Device-associated infections in Canadian acute-care hospitals from 2009 to 2018

Canadian Nosocomial Infection Surveillance Program

Abstract

Background: Healthcare-associated infections (HAIs) pose a serious risk to patient safety and quality of care. The Canadian Nosocomial Infection Surveillance Program (CNISP) conducts national surveillance of HAIs at sentinel acute-care hospitals across Canada. This report provides an overview of 10 years of Canadian data on the epidemiology of select device-associated HAIs.

Methods: Over 40 hospitals submitted data between 2009 and 2018 for hip and knee surgical site infections (SSIs), cerebrospinal fluid shunt SSIs, paediatric cardiac SSIs and/or central line-associated bloodstream infections (CLABSIs). Counts, rates, patient and hospital characteristics, as well as pathogen distributions and antimicrobial susceptibilities are presented.

Results: A total of 4,300 device-associated infections were reported. Central line-associated bloodstream infections were the most common device-associated HAI reported (n=2,973, 69%) and hip and knee arthroplasty infections were the most common SSIs reported (66% of SSIs). Our findings show decreasing CLABSI rates in neonatal intensive care units (4.2 to 1.9 per 1,000 line-days, p<0.0001) and decreasing knee SSI rates (0.69 to 0.30 infections per 100 surgeries, p=0.007). Rates of device-associated HAIs have remained relatively consistent over the 10-year surveillance period. Overall, 4,599 pathogens were identified from device-associated HAIs; 70% of these were related to CLABSIs. Coagulase-negative staphylococci (29%) and Staphylococcus aureus (14%) were the most frequently reported pathogens. Gram-positive pathogens represented 68% of identified pathogens, gram-negative pathogens represented 22% and fungi represented 9%.

Conclusion: Understanding the national burden of device-associated HAIs is essential for developing and maintaining benchmark rates for informing infection and prevention control and antimicrobial stewardship policies and programs.

Introduction

Healthcare-associated infections (HAIs) pose a serious risk to patient safety and quality of care and contribute to prolonged hospital stays, increased antimicrobial resistance, costs to the health system and unnecessary deaths (1). Risk factors for HAIs include the use of invasive devices, surgical procedures and inappropriate antibiotic use (2). In Canada, surgical site infections (SSIs) affect an estimated 26,000 to 65,000 patients annually (3). In a 2017 Canadian point prevalence study at sentinel hospitals, device-associated infections accounted for 35.6% of all HAIs reported. Of the device-associated infections, SSIs associated with a prosthetic implant accounted for 19.4% and central line-associated bloodstream infections (CLABSIs) accounted for 21.2% (4).

Device-associated HAI antimicrobial susceptibility information has important implications for antibiotic resistance (5); impacting length of stay and healthcare costs (6). Cumulative antibiograms are a valuable resource for clinical decision-making while sensitivity results are pending (7). The risk of device-associated HAIs varies among patient populations and hospital types; patients admitted to the intensive care unit (ICU) are at higher risk of developing an HAI (8).
Understanding the trends in device-associated HAIs is essential to effective infection prevention and control. Drawing on a decade of HAI data (2009–2018) from over 40 sentinel acute-care hospitals across Canada participating in the Canadian Nosocomial Infection Surveillance Program (CNISP), this report provides an epidemiological overview of select device-associated HAIs.

**Methods**

**Design**

Established in 1994, the CNISP, a collaboration between the Public Health Agency of Canada, the Association of Medical Microbiology and Infectious Disease Canada and sentinel hospitals across Canada, conducts national HAI surveillance at sentinel acute-care hospitals across Canada. This report presents data on device-associated HAIs for the following infections: hip and knee SSIs; cerebrospinal fluid shunt SSIs (CSF-shunt-SSIs); paediatric cardiac surgical site infections (paediatric-cardiac-SSIs); and CLABSIs.

**Case definitions**

Device-associated HAIs were defined according to standardized protocols and expert-reviewed case definitions (Appendix 1). Only CLABSIs identified in ICU settings were included in surveillance. Only complex infections, defined as deep incisional and organ space, were included in hip and knee SSI surveillance.

**Data source**

Participating hospitals submitted epidemiological data on CSF-shunt-SSIs and CLABSIs occurring between January 1, 2009 and December 31, 2018. Paediatric-cardiac-SSI surveillance started in January 2010. Hip and knee SSI surveillance started in January 2011. Data submission and case identification were supported by annual training sessions and continuous evaluations of data quality.

**Statistical analysis**

CLABSI rates were calculated by dividing the number of cases by line-day denominators. Hip and knee SSI, CSF-shunt-SSI and paediatric-cardiac-SSI rates were calculated by dividing the number of cases by surgery denominators. Proportions of pathogens were calculated by dividing the number of pathogens by the total number of pathogens identified. Missing and incomplete data were excluded from analyses, therefore denominators may vary. Interquartile ranges (IQR) were calculated. The Mann-Kendall test or negative binomial regression was used to test trends over time. Significance testing was two-tailed and differences were considered significant at p-value ≤0.05. Analyses were conducted using Excel and SAS 9.4.

**Results**

Between 2009 and 2018, over 40 hospitals contributed device-associated HAI data to CNISP, most of which were medium (201–499 bed) adult hospitals (Table 1). Overall, 4,300 device-associated infections were reported. CLABSIs were the most common device-associated HAI (n=2,973, 69%). Hip and knee SSI were the most common type of SSI reported (66% of SSIs, n=871/1,327).

**Table 1: Characteristics of acute-care hospitals participating in device-associated HAI surveillance and frequency of device-associated hospital-acquired infections, 2009–2018**

| Characteristic of hospitals | CSF shunt SSI | Paediatric cardiac SSI | Hip and knee SSI | CLABSI-adult ICU | CLABSI-adult CVICU | CLABSI-PICU | CLABSI-NICU |
|-----------------------------|---------------|------------------------|------------------|------------------|-------------------|-------------|-------------|
| Years of surveillance       | 2009–2018     | 2010–2018              | 2011–2018        | 2009–2018        | 2009–2018         | 2009–2018   | 2009–2018   |
| Number of HAIs reported     | 266           | 190                    | 871              | 1,331            | 192               | 348         | 1,102       |
| Total participating          | 8–14          | 3–4                    | 12–25            | 22–41            | 5–8               | 5–10        | 9–17        |
| Hospital type                |               |                        |                  |                  |                   |             |             |
| Adult*                      | 2–5           | NA                     | 8–16             | 12–27            | 3–7               | NA          | 2–3         |
| Mixed                       | 2–4           | NA                     | 4–9              | 4–14             | 1–2               | 0–4         | 1–6         |
| Paediatric                   | 4–7           | 3–4                    | NA               | NA               | NA                | NA          | 4–6         | 4–8         |
| Hospital size                |               |                        |                  |                  |                   |             |             |
| Small (1–200 beds)           | 3–7           | 2–4                    | 1–2              | 1–4              | 0–1               | 3–5         | 4–7         |
| Medium (201–499 beds)        | 4–8           | 1                      | 7–15             | 10–27            | 2–4               | 1–5         | 1–7         |
| Large (500+ beds)            | 0–1           | NA                     | 5–8              | 5–10             | 2–3               | 0           | 1–3         |
| Total beds (2018)            | 3,558         | 693                    | 9,973            | 16,701           | 3,570             | 2,209       | 5,500       |

Abbreviations: CLABSI, central line-associated bloodstream infection; CSF-shunt SSI, cerebrospinal fluid shunt surgical site infection; CVICU, cardiovascular surgery intensive care unit; HAIs, healthcare-associated infections; ICU, intensive care unit; NA, not applicable; NICU, neonatal intensive care unit; PICU, paediatric intensive care unit; SSI, surgical site infection.

* Seven hospitals classified as “Adult” also had a NICU.

Overall, 4,599 pathogens were identified from device-associated HAI cases between 2014 and 2018; 69.8% of these were related to CLABSIs. Coagulase-negative staphylococci and *Staphylococcus aureus* were the most frequently reported pathogens (Table 2). Gram-positive pathogens represented 68.3% of identified pathogens, gram-negative pathogens represented 22.3% and fungi represented 9.4%.

**Central line-associated bloodstream infections**

Between 2009 and 2018, there were 2,973 reported CLABSIs; the majority of which occurred in adult mixed ICUs (n=1,331, 44.8%) and NICUs (n=1,102, 37.1%). Among CLABSIs identified in adult ICUs, the median age was 63 years (IQR=52–73 years). Males represented 62% of adult CLABSIs. One-third of adult CLABSI patients died within 30 days following the first positive
Among CLABSIs identified in paediatric intensive care units (PICUs), the median age was six months (IQR=2−22 months). Males represented 51% of PICU cases and within 30 days of positive culture, 11% of infected patients had died (n=37/342). Among CLABSIs identified in the neonatal intensive care unit (NICU), the median age at first positive culture was 20 days (IQR=10−45 days). Males represented 57% of NICU cases and within 30 days of positive culture, 8% of infected patients had died (n=88/1,077).

Overall, NICUs had higher rates of CLABSIs (2.7 cases per 1,000 line-days, on average) than PICUs (1.9/1,000 line-days), adult mixed ICUs (1.1/1,000 line-days) and adult cardiovascular surgery ICUs (0.7/1,000 line-days). While rates remained relatively constant for adult ICUs and PICUs, a 54.8% decrease was observed among NICUs (from 4.2 to 1.9/1000 line-days, 2009 to 2018, \( p<0.0001 \)) (Table 3).

### Hip and knee surgical site infections

Between 2011 and 2018, 871 complex hip and knee SSIs were reported; the majority of which were hip surgeries (n=530, 60.8%). Fifty-two percent (n=455) were organ space infections and 47.8% (n=416) were deep incisional infections (Table 4).

| Year | CLABSI rate per 1,000 line-days |
|------|----------------------------------|
|      | Adult mixed ICU | Adult CV-surgery ICU | NICU | PICU |
| 2009 | 1.4 | 0.8 | 4.2 | 2.0 |
| 2010 | 1.1 | 0.9 | 3.9 | 1.7 |
| 2011 | 0.9 | 1.0 | 4.1 | 1.6 |
| 2012 | 1.0 | 1.3 | 3.5 | 1.4 |
| 2013 | 1.1 | 0.5 | 2.8 | 1.3 |
| 2014 | 0.9 | 0.5 | 2.1 | 2.0 |
| 2015 | 1.1 | 0.7 | 2.3 | 2.4 |
| 2016 | 1.0 | 0.5 | 2.3 | 1.7 |
| 2017 | 1.2 | 0.4 | 1.8 | 2.0 |
| 2018 | 1.2 | 0.9 | 1.9 | 2.1 |
| Overall | 1.1 | 0.7 | 2.7 | 1.9 |

Abbreviations: CLABSI, central line-associated bloodstream infection; CV, cardiovascular; ICU, intensive care unit; NICU, neonatal intensive care unit; PICU, paediatric intensive care unit

Median patient age was 69 and 67 years for hip and knee SSIs, respectively. Median time from procedure to infection was 20 days for hip infections and 22 days for knee infections. Upon collection of additional data beginning in 2018, the median length of stay for hip and knee surgeries was four and three days, respectively. Ninety-one percent of patients with a surgical site infection were readmitted following hip or knee arthroplasty (hip, n=83/91, 91.2%; knee, n=33/37, 89.1%) and 64.8% (n=83/128) required a revision surgery. At 30 days post-surgery, one death was reported in 2018 among the hip-SSI patients.

### Table 2: Distribution and rank of the five most frequently reported gram-negative, gram-positive and fungal pathogens, 2009–2018

| Category | Rank | Pathogen | N   | % of total pathogens identified |
|----------|------|----------|-----|--------------------------------|
| Gram-positive | 1     | Coagulase-negative staphylococci | 1,320 | 28.7 |
|           | 2     | Staphylococcus aureus | 653 | 14.2 |
|           | 3     | Enterococcus spp. | 519 | 11.3 |
|           | 4     | Streptococcus | 137 | 3.0 |
|           | 5     | Methicillin-resistant S. aureus | 120 | 2.6 |
| Other gram-positive | | | 392 | 8.5 |
| Gram-negative | 1     | Klebsiella spp. | 226 | 4.9 |
|           | 2     | Escherichia coli | 197 | 4.3 |
|           | 3     | Enterobacter | 170 | 3.7 |
|           | 4     | Pseudomonas aeruginosa | 133 | 2.9 |
|           | 5     | Serratia | 87 | 1.9 |
| Other gram-negative | | | 214 | 4.7 |
| Fungi | 1     | Candida albicans | 210 | 4.6 |
|           | 2     | Other Candida spp. | 199 | 4.3 |
| Other fungi | | | 22 | 0.5 |
| Total | | | 4,599 | 100.0 |

* Up to four pathogens per device-associated hospital-acquired infection were included in the analysis
* Paediatric-cardiac-surgical site infection surveillance started in 2010. Hip and knee surgical site infection surveillance started in 2011
* Coagulase-negative staphylococci include S. lugdunensis, S. haemolyticus, S. epidermidis and S. capitis
* Staphylococcus aureus includes methicillin-susceptible S. aureus and unspecified S. aureus
* Percentage rounded to the nearest whole number

### Table 3: Rate of central line-associated bloodstream infection per 1,000 line days by intensive care unit type, 2009–2018

| Year | Adult mixed ICU | Adult CV-surgery ICU | NICU | PICU |
|------|-----------------|----------------------|------|------|
| 2009 | 1.4 | 0.8 | 4.2 | 2.0 |
| 2010 | 1.1 | 0.9 | 3.9 | 1.7 |
| 2011 | 0.9 | 1.0 | 4.1 | 1.6 |
| 2012 | 1.0 | 1.3 | 3.5 | 1.4 |
| 2013 | 1.1 | 0.5 | 2.8 | 1.3 |
| 2014 | 0.9 | 0.5 | 2.1 | 2.0 |
| 2015 | 1.1 | 0.7 | 2.3 | 2.4 |
| 2016 | 1.0 | 0.5 | 2.3 | 1.7 |
| 2017 | 1.2 | 0.4 | 1.8 | 2.0 |
| 2018 | 1.2 | 0.9 | 1.9 | 2.1 |
| Overall | 1.1 | 0.7 | 2.7 | 1.9 |

Abbreviations: CLABSI, central line-associated bloodstream infection; CV, cardiovascular; ICU, intensive care unit; NICU, neonatal intensive care unit; PICU, paediatric intensive care unit

### Table 4: Frequency of hip and knee surgical site infections by type and rate per 100 surgeries, 2011–2018

| Year | Deep incisional SSI | Organ/Space SSI | All hip and knee SSI |
|------|---------------------|-----------------|----------------------|
|      | Cases (n) | % | Cases (n) | % | Cases (n) | Rate per 100 surgeries |
| Hip arthroplasty | | | | | | |
| 2011 | 18 | 43.9 | 23 | 56.1 | 41 | 0.82 |
| 2012 | 32 | 66.7 | 16 | 33.3 | 48 | 0.73 |
| 2013 | 36 | 57.1 | 27 | 42.9 | 63 | 0.79 |
| 2014 | 36 | 50.7 | 35 | 49.3 | 71 | 0.85 |
| 2015 | 34 | 51.5 | 32 | 48.5 | 66 | 0.75 |
| 2016 | 28 | 41.2 | 40 | 58.8 | 68 | 0.79 |
| 2017 | 34 | 41.5 | 48 | 58.5 | 82 | 0.80 |
| 2018 | 29 | 31.9 | 62 | 68.1 | 91 | 0.87 |
| Overall | 247 | 46.6 | 283 | 53.4 | 530 | 0.80 |
From 2011 to 2018, the rate of hip SSI was stable (from 0.82 to 0.87 infections per 100 surgeries, p=0.26), while the rate of knee SSI decreased significantly (from 0.69 to 0.30 infections per 100 surgeries, p=0.007). *S. aureus* and coagulase-negative staphylococci were the most commonly identified pathogens from hip and knee SSI cases (32% and 17% of identified pathogens, respectively).

**Cerebrospinal fluid shunt surgical site infections**

Between 2009 and 2018, 266 CSF-shunt-SSIs were reported; 143/260 (55%) were identified from new surgeries and 117/260 (45%) were identified from revision surgeries. The median age of cases was 46 years (IQR=29–67 years) for adult patients and 0.6 years (IQR=0.2–6.8 years) for paediatric patients. Females represented 53.4% (n=140/262) of cases. Median days from surgery to infection were 29 days (IQR=14–64 days).

From 2009 to 2018, the overall rate of CSF-shunt-SSI was 3.2/100 surgeries (range: 1.9 to 5.7/100 surgeries, Table 5). Infection rates were similar at paediatric hospitals (n=3.3/100 surgeries) and adult/mixed hospitals (n=3.2/100 surgeries). Coagulase-negative staphylococci and *S. aureus* were the most commonly identified pathogens from CSF-shunt-SSIs (41% and 22% of identified pathogens, respectively).

**Paediatric cardiac surgical site infections**

Between 2010 and 2018, there were 190 paediatric-cardiac-SSIs reported (Table 6). Most cases were superficial infections (58.7%) or organ/space infections (32.3%). The average age of patients with a paediatric-cardiac-SSI was 19 days old (IQR=7–213 days). On average, the time from surgery to date of onset of infection was 10 days (IQR=5–19 days). Three deaths were reported within 30 days of onset of infection (1.6% of cases) but all three deaths were unrelated to the paediatric-cardiac-SSI.

### Table 4: Frequency of hip and knee surgical site infections by type and rate per 100 surgeries, 2011–2018 (continued)

| Year | Deep incisional SSI | Organ/Space SSI | All hip and knee SSI |
|------|---------------------|-----------------|---------------------|
|      | Cases (n) | % | Cases (n) | % | Cases (n) | Rate per 100 surgeries |
|      | Knee arthroplasty |     |     |     |     |     |
| 2011 | 20 | 51.3 | 19 | 48.7 | 39 | 0.69 |
| 2012 | 26 | 52.0 | 24 | 48.0 | 50 | 0.65 |
| 2013 | 21 | 55.3 | 17 | 44.7 | 38 | 0.41 |
| 2014 | 26 | 48.1 | 28 | 51.9 | 54 | 0.56 |
| 2015 | 21 | 47.7 | 23 | 52.3 | 44 | 0.43 |
| 2016 | 15 | 41.7 | 21 | 58.3 | 36 | 0.35 |
| 2017 | 20 | 46.5 | 23 | 53.5 | 43 | 0.36 |
| 2018 | 20 | 54.1 | 17 | 45.9 | 37 | 0.30 |
| Overall | 169 | 49.6 | 172 | 50.4 | 341 | 0.47 |

Abbreviation: SSI, surgical site infection

### Table 5: Cerebrospinal fluid shunt surgical site infection rates per 100 surgeries by hospital type, 2009–2018

| Year | Adult and mixed hospitals | Paediatric hospitals | All hospitals |
|------|---------------------------|---------------------|---------------|
|      | Rate/100 surgeries |       |       |       |
| 2009 | 2.9 | 2.8 | 2.9 |
| 2010 | 3.2 | 3.9 | 3.5 |
| 2011 | 5.0 | 6.3 | 5.7 |
| 2012 | 2.5 | 3.9 | 3.2 |
| 2013 | 2.6 | 2.8 | 2.7 |
| 2014 | 1.6 | 2.6 | 2.0 |
| 2015 | 3.3 | 2.1 | 2.7 |
| 2016 | 4.4 | 2.4 | 3.3 |
| 2017 | 4.6 | 3.2 | 3.9 |
| 2018 | 2.4 | 2.3 | 2.4 |
| Overall | 3.2 | 3.3 | 3.2 |

### Table 6: Paediatric cardiac surgical infection rates by year and infection type, 2010–2018

| Year | Superficial | Organ/space | Deep | All paediatric cardiac surgical site infections |
|------|-------------|-------------|------|-----------------------------------------------|
|      | Cases | % of annual cases | Cases | % of annual cases | Cases | % of annual cases | Cases | Rates/100 surgeries |
| 2010 | 9 | 40.9 | 10 | 45.5 | 3 | 13.6 | 22 | 4.1 |
| 2011 | 8 | 53.3 | 5 | 33.3 | 2 | 13.3 | 15 | 3.1 |
| 2012 | 15 | 83.3 | 2 | 11.1 | 1 | 5.6 | 18 | 2.9 |
| 2013* | 12 | 63.2 | 7 | 36.8 | 0 | 0.0 | 19 | 4.6 |
| 2014 | 11 | 57.9 | 8 | 42.1 | 0 | 0.0 | 19 | 3.5 |
| 2015 | 12 | 63.2 | 6 | 31.6 | 1 | 5.3 | 19 | 3.5 |
| 2016 | 9 | 64.3 | 3 | 21.4 | 2 | 14.3 | 14 | 3.0 |
| 2017 | 17 | 70.8 | 5 | 20.8 | 2 | 8.3 | 24 | 4.4 |
| 2018 | 18 | 46.2 | 15 | 38.5 | 6 | 15.4 | 40 | 7.5 |
| Overall | 111 | 58.7 | 61 | 32.3 | 17 | 9.0 | 190 | 4.1 |

* Excludes one site in 2013 with missing denominator data (number of cases=0 in that year). One case missing infection type info

Overall, the average paediatric-cardiac-SSI rate was 4.1/100 surgeries. While rates remained generally consistent (p=0.35), there was a significant increase in 2018 (n=7.5/100 surgeries, p<0.001) compared to the overall rates from 2010 to 2017.
S. aureus and coagulase-negative staphylococci were the most commonly identified pathogens from paediatric-cardiac-SSIs (43% and 24% of identified pathogens, respectively).

**Antibiogram**

Antimicrobial susceptibility testing results for the most frequently identified gram-positive, gram-negative and fungal pathogens from device-associated HAIs are listed in Table 7. Oxacillin/cloxacillin resistance was found in 13% (n=38/288) of all S. aureus isolates. Meropenem resistance was low among the gram-negative pathogens with 2/36 Klebsiella isolates, 1/33 E. coli isolates resistant and 0/33 Enterobacter isolates resistant to meropenem. Thirty-two vancomycin-resistant Enterococci were identified (n=32/187, 17%, Enterococcus spp.).

**Discussion**

This report describes 4,300 device-associated HAIs reported over ten years of surveillance. With the exception of decreasing CLABSI rates in NICUs and decreasing knee-SSI rates, rates of device-associated HAIs have remained relatively consistent. In general, the most frequently reported pathogens among device-associated HAIs in Canada aligned with results from the United States (US): S. aureus, E. coli and Klebsiella ranked in the top five pathogens in our surveillance and in a 2020 US National Healthcare Surveillance Network (NHSN) report of adult HAIs (including CLABSIs, various SSIs, catheter-associated urinary tract infections and ventilator-associated events) (5).

**Table 7: Antibiogram results from pathogens identified from device-associated hospital-associated infections, 2014–2018**

| Antibiotic | Coagulase-negative staphylococci | S. aureus | Enterococcus spp. | Klebsiella spp. | E. coli | Enterobacter | C. albicans | Candida spp. |
|------------|---------------------------------|-----------|-------------------|----------------|--------|-------------|------------|-------------|
|            | # of resistant | % | # of resistant | % | # of resistant | % | # of resistant | % | # of resistant | % | # of resistant | % | # of resistant | % | # of resistant | % | # of resistant | % | # of resistant | % |
| Amoxicillin | 5/8 | 63 | 2/10 | 20 | 61/235 | 26 | 76/78 | 97 | 56/86 | 65 | 51/55 | 93 | NA | NA | NA | NA |
| Cefazolin | 125/154 | 81 | 17/158 | 11 | NA | NA | 21/58 | 36 | 24/76 | 32 | 47/48 | 98 | NA | NA | NA | NA |
| Ceftriaxone | NA | NA | 1/1 | 9 | NA | NA | 5/6 | 8 | 11/54 | 20 | 24/50 | 48 | NA | NA | NA | NA |
| Clindamycin | 109/193 | 56 | 47/213 | 22 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Ciprofloxacin | 1/7 | 14 | 2/14 | 14 | NA | NA | 6/72 | 8 | 23/68 | 34 | 0/64 | 0 | NA | NA | NA | NA |
| Cloxacillin/Oxacillin | 241/308 | 78 | 38/238 | 16 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Erythromycin | 57/89 | 64 | 34/104 | 33 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Gentamicin | 15/31 | 48 | 2/27 | 7 | 7/58 | 12 | 6/84 | 7 | 11/81 | 14 | 1/14 | 7 | NA | NA | NA | NA |
| Meropenem | NA | NA | NA | NA | NA | NA | 2/36 | 6 | 1/33 | 3 | 0/36 | 0 | NA | NA | NA | NA |
| Piperacillin-tazobactam | NA | NA | NA | NA | NA | NA | 7/60 | 12 | 12/60 | 20 | 21/48 | 44 | NA | NA | NA | NA |
| Penicillin | 85/87 | 98 | 81/86 | 94 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Rifampin | 1/59 | 2 | 0/33 | 0 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Trimethoprim-sulfamethoxazole | 58/147 | 39 | 4/177 | 2 | NA | NA | 5/56 | 9 | 28/59 | 47 | 9/53 | 17 | NA | NA | NA | NA |
| Tobramycin | NA | NA | NA | NA | NA | NA | 6/72 | 8 | 3/80 | 4 | 2/61 | 3 | NA | NA | NA | NA |
| Vancomycin | 3/293 | 1 | 1/140 | 1 | 32/187 | 17 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Amphotericin B | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0/11 | 0 | 0/9 | 0 |
| Caspofungin | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 1/40 | 3 | 0/11 | 0 |
| Fluconazole | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 1/55 | 2 | 19/59 | 32 |

Abbreviation: NA, not available

* Antibiotic/organism combinations with fewer than six tests were excluded
* Coagulase-negative staphylococci include S. lugdunensis, S. haemolyticus, S. epidermidis, S. capitis and S. warneri
* Includes methicillin-susceptible S. aureus and methicillin-resistant S. aureus
Surgical site infections

Hip and knee-SSIs were the most common SSI reported in our surveillance. Similar to results from the European Centre for Disease Prevention and Control, a decreasing trend in knee SSI was observed among CNISP hospitals, while hip SSI remained stable (9). In addition, a US point prevalence study observed a significant reduction in the prevalence of complex SSIs between 2011 and 2015 (10). Our findings indicate that the most common pathogens identified among hip and knee-SSIs were *S. aureus* and coagulase-negative staphylococci, consistent with results from other regions (9,11). Frequent identification of *S. aureus* and coagulase-negative staphylococci may be related to the use of implant devices and contamination from the patient’s endogenous skin flora (5). Hip and knee-SSIs affect an older population as joint replacements typically occur among older adults (12). As populations age, hip and knee joint replacements are rising and are linked to a rise in surgical complications (i.e. prosthetic joint infections) (12). High observed rates of readmission and revision surgery highlight the financial and resource burden placed on the healthcare system due to hip and knee-SSI (13).

Our overall rate of CSF-shunt-SSIs (n=3.2/100 surgeries) is on the lower end of what is reported internationally; a 2012 review found that reported rates of infection vary from 3% to 12% of shunt operations (14). Stratification of our CSF-shunt-SSI data by paediatric or adult hospital showed little difference in infection rates and in pathogen distributions between paediatric and adult/mixed settings. However, a previous study among CNISP hospitals, conducted between 2000 and 2002, had identified that CSF-shunt-SSIs were more common in children than in adults (15). In this earlier study, the infection rate among paediatric patients was higher than found in this study (4.9% of surgeries in 2000–2002 versus 3.3% 2009–2018) suggesting that SSI rates among paediatric populations have decreased.

Limited literature on paediatric-cardiac-SSI, differences in patient populations and lengths of follow-up makes direct comparisons difficult, but our overall rate of paediatric-cardiac-SSIs (n=4.1/100 surgeries) is similar to the ranges in infection rates reported elsewhere. A 2009–2012 intervention study of neonates undergoing cardiac surgery conducted at a tertiary-care centre in New York found pre and post-intervention paediatric-cardiac-SSI rates of 6.2/100 surgeries and 5.8/100 surgeries, respectively (16). In a 2012–2013 French study of patients younger than one year of age, 19% of patients presented with an SSI (17). A 2010–2012 retrospective study of paediatric patients (younger than 18 years of age) undergoing cardiac surgery at two hospitals in New York found a rate of 1.4 HAIs/100 procedures (18).

There was a significant increase in the rate of paediatric-cardiac-SSI in 2018 to 7.5/100 surgeries. This increase was limited to two hospital sites, where investigations are ongoing. This increase should be interpreted with caution as rates are calculated from a small number of cases and may be sensitive to random fluctuation at individual hospitals.

Central line-associated bloodstream infections

Central line-associated bloodstream infections were the most commonly reported device-associated HAI (69% of included HAIs); however, it is important to note that the number of hospitals participating in the surveillance of each HAI differs and that the surveillance periods for some HAIs were shorter. In a point prevalence study of HAIs, the frequencies of SSIs (19%) and CLABSIs (21%) were very similar (5).

There were no substantive changes in CLABSI rates among surveyed adult ICUs or PICUs; however, there was a 55% decrease in CLABSI rates among NICUs. The methods of measurement differ, but CLABSI rates in NICUs have also decreased in the US; between 2010 and 2016, standardized incidence ratios (defined as the change in relation to the number of CLABSIs per central line days) for CLABSIs in NICUs and rates of central line use in NICUs decreased in the US (19). In addition, CLABSI rates in other ICU types in the US also decreased between 2010 and 2016 (19). Updated NHSN guidelines have been credited for the reduction in rates in the US (20). It is possible that improvements to rates in Canada occurred prior to the study period.

Our overall CLABSI rates in adult ICUs (0.7 and 1.1/1,000 central-line-days for cardiovascular intensive care units and mixed ICUs, respectively) are similar to ranges reported in the US and Australia. In the US, the CLABSI rate in ICUs was estimated to be 0.8/1,000 central-line-days in 2010–2015 (21). In Australia, annual rates of CLABSIs in ICUs ranged between 0.9 and 1.7/1,000 central-line-days in 2010–2013 (22). Higher rates are seen in other regions; a large surveillance study of 703 intensive care units in Latin America, Europe, Eastern Mediterranean, Southeast Asia and Western Pacific reported a CLABSI rate of 4.1/1,000 central-line-days between January 2010 and December 2015 (21).

Antibiogram

The percentage of *S. aureus* isolates that were methicillin-resistant *S. aureus* (MRSA) in this study (13%) is similar to what was reported from a Swiss surveillance network where 8% of *S. aureus* SSI cases were MRSA in 2010–2015 (23). Higher rates of MRSA have been reported elsewhere. In the US, 42% to 48% of *S. aureus* isolates from HAIs (including SSI, CLABSI and others) in NHSN surveillance were MRSA (5). A Japanese study of SSIs at 27 medical centres, found that 72% of *S. aureus* isolates were MRSA in 2010 (24).

Of identified *Enterococcus* spp., 17% were vancomycin-resistant *Enterococci* in our surveillance. In NHSN surveillance in the US, 8.5% of *Enterococcus faecalis* and 84.5% of *Enterococcus faecium* pathogens identified from CLABSIs in ICUs were vancomycin-resistant *Enterococci* in 2015–2017 (5).
Meropenem resistance was low among the gram-negative pathogens with 2/36 (6%) Klebsiella isolates and 1/33 (3%) E. coli isolates resistant to meropenem. In the US, the percent of carbapenem-resistant Enterobacteriaceae among Klebsiella spp. ranged from 3.1% (among SSIs) to 6.9% (among expanded list of device-associated infections); the percent of carbapenem-resistant Enterobacteriaceae among E. coli ranged from 0.6% (among SSIs) to 0.7% (among expanded list of device-associated infections) (5).

Strengths and limitations
The strength of this study lies in the standardized collection of detailed data from a large network of sentinel hospitals over a decade. While the CNISP network extends across Canada, participating hospitals may not be representative of the general Canadian inpatient population; hospitals participating in CNISP tend to be larger, teaching hospitals in urban centres. The CNISP is currently undergoing a recruitment process to increase representativeness and bed coverage, especially in northern, rural and indigenous populations. The CNISP’s data, although standardized, may be sensitive to changes in hospital participation, infection prevention and control practices and the application of surveillance definitions. Differences in surveillance protocols and case definitions limit the ability to compare data from other countries. However, the data presented in this report are routinely used by Canadian hospitals for benchmarking.

For CLABSI surveillance, we do not have data on infections occurring outside of ICU settings; however, in the US, CLABSIs outside of the ICU setting represented 55% of all CLABSIs (19).

Conclusion
This report provides an updated summary of rates, pathogen distributions and antimicrobial resistance among select device-associated HAIs and relevant pathogens. Understanding the national burden of device-associated HAIs is essential for developing and maintaining benchmark rates for informing infection and prevention control and antimicrobial stewardship policies and programs.

Authors’ statement
Canadian Nosocomial Infection Surveillance Program hospitals provided expertise in the development of protocols in addition to the submission of epidemiological data. Epidemiologists from the Public Health Agency of Canada were responsible for the conception, analysis, interpretation, drafting and revision of this paper.

Competing interests
None.

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Appendix 1: Case definitions

Central line-associated bloodstream infection (CLABSI)

Only central line-associated bloodstream infections (BSIs) related to an intensive care unit (ICU) admission were included in surveillance.

BSI case definition:

BSI is NOT related to an infection at another site and it meets one of the following criteria:

Criterion 1: Recognized pathogen cultured from at least one blood culture, unrelated to infection at another site.

OR

Criterion 2: At least one of: fever (>38°C core), chills, hypotension; if aged <1 year: fever (>38°C core), hypothermia (<36°C core), apnea, or bradycardia AND common skin contaminant (see list below) cultured from ≥2 blood cultures drawn on separate occasions, or at different sites, unrelated to infection at another site. Different sites may include peripheral veins, CVCs, or separate lumens of a multilumen catheter. Different times include two blood cultures collected on the same or consecutive calendar days via separate venipunctures or catheter entries. The collection date of the first positive blood culture is the date used to identify the date of positive culture. Two positive blood culture bottles filled at the same venipuncture or catheter entry constitute only one positive blood culture.

CLABSI case definition:

A laboratory-confirmed bloodstream infection where a central line catheter (CL) or umbilical catheter (UC) was in place for >2 calendar days on the date of the positive blood culture, with day of device placement being Day 1. If admitted or transferred into a facility with a CL/UC in place (e.g. tunneled or implanted central line), day of first access is considered Day 1.

AND

A CL or UC was in place on the date of the positive blood culture or the day before. If a CL or UC was in place for >2 calendar days and then removed, the BSI criteria must be fully met on the day of discontinuation or the next day. If the patient is admitted or transferred into the ICU with a CL in place, the day of first access is considered Day 1. “Access” is defined as line placement, infusion or withdrawal through the line.

ICU-related case definition:

CLABSI onset during ICU stay and the CL has been in place >2 calendar days. The CLABSI would be attributable to the ICU if it occurred on the day of transfer or the next calendar day after transfer out of the ICU.

Common skin contaminant:

Diphtheroids, Corynebacterium spp., Bacillus spp., Propionibacterium spp., coagulase-negative staphylococci (including S. epidermidis), viridans group streptococci, Aerococcus spp., Micrococcus spp. and Rhodococcus spp.

Hip and knee surgical site infection (SSI)

Only complex surgical site infections (deep incisional or organ/space) following hip and knee arthroplasty were included in surveillance.

A deep incisional SSI must meet the following criterion:

Infection occurs within 90 days after the operative procedure and the infection appears to be related to the operative procedure and involves deep soft tissues (e.g. facial and muscle layers) of the incision and the patient has at least ONE of the following:
1. Purulent discharge from the deep incision but not from the organ/space component of the surgical site.
2. Deep incision that spontaneously dehisces or is deliberately opened by the surgeon and is culture-positive or not cultured when the patient has at least one of the following signs or symptoms: fever (>38°C), or localized pain or tenderness. A culture-negative finding does not meet this criterion.
3. An abscess or other evidence of infection involving the deep incision is found on direct examination, during reoperation, or by histopathologic or radiologic examination.
4. Diagnosis of a deep incisional SSI by a surgeon or attending physician.

An organ/space SSI must meet the following criterion:

Infection occurs within 90 days after the operative procedure and the infection appears to be related to the operative procedure and infection involves any part of the body, excluding the skin incision, fascia, or muscle layers, that is opened or manipulated during the operative procedure and patient has at least ONE of the following:
1. Purulent drainage from a drain that is placed through a stab wound into the organ/space.
2. Organisms isolated from an aseptically obtained culture of fluid or tissue in the organ/space.
3. An abscess or other evidence of infection involving the organ/space that is found on direct examination, during reoperation, or by histopathologic or radiologic examination.
4. Diagnosis of an organ/space SSI by a surgeon or attending physician.

**Cerebrospinal fluid shunt surgical site infection**

Only patients who underwent a placement or revision of a cerebrospinal fluid (CSF) shunting device and the infection occurred within one year of surgery were included in surveillance.

**CSF shunt-associated surgical site infection case definition:**

A patient is identified as having CSF shunt SSI if the patient meets the following criteria:

- **Criterion 1:** An internalized CSF shunting device is in place
- **Criterion 2:** A bacterial or fungal pathogen(s) is identified from the cerebrospinal fluid
- **Criterion 3:** The pathogen is associated with at least ONE of the following:
  1. Fever (temperature ≥38°C)
  2. Neurological signs or symptoms
  3. Abdominal signs or symptoms
  4. Signs or symptoms of shunt malfunction or obstruction

**Paediatric cardiac surgery surgical site infection**

Only surgical site infections following open-heart surgery with cardiopulmonary bypass among paediatric patients (<18 years of age) were included in surveillance.

**A superficial incisional SSI must meet the following criterion:**

Infection occurs within 30 days after the operative procedure and involves only skin and subcutaneous tissue of the incision and at least ONE of the following:

1. Purulent drainage from the superficial incision.
2. Organisms isolated from an aseptically-obtained culture of fluid or tissue from the superficial incision.
3. At least ONE of the following signs or symptoms of infection:
   - Pain or tenderness, localized swelling, redness, or heat and the superficial incision is deliberately opened by surgeon, and is culture-positive or not cultured. A culture-negative finding does not meet this criterion
   - Diagnosis of superficial incisional SSI by the surgeon or attending physician

**A deep incisional SSI must meet the following criterion:**

Infection occurs within 90 days after the operative procedure and the infection appears to be related to the operative procedure and involves deep soft tissues (e.g. facial and muscle layers) of the incision and the patient has at least ONE of the following:

1. Purulent drainage from the deep incision but not from the organ/space component of the surgical site.
2. Deep incision spontaneously dehisces or is deliberately opened by the surgeon and is culture-positive or not cultured when the patient has at least one of the following signs or symptoms: fever (>38°C), or localized pain or tenderness. A culture-negative finding does not meet this criterion.
3. An abscess or other evidence of infection involving the deep incision is found on direct examination, during reoperation, or by histopathologic or radiologic examination.
4. Diagnosis of a deep incisional SSI by a surgeon or attending physician.

**An organ/space SSI must meet the following criterion:**

Infection occurs within 90 days after the operative procedure and the infection appears to be related to the operative procedure and infection involves any part of the body, excluding the skin incision, fascia, or muscle layers, that is opened or manipulated during the operative procedure and the patient has at least ONE of the following:

1. Purulent drainage from a drain that is placed through a stab wound into the organ/space.
2. Organisms isolated from an aseptically-obtained culture of fluid or tissue in the organ/space.
3. An abscess or other evidence of infection involving the organ/space that is found on direct examination, during reoperation, or by histopathologic or radiologic examination.
4. Diagnosis of an organ/space SSI by a surgeon or attending physician.