, 15]. Only in MDR *Pseudomonas*, 2 cephalosporins (cefepime and ceftazidime) rather than 4 cephalosporins (above) were considered.

Statistical methods: Categorical variables were presented as frequencies and percentages while continuous variables were presented as means and standard deviations. Age and gender were calculated for non-duplicate patients only. The distribution of SSI pathogens and their resistance patterns were presented by surgical procedures and significant differences were evaluated using chi-square test or Fisher exact test (as appropriate). The distribution of SSI pathogens and their resistance in MNGHA hospitals were compared to corresponding rates in NHSN hospitals after pooling data from two published NHSN reports [14, 15]. SPSS (Version 25.0. Armonk, NY: IBM Corp) was used for all statistical analyses.

Results

SSI events and patients:

Out of 602 SSI events detected, 199 (33.1%) SSI events were excluded due to lack of microbiological data. The details of the exclusions by surgical types is shown in supplementary Table. Therefore, 403 SSI events were included in the current analysis. Demographics and clinical characteristics of the included SSIs are shown in Table 1. The average age was 49.5 ± 18.0 years and approximately 70.0% of the patients were females. The majority (75.5%) of the events were superficial incisional SSI, with 19.4% deep SSI and 5.1% organ/space SSI. Only 30.5% of SSI events were diagnosed before discharge. Approximately 6.3% of the patients with SSI events died during the same hospitalization.

Causative pathogens:

The distribution and rank order of different pathogens by the type of SSI are shown in Table 2. A total 492 pathogens were detected in 403 SSI events. GNPs were the most common (64.2%), followed by GPPs (34.3%) and then fungi (1.4%). The most frequent pathogens were *Staphylococcus aureus* (22.8%), *Pseudomonas* (20.1%), *Klebsiella* (12.2%), *Escherichia coli* (12.2%), *Enterobacter* (7.7%), and *Enterococcus* (5.9%). *Staphylococcus aureus* and *Pseudomonas* were equally the most

frequent pathogens in herniorrhaphy and knee prosthesis surgeries. Additionally, *Staphylococcus aureus* was the most frequent pathogen in cesarean section while *Pseudomonas* was the most frequent pathogen in coronary artery bypass graft surgery. *Escherichia coli* was the most frequent pathogen in colon, gallbladder, and other surgeries.

Resistant pathogens:

Antimicrobial resistance in different pathogens by the type of SSI is shown in Table 3. Approximately 27.7% of GPPs and 16.1% of GNPs were resistant. In GPPs, 30.3% of *Staphylococcus aureus* were methicillin-resistant (MRSA) and 13.0% of *Enterococci* were vancomycin-resistant (VRE). Approximately 25.0% of the *Klebsiella* were cephalosporin-resistant and 5.5% of *Enterobacteriaceae* were CRE (11.4% in *Klebsiella*, 2.0% in *Escherichia coli*, and 0.0% in *Enterobacter*). The highest frequency of MDR in GNPs was seen in *Acinetobacter* (58.3%), followed by *Klebsiella* (20.4%) and *Escherichia coli* (16.3%).

The distributions of overall resistance by clinical characteristics are shown in Figure 1. Resistant GPPs (including MRSA or VRE) showed some variability by the type surgery done, being highest with colon surgery ($p=0.013$). However, there was no significant variability in resistant GPPs by the type of admission, diagnostic types of SSI, time of diagnosis, nor hospital mortality. Resistant GNPs (including cephalosporin-resistant *Klebsiella*, CRE, MDR *Acinetobacter*, MDR *Pseudomonas*, MDR *Klebsiella*, or MDR *Escherichia coli*) showed significant variability with all examined characteristics with the exception of the type of admission. For example, resistant GNPs were significantly higher with colon surgery but lower with cesarean section compared with all other surgeries combined. Additionally, resistant GNPs were significantly associated with higher mortality, pre-discharge diagnosis of SSI, and with increasing the depth of SSI.

Comparisons with NHSN:

The distribution of pathogens and their resistance patterns in MNGHA compared with NHSN hospitals are shown in Figure 2. *Pseudomonas*, *Klebsiella*, *Enterobacter*, *Serratia*, and *Acinetobacter* were significantly more frequent while *Enterococcus*, *Coagulase negative staphylococci*, and *fungi* were significantly less frequent in MNGHA hospitals compared with NHSN hospitals. MRSA was significantly less frequent while cephalosporin-resistant *Klebsiella*, MDR *Klebsiella*, and MDR *Escherichia coli* were significantly more frequent in MNGHA hospitals compared with NHSN hospitals.

Discussion

This data identifies the distribution of SSI pathogens and their resistance patterns in 6 adult surgical procedures done over 10 years in multi-hospital healthcare system located in a high income Middle Eastern country. Couple of points should be highlighted while we are interpreting the current findings; this data were collected in the presence of a local guideline for surgical prophylaxis co-developed by members of surgical department and infection control committee. Additionally, surgical bundle of the Institute for Healthcare Improvement (IHI) was implemented throughout the study [27]. Compliance with the guideline and the surgical bundle, however, has varied widely between surgeries and from time to time (data not shown).

Similar to studies done in developed [5, 7, 14, 15] and developing countries [1, 28], the most frequent pathogen in the current study was *Staphylococcus aureus*, a common skin colonizer. For example, it was approximately 23% in the current study compared with 20% to 30% in these studies [1, 5, 14, 15]. However, GNPs (mainly *Pseudomonas* spp. and *Enterobacteriaceae*) were more prevalent in the current study (60%) than seen in developed countries (36%-46%) [5, 7, 14, 15]. This high contribution of GNPs was consistent with several reports from Saudi Arabia [16-18] and developing countries [1], that showed contribution rates between 55% and 77%. This may be explained by high environmental burden of GNPs, that are usually more resistant to disinfectants compared with GPPs [29]. Additionally, three of the main six surgeries included were abdominal procedures, that have been frequently linked to *Enterobacteriaceae* and *Pseudomonas* spp. [30].

In addition to the low contribution, GPPs causing SSI in the current study was generally less resistant than reported internationally. For example, MRSA rates was 30% in the current study compared with more than 40% in USA [14, 15], Europe

[5], and Asia [31, 32]. In Saudi Arabia, there has been a great variability in the published MRSA rates, probably due to mixing community and hospital isolates as well as clinical and surveillance isolates [33, 34]. Nevertheless, the current finding was consistent with the local MRSA rates obtained from HAI specimens (mainly wound), which ranged between 16% and 57% [33]. For VRE, the current rates (13%) was comparable to recent reports from Saudi Arabia [35]. Additionally, it was comparable to international rates [5, 31], with exception of North and South American ones which traditionally have very high rates of VRE [14, 15, 31]. Despite the relatively low resistance of GPPs observed in the current and local studies, reports has warned from an increasing trend in the resistance of GPPs in Saudi Arabia, specially VRE, probably due to overuse of broad-spectrum antimicrobials and development of new resistance patterns [34, 35].

In addition to higher contribution, GNPs causing SSI in the current study was generally more resistant than reported in US hospitals. For example, all GNPs in the current study (with exception of *Enterobacter*) were more resistant than NHSN hospitals, with significant difference in cephalosporin-resistant *Klebsiella*, MDR *Klebsiella*, and MDR *Escherichia coli* [14, 15]. On the other hand, the current rates was even lower than the extremely high rates of cephalosporin and carbapenem resistance among GNPs reported in some developing countries such as Egypt [20], India [36], and Iran [21]. The high rate of resistance in GNPs in the current study is probably reflecting a wide range of resistance mechanisms in GNPs observed in our hospitals, such as NDM, OXA 48 and MGrb and outer membrabe protein (OMP) resistance [37-41]. The high rate of resistance in GNPs in the current study is quite alarming as it already increased the mortality by 25%. Additionally, this can be used as a justification for initiation and continuation of broad-spectrum antibiotics, leading to a vicious cycle of enhancing resistance. Consistent with current data, a local study showed that 77% of pathogens isolated from SSI after abdominal surgery were resistant to the prophylactic antibiotic given preoperatively [16].

With the limited data available locally and regionally, this report can serve as a unique benchmark for caregivers engaged in SSI prophylaxis and antimicrobial stewardship programs. The data were prospectively collected over 10 years by well-trained IPs in 4 hospitals, using the same standard surveillance methodology and the same SSI preventive practices. The relatively large sample size allowed for presenting surgery-specific pathogen distribution and resistance patterns. The use of NHSN resistance definitions allowed for previously unmatched comparisons of resistance patterns between the two differently-matured healthcare systems. Nevertheless, few limitations are acknowledged. The analyzed data were only a sample of a much bigger number of surgeries done in the 4 hospitals during the period covered by the study and almost one-third of SSI were diagnosed clinically. However, these are typical for all studies following the NHSN definitions and NHSN-recommended targeted surveillance methodology. As in other similar studies, underestimation of SSI diagnosis cannot be excluded. However, this should be unlikely, as our population is entitled to free care in our hospitals, which make the likelihood of patients seeking medical care elsewhere is very low. Despite being beyond of the scope of this paper, the lack of extensive data analysis on the colonization rates and the risk factors that can possibly affect the resistance patterns limit the interpretation of the current findings.

In conclusion, *Staphylococcus aureus* remains the most frequent SSI pathogen, with 30% are MRSA. GNPs are responsible for approximately 60% of SSI and were generally more resistant than seen in Western countries. Resistant GNPs were associated with increased mortality. Making this information available to caregivers and healthcare leaders is critical to secure resources and ensure support in implementing interventions, such as antimicrobial stewardship programs and evidence-based SSI preventive practices [8, 12, 13].

Declarations

Ethics approval and consent to participate: IRB waived the ethics approval because no identifying patient information was used during this study. No names, patient numbers, photos, person statements, etc were used during this study.

Consent for publication: Not applicable

Availability of data and materials: Available upon request

Competing interests: The authors declare that they have no competing interests

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Authors' contributions: HB, AE, and MA contributed to data analysis, data interpretation, and writing. AA, WA, AE, ZA, and SA contributed to data writing and study design. SA, SA, MA, and SA contributed to writing and literature search.

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Tables

Table 1: Demographics and clinical characteristics of surgical site infections (SSIs) in 4 MNGHA hospitals in Saudi Arabia (2007-2016)

	CSEC (N=141)	COLO (N=22)	CBGB (N=153)	CHOL (N=19)	HER (N=16)	KPRO (N=19)	Others (N=23)	Total (N=403)
Age, mean±SD*	31.2±6.5	52.1±18.0	63.9±8.7	49.2±15.1	51.0±16.1	64.7±11.4	50.9±19.4	49.5±18.0
Gender*								
Male	0 (0.0%)	12 (54.5%)	78 (52.0%)	5 (26.3%)	4 (25.0%)	8 (42.1%)	13 (39.4%)	120 (30.0%)
Female	141 (100.0%)	10 (45.5%)	72 (48.0%)	14 (73.7%)	12 (75.0%)	11 (57.9%)	20 (60.6%)	280 (70.0%)
Hospital facility								
KAMC-Riyadh	9 (6.4%)	22 (100.0%)	131 (85.6%)	1 (5.3%)	3 (18.8%)	1 (5.3%)	12 (36.4%)	179 (44.4%)
KAMC-Jeddah	76 (53.9%)	0 (0.0%)	22 (14.4%)	13 (68.4%)	10 (62.5%)	13 (68.4%)	14 (42.4%)	148 (36.7%)
KAH-Al hasa	15 (10.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	5 (15.2%)	20 (5.0%)
IAFH-Dammam	41 (29.1%)	0 (0.0%)	0 (0.0%)	5 (26.3%)	3 (18.8%)	5 (26.3%)	2 (6.1%)	56 (13.9%)
Admission								
ICU	3 (2.1%)	6 (27.3%)	153 (100.0%)	1 (5.3%)	0 (0.0%)	0 (0.0%)	5 (15.2%)	168 (41.7%)
Wards	138 (97.9%)	16 (72.7%)	0 (0.0%)	18 (94.7%)	16 (100.0%)	19 (100.0%)	28 (84.8%)	235 (58.3%)
SSI type								
Superficial	115 (87.8%)	6 (27.3%)	117 (76.5%)	9 (81.8%)	8 (72.7%)	9 (56.3%)	20 (62.5%)	284 (75.5%)
Deep	14 (10.7%)	11 (50.0%)	32 (20.9%)	0 (0.0%)	3 (27.3%)	3 (18.8%)	10 (31.3%)	73 (19.4%)
Organ/space	2 (1.5%)	5 (22.7%)	4 (2.6%)	2 (18.2%)	0 (0.0%)	4 (25.0%)	2 (6.3%)	19 (5.1%)
Diagnosis time								
Before discharge	12 (9.7%)	13 (76.5%)	60 (40.5%)	9 (52.9%)	2 (12.5%)	3 (25.0%)	12 (40.0%)	111 (30.5%)
After discharge	81 (65.3%)	3 (17.6%)	69 (46.6%)	8 (47.1%)	10 (62.5%)	4 (33.3%)	15 (50.0%)	190 (52.2%)
On readmission	31 (25.0%)	1 (5.9%)	19 (12.8%)	0 (0.0%)	4 (25.0%)	5 (41.7%)	3 (10.0%)	63 (17.3%)
Hospital death								
No	101 (100.0%)	11 (61.1%)	116 (90.6%)	15 (100.0%)	13 (100.0%)	14 (100.0%)	29 (96.7%)	299 (93.7%)
Yes	0 (0.0%)	7 (38.9%)	12 (9.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (3.3%)	20 (6.3%)

Abbreviations: MNGHA, Ministry of National Guard Health Affairs; CSEC, cesarean section; COLO, colon surgery; CBGB, coronary artery bypass graft with both chest and donor site incisions; CHOL, gallbladder surgery; HER, herniorrhaphy; KPRO, knee prosthesis.

* Age and gender were calculated for non-duplicate patients

Table 2: Distribution and rank order of pathogens causing surgical site infections (SSIs) in 4 MNGHA hospitals in Saudi Arabia (2007-2016)

	CSEC (N=160)		COLO (N=29)		CBGB (N=194)		CHOL (N=28)		HER (N=21)		KPRO (N=22)		Others (N=38)		Total (N=492)	
	N (%)	R	N (%)	R	N (%)	R	N (%)	R	N (%)	R	N (%)	R	N (%)	R	N (%)	R
All gram positive bacteria	89 55.6%		6 20.7%		50 25.8%		6 21.4%		8 38.1%		8 36.4%		2 5.3%		169 34.3%	
<i>Staphylococcus aureus</i>	67 41.9%	1	1 3.4%	7	28 14.4%	3	3 10.7%	4	5 23.8%	1	7 31.8%	1	1 2.6%	7	112 22.8%	1
<i>Enterococcus spp.</i>	10 6.3%	6	5 17.2%	3	8 4.1%	8	2 7.1%	5	3 14.3%	3			1 2.6%	7	29 5.9%	6
<i>Coagulase negative staphylococci</i>					11 5.7%	7					1 4.5%	5			12 2.4%	11
Other gram positives	12 7.5%	5			3 1.5%	11	1 3.6%	9							16 3.3%	8
All gram negative bacteria	71 44.4%		23 79.3%		142 73.2%		17 60.7%		13 61.9%		14 63.6%		36 94.7%		316 64.2%	
<i>Acinetobacter spp.</i>	1 0.6%	10	1 3.4%	7	4 2.1%	10	1 3.6%	9			1 4.5%	5	4 10.5%	5	12 2.4%	11
<i>Pseudomonas spp.</i>	19 11.9%	2	6 20.7%	2	52 26.8%	1	2 7.1%	5	5 23.8%	1	7 31.8%	1	8 21.1%	2	99 20.1%	2
<i>Klebsiella spp.</i>	15 9.4%	4	4 13.8%	4	29 14.9%	2	4 14.3%	3	2 9.5%	5	1 4.5%	5	5 13.2%	4	60 12.2%	3
<i>Enterobacter spp.</i>	8 5.0%	7	2 6.9%	5	18 9.3%	4	2 7.1%	5	1 4.8%	7	0 0.0%		7 18.4%	3	38 7.7%	5
<i>Escherichia coli</i>	17 10.6%	3	8 27.6%	1	16 8.2%	5	5 17.9%	1	2 9.5%	5	2 9.1%	4	10 26.3%	1	60 12.2%	3
<i>Serratia spp.</i>	1 0.6%	10			13 6.7%	6	1 3.6%	9							15 3.0%	9
<i>Proteus spp.</i>	7 4.4%	8			3 1.5%	11			3 14.3%	3					13 2.6%	10
Other gram negatives	3 1.9%	9	2 6.9%	5	7 3.6%	9	2 7.1%	5			3 13.6%	3	2 5.3%	6	19 3.9%	7
ungi					2 1.0%	13	5 17.9%	1							7 1.4%	13
All pathogens	160 100.0%		29 100.0%		194 100.0%		28 100.0%		21 100.0%		22 100%		38 100.0%		492 100.0%	

Abbreviations: As in Table 1. N(%), number of pathogens and percentage; R, rank.

Table 3: Antimicrobial resistance in selected pathogens causing surgical site infections (SSIs) in 4 MNGHA hospitals in Saudi Arabia (2007-2016)

	CSEC (N=137)		COLO (N=27)		CBGB (N=155)		CHOL (N=19)		HER (N=18)		KPRO (N=18)		Others (N=36)		Total (N=410)		
	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	Rank
Gram positive pathogens																	
MRSA	60	20	1	1	26	6	3	1	3	0	5	2	1	0	99	30	
	90%	33%	100%	100%	93%	23%	100%	33%	60%	0%	71%	40%	100%	0%	88%	30%	2
VRE	9	0	2	1	7	1	1	1	3	0			1	0	23	3	
	90%	0%	40%	50%	88%	14%	50%	100%	100%	0%			100%	0%	79%	13%	6
Overall resistance	67	20	3	2	33	7	4	2	5	0	5	2	2	0	119	33	
	89%	30%	50%	67%	92%	21%	80%	50%	71%	0%	71%	40%	100%	0%	86%	28%	
Gram negative pathogens																	
CephR <i>Klebsiella</i>	15	1	4	1	24	4	3	2	2	2	1	1	3	2	52	13	
	100%	7%	100%	25%	83%	17%	75%	67%	100%	100%	100%	100%	60%	67%	87%	25%	3
CRE	35	1	7	2	37	0	8	0	4	0	3	1	16	2	110	6	
	92%	3%	64%	29%	61%	0%	80%	0%	80%	0%	100%	33%	80%	13%	74%	5%	8
MDR <i>Acinetobacter</i>	1	0	1	1	4	2	1	1			1	1	4	2	12	7	
	100%	0%	100%	100%	100%	50%	100%	100%			100%	100%	100%	50%	100%	58%	1
MDR <i>Pseudomonas</i>	18	0	6	1	51	4	2	0	5	0	6	1	8	1	96	7	
	95%	0%	100%	17%	98%	8%	100%	0%	100%	0%	86%	17%	100%	13%	97%	7%	7
MDR <i>Klebsiella</i>	10	0	4	1	24	3	4	1	2	2	1	1	4	2	49	10	
	67%	0%	100%	25%	83%	13%	100%	25%	100%	100%	100%	100%	80%	50%	82%	20%	4
MDR <i>Escherichia coli</i>	12	2	7	2	15	0	5	2	1	0	1	0	8	2	49	8	
	71%	17%	88%	29%	94%	0%	100%	40%	50%	0%	50%	0%	80%	25%	82%	16%	5
Overall resistance	54	3	15	6	93	10	11	3	9	2	10	3	26	8	218	35	
	96%	6%	88%	40%	90%	11%	92%	27%	100%	22%	91%	30%	90%	31%	92%	16%	

Abbreviations: As in Table 1. T, number and percentage of pathogens tested out of pathogens causing infection; R, number and percentage of pathogens resistant out of pathogens tested; MRSA, methicillin-resistant *Staphylococcus aureus*; VRE, vancomycin-resistant *Enterococcus*; CephR *Klebsiella*, cephalosporin resistant *Klebsiella*; CRE, carbapenem resistant *Enterobacteriaceae*; MDR, multidrug resistant gram negative pathogens that tested non-susceptible (resistant or intermediate) to at least one agent in at least 3 out of 5 antimicrobial classes (see methods). Overall resistance; an pathogen with one or more of the above types of resistance.

Figures

Figure 1

Overall resistance rates of pathogens causing surgical site infections (SSIs) by clinical characteristics in 4 MNGHA hospitals in Saudi Arabia (2007-2016) Note: Gram positive resistance includes MRSA or VRE. Gram negative resistance include CephR Klebsiella, CRE, MDR Acinetobacter, MDR Pseudomonas, MDR Klebsiella, or MDR E-coli, as shown in Table 3. * indicate significant differences.

Figure 2

Comparisons of the percentage of pathogens causing SSI (left) and their resistance of patterns (right*) in MNGHA hospitals (2007-2016) and NHSN hospitals (2009-2014) Abbreviations: As in Table 3; SSI, surgical site infections. NHSN VRE rate shown was the rate of both *Enterococcus faecalis* and *Enterococcus faecium* combined. * indicate significant differences.

Supplementary Files

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- [BurdenMDROSSI4Supplementarytable.docx](#)