Research

Emerging antimicrobial resistance among *Escherichia coli* strains in bloodstream infections in Toronto, 2006–2016: a retrospective cohort study

Sophie Mineau MD, Robert Kozak PhD, Melissa Kissoon BSc, Aimee Paterson MSc, Anthony Oppedisano BSc, Firas Douri MSc, Kate Gogan, Barbara M. Willey ART, Allison McGeer MD MSc, Susan M. Poutanen MD MPH

Abstract

Background: Enterobacteriaceae that produce extended-spectrum β-lactamase (ESBL) have emerged as a serious threat, with variable rates depending on geographic region. We determined the prevalence of ESBL-producing *Escherichia coli*, *Klebsiella pneumoniae*, *K. oxytoca* and *Proteus mirabilis* in bloodstream infections in Toronto from 2006 through 2016.

Methods: All patients with *E. coli*, *K. pneumoniae*, *K. oxytoca* and *P. mirabilis* isolated from blood in a tertiary care microbiology laboratory in Toronto between 2006 and 2016 (1 isolate per species per patient per year) were included in this retrospective cohort study. Organisms were identified by conventional methods, and susceptibility testing was performed according to Clinical and Laboratory Standards Institute standards. Screening for ESBL and phenotypic confirmatory testing were done with a modified Clinical and Laboratory Standards Institute method. ST131 clonal type was determined by means of an established protocol.

Results: The proportion of ESBL-producing *E. coli* isolates increased significantly between 2006 and 2016, from 6.4% (19/296) to 17.3% (89/513) ($p < 0.001$). This trend was seen in both intensive care units and emergency departments. Concurrently, the proportion of ST131 among ESBL-producing *E. coli* also increased significantly, from 31.6% (6/19) in 2006 to 73.0% (65/89) in 2016 ($p = 0.03$). Among ESBL-producing *E. coli,* significant resistance was noted to multiple antimicrobial classes. Comparable increases in the proportion of ESBL-producing *K. pneumoniae*, *K. oxytoca* and *P. mirabilis* were not noted.

Interpretation: We observed a significant increase in the proportion of ESBL-producing *E. coli* in bloodstream infections in Toronto temporally correlated with an increase in the ST131 clonal type. Recognition of this dramatic rise is important to inform empiric antibiotic treatment.

The increase in antimicrobial-resistant organisms has reached alarming proportions. The Public Health Agency of Canada has stated that antimicrobial resistance is an increasingly serious threat to global public health.[1] The World Health Organization identified 12 bacterial groups that are of great concern.[2] The Centers for Disease Control and Prevention identified 18 microorganisms that pose urgent, serious and concerning threats.[3] Enterobacteriaceae that produce extended-spectrum β-lactamase (ESBL) are included on their lists as a "Priority 1: Critical" organism[2] or a "serious threat."[3] Within the Enterobacteriaceae, ESBL-producing *Escherichia coli* is a frequent cause of infection, with bloodstream infections being associated with substantial mortality rates (14%–30%).[4–6] Extended-spectrum β-lactamases are enzymes that are capable of hydrolyzing most β-lactam antimicrobials, and the plasmids on which they are transported frequently contain other resistance genes.[7,8] This leaves few treatments available to physicians and increases the likelihood of *E. coli*'s developing resistance to all available drugs.

The prevalence of ESBL production among *E. coli* isolates has increased worldwide and varies between regions. Rates as high as 70% have been reported in regions in Southeast Asia.[9,10] There is a paucity of recent published Canadian data. Historically, the prevalence of ESBL production in *E. coli* in

Canada was less than 5% until the last decade.[11] Peirano and colleagues[12] reported a rate of 14% among bloodstream *E. coli* isolates in 2010, and a national rate of 7.1% among *E. coli* from blood, urine, respiratory and wound specimens combined collected from 2007 to 2011 was reported as part of the CANWARD national surveillance study.[11] In both studies, these increases correlated with an increased prevalence of the ST131 clone of *E. coli*, which is thought to be a driving force behind the rise in ESBLs worldwide.[7,13] Identifying increases in ESBL prevalence is important to inform empiric treatment, as inappropriate therapy has been linked to worse outcomes.[14–16] The purpose of our study was to determine the local prevalence of ESBL-producing *E. coli*, *Klebsiella pneumoniae*, *K. oxytoca* and *Proteus mirabilis* among blood culture isolates over the last 11 years in the Toronto region.

Methods

Design and setting

This retrospective cohort study was performed through the University Health Network/Sinai Health System Department of Microbiology's large tertiary care academic microbiology laboratory, which serves 4 acute care hospital sites, 4 rehabilitation centres and 3 long-term care/palliative/mental health sites in Toronto. With the exception of a neonatal intensive care unit, the population served is an adult population.

Study participants and bacterial isolates

All patients with bacteremia due to *E. coli*, *K. pneumoniae*, *K. oxytoca* or *P. mirabilis* between Jan. 1, 2006, and Dec. 31, 2016 at the University Health Network and Sinai Health System were included in this study. The condition of all patients contributing blood culture isolates remained stable over the 11-year period. We reviewed the records of all patients with *E. coli*, *K. pneumoniae*, *K. oxytoca* or *P. mirabilis* isolates recovered from blood cultures in the laboratory between 2006 and 2016 as identified in the laboratory information system. Following standard Clinical and Laboratory Standards Institute recommendations for annual antibiograms so that data are representative of typical antibiograms,[17] we included 1 isolate per species per patient per year. Organisms isolated between January 2006 and March 2013 were identified with the Vitek 2 system (bioMérieux), and organisms isolated from April 2013 to December 2016 were identified with the Vitek MS MALDI-TOF (matrix-assisted laser desorption ionization — time of flight) mass spectrometry system (bioMérieux).

Antimicrobial susceptibility testing

Antimicrobial susceptibility testing was performed at the time of isolation with the Vitek 2 system or disk diffusion (Oxoid) according to Clinical and Laboratory Standards Institute standards current at the time of testing.[18] All isolates were tested for susceptibility to ciprofloxacin, trimethoprim–sulfamethoxazole, tobramycin, gentamicin, and either meropenem or imipenem. Ertapenem susceptibility results were available from 2009 to 2016 only.

Extended-spectrum β-lactamase screening and phenotypic confirmatory testing

Before October 2015, *E. coli*, *K. pneumoniae*, *K. oxytoca* and *P. mirabilis* isolates were screened for ESBL production as part of routine laboratory procedures. All isolates with a cefpodoxime minimum inhibitory concentration of 1 mg/L or greater with the Vitek 2 system were considered screen-positive. A double-disk test was used for phenotypic confirmation of all screen-positive isolates by means of a modified protocol based on the work of M'Zali and colleagues.[19] Mueller–Hinton agar was inoculated with 0.5 McFarland bacterial suspension, and an amoxicillin–clavulanic acid disk was placed in the centre; cefpodoxime, ceftriaxone, ceftazidime and aztreonam disks were placed around it, with 15 mm between disk edges. After 18–24 hours of incubation, class A ESBL production was identified by potentiation of the inhibition zone around the amoxicillin–clavulanic acid disk near any of the surrounding disks. After October 2015, susceptibility results were reported based on Clinical and Laboratory Standards Institute interpretations with the Vitek 2 system. All *E. coli*, *K. pneumoniae*, *K. oxytoca* and *P. mirabilis* isolates from this period that were or were not susceptible to ceftriaxone were subcultured twice from stock stored in glycerol broth at –80°C, and ESBL production was identified retrospectively by means of the double-disk test. *K. oxytoca* isolates with a phenotype suggestive of K1 β-lactamase hyperproduction (positive with the double-disk test but susceptible to ceftazidime) were considered non–class-A ESBLs. Isolates that could not be recovered were excluded from the study.

ST131 detection among *E. coli* producing extended-spectrum β-lactamase

All *E. coli* isolates from 2006 through 2016 were subcultured twice from stock stored in glycerol broth at –80°C, and DNA extraction was completed with a boiled lysate protocol.[20] ST131 clones were identified by means of a polymerase chain reaction assay that targeted the *pabB* gene based on the method previously described by Clermont and colleagues.[21] Isolates that could not be recovered were excluded from the ST131 analysis.

Statistical analysis

We used the χ^2 test for trends to analyze trends in susceptibility, proportion of ESBL-producing isolates and proportion of ST131 *E. coli* isolates over the study period. We used the Fisher exact test to analyze differences in susceptibility between ESBL-producing and non–ESBL-producing *E. coli*. All analyses were conducted with GraphPad InStat (GraphPad Software). We performed analysis for all blood culture isolates and carried out subset analyses for intensive care unit and emergency department isolates. A 2-sided *p* value of < 0.05 was considered statistically significant.

Ethics approval

This study did not involve patients or accessing patients' medical records; thus, ethics review was not needed.

Results

During the study period, 6754 patients (3427 males [50.7%], 3327 females [49.3%]) met the study inclusion criteria. They had a total of 4615 *E. coli*, 1541 *K. pneumoniae*, 261 *K. oxytoca* and 342 *P. mirabilis* blood culture isolates. One *E. coli* isolate and 1 *K. pneumoniae* isolate from 2016 were excluded because of a presumed loss of the resistance plasmid detected on ESBL confirmatory testing, and 2 *K. pneumoniae* isolates from 2016 were excluded as they could not be recovered from the glycerol stock; this left a total of 6755 isolates that could be analyzed with regard to ESBL production. Ten ESBL-producing *E. coli* isolates (1 from each of 2008, 2010 and 2013, 2 from 2009 and 5 from 2011) could not be recovered from the glycerol stock and were excluded from ST131 analysis.

Extended-spectrum β-lactamase production

E. coli (542 [11.7%]) and *K. pneumoniae* (81 [5.3%]) isolates that produced ESBL predominated. There were 10 (3.8%) ESBL-producing *K. oxytoca* isolates and 3 (0.9%) ESBL-producing *P. mirabilis* isolates.

Trends in extended-spectrum β-lactamase production

E. coli

The proportion of ESBL-producing *E. coli* isolates increased significantly over the study period, from 6.4% (19/296) in 2006 to 17.3% (89/513) in 2016 ($p < 0.001$, χ^2 test for trend) (Table 1, Figure 1). This trend was observed in both the intensive care unit and the emergency department, where the proportion of ESBL-producing *E. coli* isolates increased from 11.1% (1/9) to 25.8% (8/31) ($p = 0.02$, χ^2 test for trend) and from 3.3% (6/180) to 14.8% (47/318) ($p < 0.001$, χ^2 test for trend), respectively (Table 2, Figure 1). In addition, the fre-

quency of the ST131 clonal type within ESBL-producing *E. coli* isolates increased from 31.6% (6/19) to 73.0% (65/89) over the study period ($p = 0.03$, χ^2 test for trend) (Table 1, Figure 1).

K. pneumoniae, K. oxytoca and P. mirabilis

During the study period, ESBL production among *K. pneumoniae* isolates showed an upward trend, from 5.0% (6/120) of isolates in 2006 to 9.2% (18/196) in 2016 ($p = 0.04$, χ^2 test for trend). The proportion of ESBL-producing *K. oxytoca* isolates decreased ($p = 0.002$, χ^2 test for trend), although the absolute number of ESBL-producing isolates remained low throughout the study period. The proportion of ESBL-producing *P. mirabilis* isolates remained relatively stable (Table 1). Owing to the small number of these isolates, we did not perform subset analysis of trends in the intensive care unit and the emergency department.

Antimicrobial susceptibility

E. coli

There was a significant decrease over the study period in *E. coli* susceptibility to ceftriaxone ($p < 0.001$, χ^2 test for trend) and ciprofloxacin ($p = 0.008$, χ^2 test for trend). Rates of susceptibility to other antimicrobial classes remained relatively stable (Figure 2, A). Susceptibility to ciprofloxacin, trimethoprim–sulfamethoxazole, tobramycin and gentamicin were significantly lower in ESBL-producing *E. coli* than in non–ESBL-producing *E. coli* in 2016 (Table 3). Susceptibility to ertapenem and meropenem/imipenem did not differ significantly between ESBL-producing and non–ESBL-producing *E. coli*. Among the former, a significant increase in aminoglycoside susceptibility was noted between 2006 and 2016 ($p < 0.001$ for both tobramycin and gentamicin, χ^2 test for trend). Susceptibility to ciprofloxacin, trimethoprim–sulfamethoxazole, ertapenem and

Table 1: Proportion of *Escherichia coli, Klebsiella pneumoniae, K. oxytoca* and *Proteus mirabilis* blood culture isolates that produced extended-spectrum β-lactamase, including proportion of ST131 clonal type within *E. coli* isolates that produced extended-spectrum β-lactamase, 2006–2016

Organism	Year; no. (%) of isolates											p value*
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
Escherichia coli	19/296 (6.4)	13/309 (4.2)	29/355 (8.2)	28/376 (7.4)	33/394 (8.4)	51/428 (11.9)	58/457 (12.7)	81/485 (16.7)	65/485 (13.4)	76/516 (14.7)	89/513 (17.3)	< 0.001
Klebsiella pneumoniae	6/120 (5.0)	5/109 (4.6)	5/87 (5.7)	0/115 (0.0)	6/139 (4.3)	9/136 (6.6)	4/129 (3.1)	8/162 (4.9)	11/154 (7.1)	9/191 (4.7)	18/196 (9.2)	0.04
K. oxytoca	0/4 (0.0)	3/20 (15.0)	3/23 (13.0)	1/25 (4.0)	1/22 (4.5)	0/18 (0.0)	1/23 (4.3)	0/23 (0.0)	1/30 (3.3)	0/40 (0.0)	0/33 (0.0)	0.002
Proteus mirabilis	0/23 (0.0)	0/30 (0.0)	0/26 (0.0)	0/27 (0.0)	0/34 (0.0)	0/31 (0.0)	2/38 (5.3)	0/30 (0.0)	0/32 (0.0)	0/36 (0.0)	1/35 (2.8)	0.3
ST131 clonal type among ESBL-producing *E. coli*	6/19 (31.6)	8/13 (61.5)	20/28 (71.4)	16/26 (61.5)	19/32 (59.4)	27/46 (58.7)	36/58 (62.1)	54/80 (67.5)	40/65 (61.5)	48/76 (63.2)	65/89 (73.0)	0.03

Note: ESBL = extended-spectrum β-lactamase.
*For the trend observed between 2006 and 2016 (χ² test for trend).
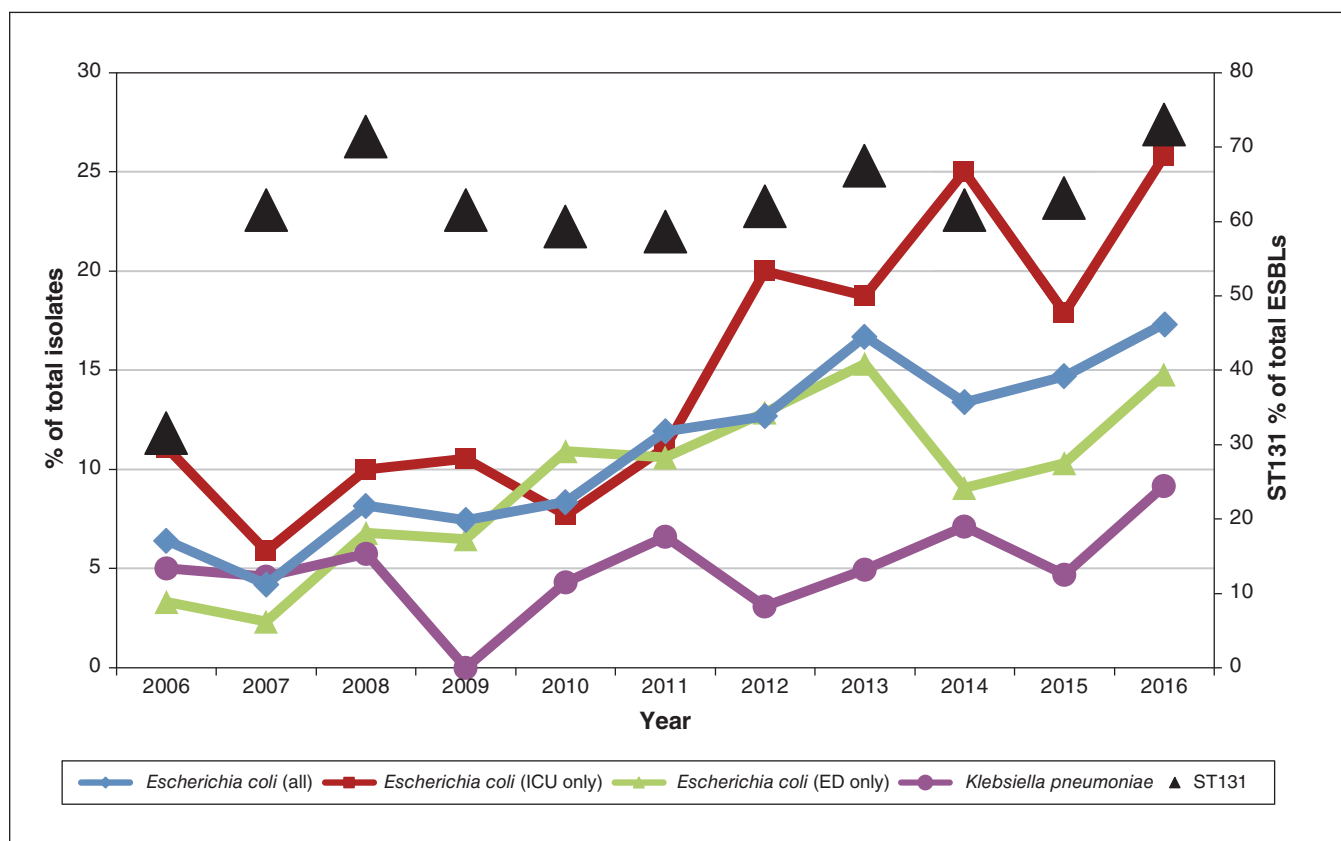
Figure 1: Proportion of *Escherichia coli* and *Klebsiella pneumoniae* blood culture isolates that produced extended-spectrum β-lactamase (ESBL), altogether and in intensive care units (ICUs) and emergency departments (EDs), and proportion of ST131 clonal type within *E. coli* isolates that produced ESBL, 2006–2016.

Table 2: Proportion of *Escherichia coli* blood culture isolates that produced extended-spectrum β-lactamase in intensive care units and emergency departments, 2006–2016

Setting	Year; no. (%) of isolates											*p* value*
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
Intensive care unit	1/9 (11.1)	1/17 (5.9)	1/10 (10.0)	2/19 (10.5)	2/26 (7.7)	2/18 (11.1)	5/25 (20.0)	6/32 (18.8)	7/28 (25.0)	7/39 (17.9)	8/31 (25.8)	0.02
Emergency department	6/180 (3.3)	4/172 (2.3)	14/206 (6.8)	13/201 (6.5)	14/128 (10.9)	28/264 (10.6)	35/272 (12.9)	44/287 (15.3)	27/298 (9.1)	31/300 (10.3)	47/318 (14.8)	< 0.001

*For the trend observed between 2006 and 2016 (χ^2 test for trend.)

meropenem/imipenem remained relatively stable among ESBL-producing *E. coli* (Figure 2, B).

K. pneumoniae, K. oxytoca and *P. mirabilis*

Rates of *K. pneumoniae, K. oxytoca* and *P. mirabilis* susceptibility to ciprofloxacin, trimethoprim–sulfamethoxazole, tobramycin, gentamicin, ertapenem and meropenem/imipenem remained relatively stable over the study period. In 2016, *K. pneumoniae* the rates of global susceptibility to these antibiotics were 90.8%, 85.2%, 93.4%, 95.9%, 100.0% and 99.5%, respectively. For *K. oxytoca*, in 2016, the susceptibility rate was 100.0% for all 6 antimicrobial agents, and for *P. mirabilis*, the

susceptibility rates were 71.4%, 77.1%, 97.1%, 97.1%, 100.0% and 100.0%, respectively. Given the small numbers of each of these species, we did not perform subset analysis of ESBL producers compared to non–ESBL-producers.

Interpretation

We found a significant increase in the proportion of ESBL-producing *E. coli* isolates in bloodstream infections from 2006 to 2016 in Toronto. The most striking increase was seen in the intensive care units served by our laboratory, where 25.8% of *E. coli* isolates were ESBL producers in 2016, compared to
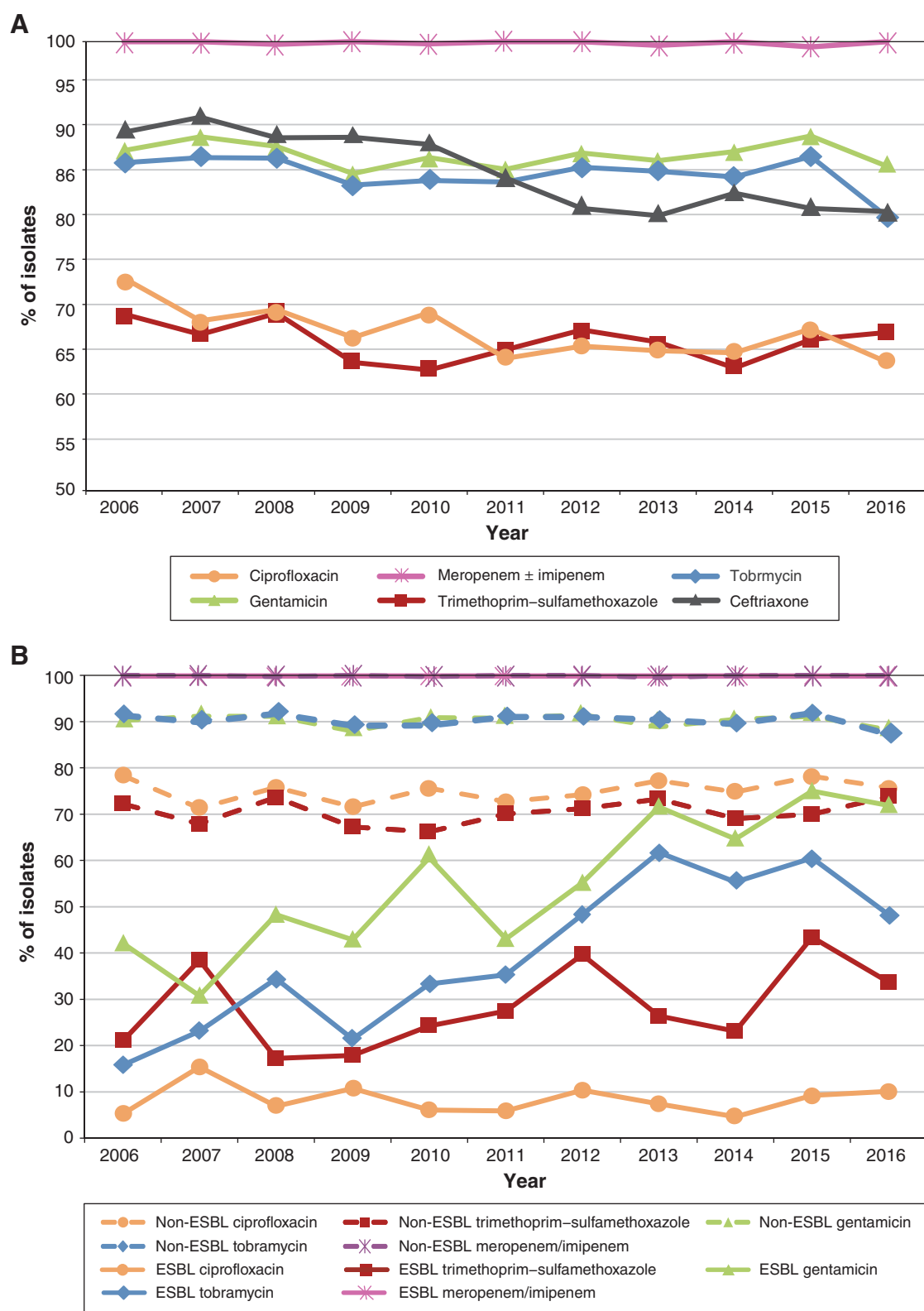
Figure 2: Antimicrobial susceptibilities of *Escherichia coli* blood culture isolates, 2006–2016. (A): Extended-spectrum β-lactamase (ESBL) producers and non–ESBL-producers combined. (B): Non–ESBL-producers and ESBL producers separately.

Table 3: Susceptibility to selected antimicrobial agents of all *Escherichia coli* isolates, *E. coli* that did not produce extended-spectrum β-lactamase and *E. coli* that produced extended-spectrum β-lactamase, 2016

Agent	% of isolates susceptible			
	All *Escherichia coli* $n = 513$	Non–ESBL-producing *Escherichia coli* $n = 424$	ESBL-producing *Escherichia coli* $n = 89$	p value*
Ciprofloxacin	64.3	75.7	10.1	< 0.001
Trimethoprim–sulfamethoxazole	66.9	73.8	33.7	< 0.001
Tobramycin	80.5	87.3	48.3	< 0.001
Gentamicin	85.4	88.2	71.9	< 0.001
Ceftriaxone	81.3	98.3	0.0	< 0.001
Ertapenem	99.8	100.0	98.9	0.2
Meropenem/imipenem	100.0	100.0	100.0	–

Note: ESBL = extended spectrum β-lactamase.
*For the difference in susceptibility between non–ESBL-producing *E. coli* and ESBL-producing *E. coli* (Fisher exact test).

11.1% in 2006. The proportion of ESBL-producing *E. coli* isolates also increased significantly in the emergency departments served by our laboratory, with a prevalence of 14.8% in 2016 compared to 3.3% in 2006. The fact that an increase was observed in both settings suggests that this phenomenon is not being driven by 1 ward alone and is likely being driven by outpatients as well as inpatients. In parallel with this rise in prevalence of ESBL producers, the proportion of the ST131 clone among ESBL-producing *E. coli* also increased, from 31.6% in 2006 to 73.0% in 2016. Interestingly, we noted a significant increase in aminoglycoside susceptibility in ESBL-producing *E. coli* between 2006 and 2016. This may reflect a change in circulating strains or a change in resistance-selective pressure owing to changing prescribing practices.

Clinicians should be aware of their local ESBL prevalence rates and susceptibility patterns as this informs their empiric choice of treatment, preventing delays in appropriate therapy.[15,16] In 2016, 17.3% of blood culture *E. coli* isolates from centres served by our laboratory were ESBL-positive; this suggests that ceftriaxone may not be an appropriate empiric choice for treatment of suspected *E. coli* bacteremia in our patient population, especially immunocompromised patients and those presenting with sepsis, in whom agents with lower resistance rates should generally be used. Clinicians should work with their local antimicrobial stewardship teams to integrate local data, guidelines and the clinical status of patients to inform empiric treatment decisions.

Our finding of increasing ESBL prevalence is in keeping with the global trend of rising antimicrobial resistance among gram-negative bacteria.[22] The importance of regional data is illustrated by the study by Peirano and colleagues,[12] which showed a prevalence of ESBL production of 14% among *E. coli* blood culture isolates in the Calgary region in 2010, in

contrast to the rate of 2.9% among *E. coli* isolated from all specimen types in the same year reported as part of the CANWARD study.[11] There is a paucity of published data on ESBLs from the Toronto region. Lowe and colleagues[23] noted an increase in the incidence rate of ESBL-positive clinical cultures from 2005 to 2009. The CANWARD study includes organisms from sentinel sites across Canada, including our laboratory, but only the first 10 blood culture isolates, (not limited to *E. coli*) per month in the first 10 months of the year are included, and the isolates sent from our laboratory reflect less than 10% of all blood culture isolates each year and represent less than 10% of the CANWARD data. Thus, the current study provides important data on trends in ESBL production by *E. coli* and other organisms in the Toronto region.

The increasing prevalence of ESBL-producing *E. coli* that we observed in our centre is likely related to the globally increasing prevalence of ST131 *E. coli*.[11,12,24] This is corroborated by our finding of an increase in the frequency of the ST131 clonal type within ESBL-producing *E. coli*, from 31.6% in 2006 to 73.0% in 2016. ST131 *E. coli* is spreading worldwide, likely related to its multidrug resistance and possibly to virulence factors that provide a survival advantage.[8] There is a temporal correlation of a rise in ESBL prevalence after the introduction of ST131 *E. coli* into a region,[7] which likely contributes to regional differences in ESBL prevalence rates.

Limitations
Our data represent local ESBL prevalence rates, reflecting the patient population serviced by the centres supported by our laboratory, which include a large tertiary care transplantation centre, immunocompromised hematology cancer centre and oncology program in a large cosmopolitan city. It is likely that smaller community hospitals or centres that provide care to

unique patient cohorts would show different rates. Our data are also from a predominantly adult cohort and cannot provide insight to rates among pediatric patients. Furthermore, aside from a polymerase chain reaction assay for ST131 characterization, sequencing or other molecular typing was not performed on isolates, which limits our ability to fully describe the epidemiologic features of the increase in ESBL-producing *E. coli* in our region. In addition, 4 isolates from 2016 were not assessed for ESBL production owing to lack of viability of the glycerol stock or presumed loss of the ESBL-resistance plasmid, and 10 ESBL-producing *E. coli* isolates were excluded from ST131 analysis owing to lack of viability of the glycerol stock; however, given the small numbers of isolates excluded per year, we do not believe this introduced bias into the observed trends. Finally, we cannot comment on where patients may have acquired ESBL-producing *E. coli*, as information on travel history and history of past hospital admissions was not assessed.

Conclusion

Our study describes recent ESBL trends in blood cultures from a Canadian region. The significant increase in the proportion of ESBL-producing *E. coli* in bloodstream infections in our region temporally linked with the rise in the ST131 clonal type of *E. coli* highlights the ongoing threat posed by antimicrobial-resistant organisms. Recognition of this significant increase is important to inform empiric antibiotic treatment of bloodstream infections. Further investigations are needed to elucidate the epidemiologic features of ESBL-producing *E. coli* in order to inform modification of practices aimed at reducing the prevalence and limiting the spread of ESBL-producing organisms.

References

1. *Canadian Antimicrobial Resistance Surveillance System 2017 report*. Ottawa: Public Health Agency of Canada; 2017. Available: https://www.canada.ca/en/public-health/services/publications/drugs-health-products/canadian-antimicrobial-resistance-surveillance-system-report-2016.html-a3-1 (accessed 2017 Sept. 29).
2. WHO publishes list of bacteria for which new antibiotics are urgently needed [news release]. Geneva: World Organization; 2017. Available: www.who.int/mediacentre/news/releases/2017/bacteria-antibiotics-needed/en/ (accessed 2017 Sept. 29).
3. Biggest threats and data. Atlanta: Centers for Disease Control and Prevention; (updated 2018 Sept. 10). Available: https://www.cdc.gov/drugresistance/threat-report-2013/index.html (accessed 2017 Sept. 29).
4. Chung HC, Lai CH, Lin JN, et al. Bacteremia caused by extended-spectrum-beta-lactamase-producing *Escherichia coli* sequence type ST131 and non-ST131 clones: comparison of demographic data, clinical features, and mortality. *Antimicrob Agents Chemother* 2012;56:618-22.
5. Tumbarello M, Sali M, Trecarichi EM, et al. Bloodstream infections caused by extended-spectrum-beta-lactamase-producing *Escherichia coli*: risk factors for inadequate initial antimicrobial therapy. *Antimicrob Agents Chemother* 2008;52:3244-52.
6. Scarsi KK, Feinglass JM, Scheetz MH, et al. Impact of inactive empiric antimicrobial therapy on inpatient mortality and length of stay. *Antimicrob Agents Chemother* 2006;50:3355-60.
7. Nicolas-Chanoine MH, Bertrand X, Madec JY. *Escherichia coli* ST131, an intriguing clonal group. *Clin Microbiol Rev* 2014;27:543-74.
8. Mathers AJ, Peirano G, Pitout JD. The role of epidemic resistance plasmids and international high-risk clones in the spread of multidrug-resistant Enterobacteriaceae. *Clin Microbiol Rev* 2015;28:565-91.
9. Hawser SP, Bouchillon SK, Hoban DJ, et al. Emergence of high levels of extended-spectrum-beta-lactamase-producing gram-negative bacilli in the Asia-Pacific region: data from the Study for Monitoring Antimicrobial Resistance Trends (SMART) program, 2007. *Antimicrob Agents Chemother* 2009;53:3280-4.
10. Jean SS, Hsueh PR; SMART Asia-Pacific Group. Distribution of ESBLs, AmpC β-lactamases and carbapenemases among Enterobacteriaceae isolates causing intra-abdominal and urinary tract infections in the Asia-Pacific region during 2008–14: results from the Study for Monitoring Antimicrobial Resistance Trends (SMART). *J Antimicrob Chemother* 2017;72:166-71.
11. Denisuik AJ, Lagacé-Wiens PR, Pitout JD, et al.; Canadian Antimicrobial Resistance Alliance. Molecular epidemiology of extended-spectrum β-lactamase-, AmpC β-lactamase- and carbapenemase-producing *Escherichia coli* and *Klebsiella pneumoniae* isolated from Canadian hospitals over a 5 year period: CANWARD 2007–11. *J Antimicrob Chemother* 2013;68(Suppl 1):i57-65.
12. Peirano G, van der Bij AK, Gregson DB, et al. Molecular epidemiology over an 11-year period (2000 to 2010) of extended-spectrum β-lactamase-producing *Escherichia coli* causing bacteremia in a centralized Canadian region. *J Clin Microbiol* 2012;50:294-9.
13. Peirano G, Richardson D, Nigrin J, et al. High prevalence of ST131 isolates producing CTX-M-15 and CTX-M-14 among extended-spectrum-beta-lactamase-producing *Escherichia coli* isolates from Canada. *Antimicrob Agents Chemother* 2010;54:1327-30.
14. Tumbarello M, Sanguinetti M, Montuori E, et al. Predictors of mortality in patients with bloodstream infections caused by extended-spectrum-beta-lactamase-producing Enterobacteriaceae: importance of inadequate initial antimicrobial treatment. *Antimicrob Agents Chemother* 2007;51:1987-94.
15. Kumar A, Roberts D, Wood KE, et al. Duration of hypotension before initiation of effective antimicrobial therapy is the critical determinant of survival in human septic shock. *Crit Care Med* 2006;34:1589-96.
16. Kumar A, Ellis P, Arabi Y, et al.; Cooperative Antimicrobial Therapy of Septic Shock Database Research Group. Initiation of inappropriate antimicrobial therapy results in a fivefold reduction of survival in human septic shock. *Chest* 2009;136:1237-48.
17. *Analysis and presentation of cumulative antimicrobial susceptibility test data; approved guideline — 4th edition*. CLSI document M39-A4. Wayne (PA): Clinical and Laboratory Standards Institute; 2014.
18. *Performance standards for antimicrobial susceptibility testing*. 26th ed. CLSI supplement M100. Wayne (PA): Clinical and Laboratory Standards Institute; 2016.
19. M'Zali FH, Chanawong A, Kerr KG, et al. Detection of extended-spectrum beta-lactamases in members of the family Enterobacteriaceae: comparison of the MAST DD test, the double disc and the Etest ESBL. *J Antimicrob Chemother* 2000;45:881-5.
20. Holmes DS, Quigley M. A rapid boiling method for the preparation of bacterial plasmids. *Anal Biochem* 1981;114:193-7.
21. Clermont O, Dhanji H, Upton M, et al. Rapid detection of the O25b-ST131 clone of *Escherichia coli* encompassing the CTX-M-15-producing strains. *J Antimicrob Chemother* 2009;64:274-7.
22. Woerther PL, Burdet C, Chachaty E, et al. Trends in human fecal carriage of extended-spectrum β-lactamases in the community: toward the globalization of CTX-M. *Clin Microbiol Rev* 2013;26:744-58.
23. Lowe CF, McGeer A, Muller MP, et al.; Toronto ESBL Working Group. Decreased susceptibility to noncarbapenem antimicrobials in extended-spectrum-beta-lactamase-producing *Escherichia coli* and *Klebsiella pneumoniae* isolates in Toronto, Canada. *Antimicrob Agents Chemother* 2012;56:3977-80.
24. Pitout JD, DeVinney R. *Escherichia coli* ST131: a multidrug-resistant clone primed for global domination. *F1000Res* 2017;6: pii: F1000 Faculty Rev-195.

Affiliations: Department of Microbiology (Mineau, Kozak, Kissoon, Paterson, Oppedisano, Douri, Gogan, Willey, McGeer, Poutanen), University Health Network/Sinai Health System, Toronto, Ont.; Centre intégré de santé et de services sociaux de Chaudière-Appalaches (Mineau), Sainte-Marie, Que.; Lawrence Park Collegiate Institute (Gogan); Departments of Laboratory Medicine and Pathobiology and of Medicine (McGeer, Poutanen), University of Toronto, Toronto, Ont.