ORIGINAL ARTICLE

Correlation between hand hygiene compliance and methicillin-resistant *Staphylococcus aureus* incidence

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ABSTRACT

Background: The objectives of the study are to investigate the relationship between hand hygiene compliance and hospital-acquired methicillin-resistant *Staphylococcus aureus* (MRSA) incidence, and to propose a new method for estimating Pearson correlation between pair of rates.

Methods: 2011-2014 hand hygiene audit data were linked to hospital-acquired MRSA data in the province of Alberta, Canada. Hand hygiene compliance and hospital-acquired MRSA incidence rates were calculated at the unit, site, zone and provincial levels. Pearson correlation coefficients were calculated for the pairs of the rates. The 95% confidence limits of the Pearson correlation coefficients were estimated based on the information contained in hospital-acquired MRSA incidence rates.

Results: Strong longitudinal correlations between hospital-acquired MRSA incidence and hand hygiene compliance were found at the provincial level and for the Calgary Zone and Edmonton Zone (<-0.95). At the site level, a strong correlation was found for the Foothills Medical Centre (-0.88).

Conclusion: Combining the traditional Pearson correlation technique with the proposed inference method provides a simple and proper method for detecting the relationship between healthcare-acquired infection and hand hygiene.

KEY WORDS:

Correlation study; Hand hygiene; Incidence; Infection; Methicillin-resistant *Staphylococcus aureus*; Statistical method

INTRODUCTION

In Canada, more than 200,000 patients acquire an infection each year while receiving healthcare, and more than 8,000 of these patients die from such infections (1). As a result, eliminating healthcare-acquired infections has become a key priority for healthcare quality and patient safety programs (2).

Methicillin-resistant *Staphylococcus aureus* (MRSA), the most common cause of serious healthcare-acquired infections (3) is a bacterium that is resistant to many antibiotics. In healthcare facilities MRSA can cause life-threatening bloodstream infections, pneumonia and surgical site infections. The overall incidence of both MRSA colonization and MRSA infection increased 19-fold in Canadian hospitals from 1995 to 2009(4).

Hand hygiene is a strategy for preventing hospital-acquired infections including MRSA. Alberta Health Services (AHS) conducted provincial wide hand hygiene compliance audits from 2011. To investigate the relationship between hand hygiene compliance and hospital-acquired MRSA incidence, hand hygiene compliance audit data and hospital-acquired MRSA surveillance data collected by AHS were linked.

AHS is Canada's first and largest province-wide, fully integrated healthcare system, which has 106 acute care hospitals, five stand-alone psychiatric facilities, 8,471 acute care beds, 23,742 continuing care beds/spaces, 208 community palliative and hospice beds, 2,439 addiction and mental health beds plus equity partnerships with 42 primary care networks. AHS is organized into five geographic zones: South, Calgary, Central, Edmonton and North. Hand hygiene and hospital-acquired MRSA data used for this study are from acute care facilities across the five zones that have both hospital-acquired MRSA surveillance data and hand hygiene compliance audit data.

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Pearson correlation coefficients between annual hand hygiene compliances and hospital-acquired MRSA incidence rates were calculated at unit, site, zone and provincial levels. Due to the small sample sizes (4 pairs of annual rates) the results were unreliable. Therefore, a new method to estimate confidence limits of the Pearson correlation coefficient is proposed.

METHODS

Data collections and linkages

Hand hygiene compliance for nurses, physicians and other healthcare providers in acute care units were observed by trained auditors between May and August using the direct observation method for the "Four Moments for Hand Hygiene" (5, 6) from 2011 to 2014. Auditors received standardized training on conducting audits and were guided by an Infection Control Professional mentor at each site. Auditors and mentors met often to discuss difficult cases and to review methodology to improve inter-rater consistency.

Province-wide surveillance for hospital-acquired MRSA cases began in January 2010. All patients admitted to one of AHS' acute care or acute tertiary rehabilitation care facilities that had a newly identified positive MRSA cultures were included in the surveillance. Hospital-acquired MRSA (colonized and infected) is defined as those cases that have been identified after the patient has been admitted >48 hours in an AHS facility or have been admitted for <48 hours prior to identification of an MRSA, but the patient had a previous acute care admission from the same or different AHS facility within 14 days.

Unit-based patient-days were derived from the Admission, Discharge and Transfer (ADT) databases maintained by the Analytics department of AHS for the period of January 2011 to December 2014. Unit-level elapsed patient-days, the exact length of stay in a unit, were calculated for each patient stay in an acute care facility operated by AHS. Elapsed patient-days calculated from the ADT databases are accurate to the minute.

Annual hand hygiene compliance audit data were first merged with denominator (patient-days) data by unit. The units which did not participate in provincial hand hygiene audits were excluded. Then hospital-acquired MRSA data were merged with denominator data which had been linked to hand hygiene data at the unit level. Using the linked data, hand hygiene compliance, hospital-acquired MRSA incidence and their 95% confidence limits were calculated at the unit, site and zone levels. If there were no hospital-acquired MRSA cases, the rates were set to zero.

The entire patient-days for the hospitalized patients, rather than the patient-days at risk of acquiring a MRSA, were used as the denominators of hospital-acquired MRSA incidences. Because the patients infected or colonized with hospital-acquired MRSA during their unit stays were fewer than other patients in the units, the slight underestimates were ignored.

Rates and confidence limits

With traditional correlation analysis, all variables are assumed to have no measurement error. In fact, very often variable measurements include errors and these errors may vary from measurement to measurement (7). Due to potential measurement errors, hand hygiene compliance rates may vary with approximately normal distribution since their sample sizes were large (≥10). The 95% confidence limits for the rates were calculated with: $p \pm 1.96\sqrt{p(1-p)/n}$, where p is the hand hygiene compliance rate and n is the number of hand hygiene observations.

Hospital-acquired MRSA (colonization and infection) incidences may also vary due to potential measurement errors. Because the numbers of hospital-acquired MRSA cases are smaller, hospital-acquired MRSA incidences usually do not satisfy the normal approximation of the distribution, especially at the unit level. Assuming that the hospital-acquired MRSA cases had a Poisson distribution and the number of patient-days were fixed, the 95% confidence limits were estimated for each of the calculated hospital-acquired MRSA incidence rate by using the following formulae (8) based on the relation between the Poisson distribution and chi-square distribution (9,10):

$$\text{Lower Limit} = 10{,}000 \times CINV(0.025,\ 2\times \text{case}) / (2\times PD)$$
and
$$\text{Upper Limit} = 10{,}000 \times CINV(0.975,\ 2\times \text{case}+2) / (2\times PD)$$

where *CINV* is a SAS function which returns the α/2th (0.025) and (1- α/2)th (0.975) quantiles from the chi-squared distribution with degrees of freedom $2\times case$ and $2\times case+2$ respectively, *case* is the number of hospital-acquired MRSA cases and *PD* is patient-days. Significance level α was 0.05. Because the unit of hospital-acquired MRSA incidence we used was per 10,000 patient-days, a constant of 10,000 was multiplied.

The ratio of the relative variation (*RRV*) for each hospital-acquired MRSA incidence to the hand hygiene compliance was calculated using the equation below:

$$RRV = \frac{\dfrac{\text{Upper limit of MRSA indicdence - Lower limit of MRSA incidence}}{\text{MRSA incidence}}}{\dfrac{\text{Upper limit of hand hygiene compliance - Lower limit of hand hygiene compliance}}{\text{Hand hygiene compliance}}}$$

Correlation coefficients and confidence limits

Because the hand hygiene compliance rates were based on larger numbers in the numerators and denominators, the compliance rates were more stable than hospital-acquired MRSA incidence rates. For simplicity, we assume that hand hygiene compliance rates are fixed and hospital-acquired MRSA incidence rates vary randomly. Under this assumption, the real hospital-acquired MRSA incidence rates would be some values between the lower and upper confidence limits of the calculated rates with a 95% probability.

Longitudinal Pearson correlation coefficients between hospital-acquired MRSA incidence and hand hygiene compliance were calculated at the unit, site, zone, and provincial levels. For each of the calculated correlation coefficient between the rates, $2^4=16$ different Pearson correlation coefficients were calculated by using lower limit or upper limit values of the four annual hospital-

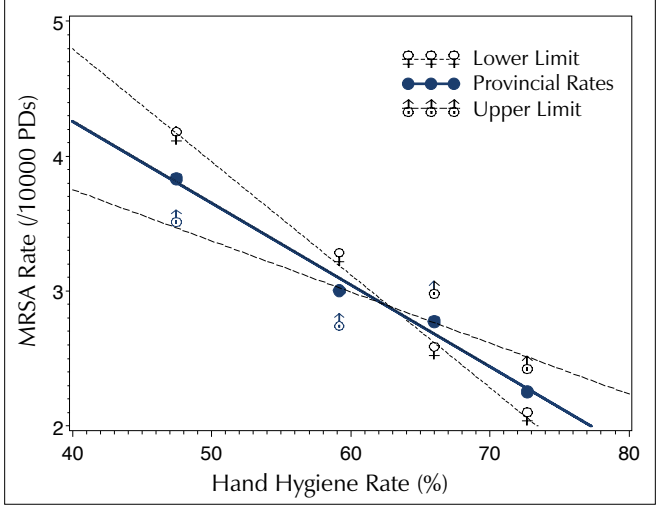
acquired MRSA incidences. The smallest and largest ones among the 16 correlation coefficients were considered to be the lower and upper confidence limits of the corresponding correlation coefficients between the rates, respectively. If the lower and upper limits have the same direction (positive or negative), the correlation coefficient was considered to be statistically significant (i.e., null hypothesis can be rejected).

As an example, Figure 1 depicts the scatterplot for provincial hospital-acquired MRSA incidence versus hand hygiene compliance and the regression line. The data points for the upper and lower limits of each hospital-acquired MRSA incidence versus hand hygiene compliance are also shown in the figure. Two other regression lines (dotted lines) with the largest and smallest slopes in the figure were derived by exchanging the upper and lower limits of 2011 and 2012 hospital-acquired MRSA incidences. The corresponding correlation coefficients are the upper and lower confidence limits of the provincial correlation coefficient.

This study focused on longitudinal analyses because the cross-sectional scatterplots for zone, site, and unit hospital-acquired MRSA incidence versus hand hygiene compliances for each year had no significant linear correlation between the two rates due to the diversity of the rates.

All calculations were performed using SAS version 9.3 (SAS Institute Inc., Cary, NC).

FIGURE 1: Annual provincial hospital-acquired methicillin-resistant *Staphylococcus aureus* (MRSA) incidence (/10,000 patient-days) versus hand hygiene compliance with the regression lines for estimating the correlation coefficient and its 95% confidence limits



RESULTS

Table 1 shows zone and provincial hospital-acquired MRSA incidences and hand hygiene compliances for 2011, 2012, 2013 and 2014. In 2011, the Central Zone hospital-acquired MRSA incidence was much higher (5.80/10,000 patient-days) than those in other zones (1.23-4.39/10,000 patient-days). The Central Zone hospital-acquired MRSA incidence dramatically decreased to 3.55/10,000 patient-days in 2012, which was comparable with other zones. During the four years, North Zone consistently had the lowest annual hospital-acquired MRSA incidences (0.95-1.23/10,000 patient-days). Hospital-acquired MRSA incidences for South, Calgary, and Central zones, and the whole province decreased consistently over the years, while hand hygiene compliances for South Zone, Calgary Zone and the province increased gradually. Hand hygiene compliance for Central Zone did not increase obviously.

Table 1 also shows the 95% confidence limits for the annual hospital-acquired MRSA incidences and hand hygiene compliances for the zones and the province. The ratios of the relative variations (RRV) for hospital-acquired MRSA incidence to hand hygiene compliance ranged from 4.4 to 34.5 (not shown in the table). Because all RRVs >4, it is reasonable to assume that the hand hygiene compliances are fixed, and only the hospital-acquired MRSA incidence rate vary. Taking into account the variation of the hand hygiene compliance rates, the confidence intervals would be a little boarder than those estimated by the proposed method. We tested the differences by using the confidence limits for the hand hygiene rates instead of the rates themselves to calculate the confidence limits of the correlations with the same method, no obvious differences were found in our data.

Longitudinal Pearson correlation coefficients between hospital-acquired MRSA incidence and hand hygiene compliance were calculated for 93 units, 26 sites, 5 zones and the whole province. There are not enough data points for estimating correlations for those units or sites which participated in the provincial hand hygiene audits later than 2011 or had one or more zero annual MRSA rates during the study period.

The correlation coefficients, *P*-values generated by SAS PROC CORR (11) and their confidence limits derived with the proposed method for a selected unit and hospital, for each zone and the whole province are shown in Table 2. Based on the *P*-values and upper confidence limits, Calgary Zone, Edmonton Zone and the whole province had strong negative correlations between MRSA incidence and hand hygiene compliance (<-0.95). At the site level, a negative correlation (-0.88) between hospital-acquired MRSA incidence and hand hygiene rate was found at the Foothills Medical Centre, the largest hospital in Alberta (1,063 beds), with the proposed method (upper limit < 0). This correlation could not be detected by using the traditional method ($P=0.116$). Given the small number of MRSA cases per unit, only six significant correlations were found at the unit level with traditional method ($P<0.05$, only one unit was shown in the table). These are likely due to chance. These correlations lose significance when the proposed method was applied.

For a relationship to exist between MRSA and hand hygiene compliance, there must be significant number of MRSA cases occurring in the site. This means that detection of a significant relationship between MRSA and hand hygiene rates is generally restricted to tertiary or large urban centres. Of the 106 hospitals in AHS, only 5 (4.7%) hospitals have > 500 beds and only 17 (16.0%) hospitals have > 250 beds. The remainders of the hospitals vary from 5 to 249 beds with the majority < 100 beds.

TABLE 1: Hospital-acquired methicillin-resistant *Staphylococcus aureus* (MRSA) incidence and hand hygiene compliance by zone and year

Zone	Year	No. Sites	No. Units	MRSA				Hand Hygiene		
				No. Cases	Patient Day (PD)	Rate (/10,000 PDs)	95% Confidence Interval	Number Observed	Rate (%)	95% Confidence Interval
South	2011	10	26	70	159,312	4.39	3.43, 5.55	2,471	57.75	55.80, 59.70
	2012	11	29	72	165,389	4.35	3.41, 5.48	14,192	67.67	66.90, 68.44
	2013	11	34	75	187,656	4.00	3.14, 5.01	15,999	77.58	76.93, 78.23
	2014	11	35	46	211,142	2.18	1.60, 2.91	16,656	79.76	79.14, 80.37
Calgary	2011	11	59	191	537,045	3.56	3.07, 4.10	7,640	40.07	38.97, 41.16
	2012	11	61	176	588,486	2.99	2.57, 3.47	10,840	49.95	49.01, 50.90
	2013	12	75	150	646,502	2.32	1.96, 2.72	14,532	60.55	59.75, 61.34
	2014	12	100	181	877,026	2.06	1.77, 2.39	19,911	66.61	65.96, 67.27
Central	2011	21	35	122	210,418	5.80	4.81, 6.92	1,993	66.53	64.46, 68.60
	2012	24	60	127	357,634	3.55	2.96, 4.23	4,940	58.00	56.62, 59.37
	2013	25	63	130	374,913	3.47	2.90, 4.12	11,502	63.86	62.98, 64.74
	2014	25	67	95	374,120	2.54	2.05, 3.10	8,663	67.74	66.75, 68.72
Edmonton	2011	10	91	228	587,474	3.88	3.39, 4.42	5,892	41.38	40.12, 42.64
	2012	11	98	213	667,025	3.19	2.78, 3.65	8,262	59.27	58.21, 60.33
	2013	11	110	225	718,992	3.13	2.73, 3.57	6,812	55.59	54.41, 56.77
	2014	11	113	210	754,521	2.78	2.42, 3.19	12,625	74.15	73.38, 74.91
North	2011	11	16	18	146,460	1.23	0.73, 1.94	1,890	62.70	60.52, 64.88
	2012	31	37	25	262,887	0.95	0.62, 1.40	4,305	55.61	54.13, 57.09
	2013	21	40	29	267,102	1.09	0.73, 1.56	5,728	64.16	62.92, 65.40
	2014	31	40	31	282,170	1.10	0.75, 1.56	9,781	75.56	74.71,76.42
Province	2011	63	227	629	1,640,710	3.83	3.54, 4.15	19,886	47.46	46.76, 48.15
	2012	88	285	613	2,041,421	3.00	2.77, 3.25	42,539	59.18	58.71, 59.65
	2013	90	322	609	2,195,165	2.77	2.56, 3.00	54,573	66.00	65.60, 66.40
	2014	90	355	563	2,498,980	2.25	2.07, 2.45	67,636	72.69	72.36, 73.03

TABLE 2: Correlation between annual hospital-acquired methicillin-resistant *Staphylococcus aureus* (MRSA) incidence and hand hygiene compliance, and the confidence limits calculated with the proposed method

		Correlation Coefficient	P-value	Lower Limit	Upper Limit
Selected Unit	Unit 102 at Foothills Medical Centre	-0.9902	0.0098	-0.9909	0.8538
Selected Site	Foothills Medical Centre	-0.8837	0.1163	-0.9838	-0.1015
Zone	South	-0.7133	0.2867	-0.9321	0.2262
	Calgary	-0.9984	0.0016	-0.9994	-0.7194
	Central	0.1048	0.8952	-0.4176	0.4356
	Edmonton	-0.9595	0.0405	-0.9810	-0.1069
	North	0.3843	0.6157	-0.6995	0.9394
Province		-0.9929	0.0071	-0.9983	-0.8910

DISCUSSION

Why a new method?

While there are many measures of association for rates, correlation is the most commonly used approach. However, correlation technique treats the rates as fixed numbers irrespective of whether the rates are derived from millions of observations or from only a few observations (all sample sizes for our annual rates are 4). Using the traditional method, the information contained within the rates is ignored and the results are misleading.

At the unit level, traditional correlation analyses do not provide consistent or robust results, given the small number of MRSA cases per unit. For instance (Table 2), the General Surgery and Medical Oncology Unit (Unit 102) at Foothills Medical Centre had similar correlation coefficients between the rates (r=-0.9902, P=0.0098) to those derived from the provincial

rates (r=-0.9929, P=0.0071). Based on the traditional Pearson correlation technique the former is significant, but probably due to chance. The numbers of hospital-acquired MRSA cases annually collected from Unit 102 were 6, 5, 4 and 2 for 2011, 2012, 2013 and 2014 respectively. Potential measurement errors may make the real number of cases one case more or less than those collected. In this case, a small amount of variation in the case numbers can introduce a large difference in the hospital-acquired MRSA rate and in the correlation.

In Table2, most of the *P*-values derived with traditional method are consistent with the confidence limits derived with the proposed method. For example, Calgary Zone has a correlation coefficient r=-0.9984 with P=0.0016. Its lower and upper limits are negative. Both the results indicate that the correlation coefficient is statistically significant. However, for Foothills Medical Centre and its Unit 102 the results are contradictory. The *P*-value is based on four pairs of annual rates and used for inferring the correlation result to large population, while the confidence limits are derived from hospital-acquired MRSA incidence rates (which are based on larger number of observations) and used for estimating the variation of the rates due to potential measurement errors. Since the rates were collected from most of the acute care units in Alberta, the results do not need to be inferred to a larger population. Therefore, instead of *P*-values, the confidence limits derived by the proposed method can be used to determine the significances of the correlation coefficients between the rates.

Time-series analyses would be appropriate to analyze time trends in MRSA in relation to hand hygiene compliance. However, this would require a larger number of data points (e.g., quarterly data on MRSA acquisitions and hand hygiene). Only annual data were available for this study.

Previous correlation studies

Because longitudinal data are difficult to collect, reports using correlation analyses with short time sequences are limited. The most common methodologies used for determining the relationship between hand hygiene interventions and the incidence of healthcare-acquired infections were before-and-after observational studies (12, 13). Sroka et al. (14) conducted a systematic review for published before-and-after observational studies. They used the results of six selected studies to detect the relationship between the percent difference of hand hygiene compliance and the percent difference of MRSA before and after the intervention with Spearman correlation test, and concluded that there was no correlation between hand hygiene compliance and MRSA, although the amount of alcohol-based hand rub use was related to MRSA (r=0.778, P=0.014, 9 studies).

Other researchers have also used correlation test to estimate the relationship between hand hygiene and MRSA (15-17). Matsumoto et al. (15) reported a Pearson correlation between increased use of alcohol-based hand rub and decreased MRSA incidence (r^2=0.58). Glove use was also negatively correlated with MRSA (r^2=0.68). Zahar et al. (16) detected a marginally significant negative correlation between hand hygiene compliance and MRSA incidence (r=-0.51, P=0.055). Jayaraman et al. (17) did not find a significant correlation between the rates of hand hygiene and MRSA, partially due to their extremely small sample size for hand hygiene data (20 observations each month). All these correlation analyses were based on a few pairs of rates while taking no account of the information contained in the rates (i.e., magnitudes of numerators and denominators of the rates). If the proposed method were used, the results would be different.

To our knowledge, the proposed methodology is an initial approach for correlation analysis in the area of healthcare epidemiology or applied statistics. Traditional approach to confidence interval estimation (18, 19) uses Fisher's Z transformation (20) of the observed correlation coefficient to construct a confidence interval around the correlation coefficient. This confidence interval is based on the errors that occurred when taking samples from a larger population. Charles (21) suggested an alternative approach to interval estimation, which estimates both sample errors and measurement errors simultaneously. The proposed method, which estimates measurement errors only, is an appropriate method for correlation analysis with data from a whole population.

Limitations

Pearson correlation analysis only looks at the linear relationship between hand hygiene and healthcare-acquired infections. It cannot detect non-linear relationships or multiple effects. MRSA infections have numerous affecting factors, such as a patient's comorbidities, invasive procedures, prior colonization, length of hospital stay and antimicrobial use, not only hand hygiene compliance. As infections can vary greatly with type, source, and severity, examining the MRSA incidence rate needs to include various contributing factors in patient condition and hospital services. Correlation techniques do not consider the complicating factors of MRSA infection and prevention, which may explain why a strong drop in MRSA rate was observed in Central zone despite the fact that hand hygiene level remain the same. Regression analyses would be more powerful if more data were available.

Another limitation of this correlation analysis is the inability to distinguish between explanatory and response variables. It is possible that healthcare providers may have better hand hygiene compliance than they would normally have if the unit has higher hospital-acquired MRSA incidence rates, as they are more likely to be reminded more often and are generally more aware of their own practices. This could explain why the relationship between MRSA incidence and hand hygiene compliance could not be detected from our data using a cross-sectional approach.

CONCLUSIONS

Combining the traditional Pearson correlation technique with the proposed inference method provides a simple and proper method for detecting the longitudinal relationship between healthcare-acquired infection and hand hygiene compliance rates. With the proposed method, information contained in the rates can be fully used for analysis. By using Pearson correlation technique with the proposed inference method we have found

strong negative relationships between hospital-acquired MRSA incidence and hand hygiene compliance longitudinally with statistical significance at provincial, zone and site levels. We did not find any significant correlations at the unit level due to the smaller numbers of MRSA cases. Although correlation analysis has a few limitations, it is a useful technique to detect the relationship between the rates. As the creators of the novel methodology, we expect that the method will be widely used to estimate correlations between any short rate (or mean) series with potential measurement errors and not restricted to hand hygiene and healthcare-acquired infection data.

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