Patient safety is a key component of high-quality health care delivery as well as an expectation among patients and caregivers. Substantial interest in improving patient safety was prompted following the release of the Institute of Medicine’s seminal report, *To Err is Human*,1 which estimated that between 44 000 and 98 000 Americans died each year as a result of medical mistakes, with an associated cost between US$17 billion and $29 billion. The Canadian Adverse Events Study followed shortly thereafter and estimated that, in 2000, about 185 000 hospital admissions were associated with an adverse event, and close to 70 000 of these were potentially preventable.2 Despite the substantial attention these findings generated and the policy initiatives they inspired,3,4 hospital-based adverse events remain a prevalent issue.5,6 Recently, the Canadian Institute for Health Information (CIHI) partnered with the Canadian Patient Safety Institute to develop a measure of adverse events in hospital — termed “hospital harm” — using administrative health data.7 This measure is analogous to the Agency for Healthcare Research and Quality’s (AHRQ) Patient Safety Indicators8,9 and enables a renewed attention on surveillance of patient safety specific to a Canadian setting.

Although it is understood that experiencing harm in hospital increases length of hospital stay,5,9,10 costs of hospital care,5,6–17 risk of death5,11,14 and risk of re-admission,11,14 there is a lack of information on the relation between hospital harm and total cost inclusive of postdischarge use of health services and accompanying costs.14

In this study, our objective was to assess the impact of hospital harm on the incremental length of hospital stay, as well as on the incremental length of person-centred episodes of care (PCEs) and costs of PCEs, as well as their impact on the total health system.

**ABSTRACT**

**BACKGROUND:** There is a lack of data in Canada on the longitudinal effects of adverse events that occur in hospital, specifically in the period after discharge. Our objective was to quantify the impact of adverse events on hospital length of stay, length of person-centred episodes of care (PCEs) and costs of PCEs, as well as their impact on the total health system.

**METHODS:** We conducted a population-based, retrospective cohort study using linked health administrative databases. We included adults in Ontario who had an acute hospital admission between Apr. 1, 2015, and Mar. 31, 2016. We grouped hospital admissions into 1 of 9 episode types and used the Canadian Institute for Health Information methodology for hospital harm to measure adverse events. We specified generalized linear models to estimate the impact of hospital harm on the following: incremental length of index acute hospital admission, incremental length of the PCE, and incremental costs of the PCE.

**RESULTS:** Out of 610979 hospital admissions, 36 004 (5.9%) involved an occurrence of harm. The impact of harm on the incremental length of hospital stay ranged from 0.4 to 24.2 days ($p < 0.001$); the incremental length of the PCE ranged from 0.3 to 30.2 days ($p < 0.001$); and the incremental costs of the PCE ranged from $800 to $51 067 ($p < 0.001$). Total hospital days attributable to hospital harm amounted to 407 696, and the total attributable cost to the Ontario health system amounted to $1 088 330 376.

**INTERPRETATION:** We found that experiencing harm in hospital significantly affects both in-hospital and post-discharge use of health services and costs of care, and constitutes an enormous expense to Ontario’s publicly funded health system.
the incremental duration and cost of person-centred episodes of care (PCEs), inclusive of acute and postacute care. We additionally sought to assess the total health system impact associated with hospital harm. The PCE methodology creates episodes of care that span acute and postacute care and aligns itself with renewed efforts to draw attention away from sector-specific costs to focus on episodes of care and enable value-based evaluation of health care. We hypothesized that hospital harm would lead to significant incremental and total attributable increases in the outcomes of interest.

Methods

Setting and data

We conducted a population-based, retrospective cohort study in Ontario, Canada, using health administrative databases at ICES. These data are inclusive of all hospital, physician, pharmaceutical, laboratory, home care and long-term care paid for by the Ontario Ministry of Health and Long-Term Care. All records were linked sequentially for each study patient by use of encrypted health card numbers. A description of these databases appears in Appendix 1A (Appendix 1, available at www.cmaj.ca/lookup/ suppl/doi:10.1503/cmaj.1816211/-/DC1). Ontario’s health administrative data have been shown to be both valid and reliable, and have been used previously to estimate medical costs and study patterns of health services use.

Patients

We used PCEs to identify individuals eligible for study inclusion. The complete PCE methodology has been described in detail previously. Briefly, a PCE is defined as beginning with an acute hospital admission and includes subsequent care until an individual has returned to the community and is stabilized for 30 days without any institutional admissions. Person-centred episodes of care are classified according to the clinical grouping for the initial admission and are mutually exclusive. Patients aged 18–105 years on the study index date (Apr. 1, 2015) and eligible for coverage under the Ontario Health Insurance Plan at the time of hospital admission were included. To be eligible for study inclusion, patients had to be discharged alive from an acute hospital admission between Apr. 1, 2015, and Mar. 31, 2016, with a minimum length of stay of 24 hours in one of the following mutually exclusive PCEs of interest: pregnancy, trauma, mental health, cancer, renal, planned surgical, planned medical, unplanned surgical or unplanned medical. Appendix 1B (Appendix 1) contains the full list of exclusions.

Exposure

Our main exposure was the occurrence of a hospital harm in patients’ first acute hospital admission in the period between Apr. 1, 2015, and Mar. 31, 2016. We identified hospital harm using the CIHI hospital harm methodology. The CIHI defines hospital harm as a hospital admission in which a patient experiences at least 1 unintended occurrence of harm that is potentially preventable by implementing known evidence-informed safety practices. The methodology consists of 4 major categories of harm that encompass 31 groupings of harmful events. The 4 categories of harm are health care– or medication-associated conditions, health care–associated infections, patient accidents, and procedure-associated conditions. The hospital harm framework employs International Statistical Classification of Diseases and Related Health Problems, 10th Revision, Canada codes recorded in the Discharge Abstract Database to identify hospital admissions in which hospital harm occurred. In developing the hospital harm indicator, CIHI ensured a comprehensive data assurance program and included additional steps to determine how useful administrative data were for measuring the occurrence of harm in hospital, including validation of facility-level results by hospitals across Canada.

Outcomes

The primary outcomes of this study were the incremental length of acute index hospital stay, duration of the PCE, and costs of the PCE attributable to hospital harm. Length of hospital stay and length of the PCE were measured in days. To measure costs, all records of health care use paid for by the Ontario Ministry of Health and Long-term Care during a PCE were retrieved. The cost associated with each use of health care services was estimated and aggregated over the PCE by use of costing methods developed for health administrative data that have previously been described. Costs are reported in 2017 Canadian dollars. We report total attributable acute days, total attributable length of PCEs and total attributable costs of PCEs.

Covariates

We measured several covariates that were hypothesized as founders in the relation between hospital harm and the outcomes of interest: age, sex, PCE type, neighbourhood income quintile, major clinical category (most responsible diagnosis or intervention that substantially affects the pattern of care and resources consumed by a patient), Hospital Frailty Risk Score (< 5, 5–15, > 15), previous emergency department visits and hospital admissions 1 year before index, hospital type (teaching or community), and postadmission conditions. An interaction term between PCE type and hospital harm was also included. Postadmission conditions are mutually exclusive from the hospital harm indicator and capture conditions reported in previous studies of patient safety. A further discussion of the included covariates appears in Appendix 1C (Appendix 1).

Statistical analysis

We compared baseline characteristics of patients who experienced hospital harm and patients who did not using standardized differences. A standardized difference less than 0.10 was considered negligible. To obtain the best fit to our data, we use regression models and specified generalized linear models with a log link and distribution to estimate the incremental effect of hospital harm on length of index hospital stay, duration of PCE, and costs of PCE (following the approach and results of tests recommended by Manning and Mullahy for cost). Based on this regression, we estimated a prediction of each outcome in patients who did and did not experience hospital harm.
harm, and we used this difference to measure incremental outcomes. The difference between groups (those who experienced hospital harm and those who did not) was assessed via 2-tailed t tests. We then calculated the total system impact of hospital harm in terms of total attributable acute days, total attributable PCE days, and total attributable costs per PCE. A p value less than 0.05 was taken to indicate differences of hospital harm effects across groups.33 Further subgroup analyses were conducted by age (< 65 and ≥ 65 yr). Formal testing with interaction p values was conducted in considering subgroup differences.

As a sensitivity analysis, we excluded patients with electrolyte and fluid imbalance and also those who developed sepsis after their index admission from the count of patients who experienced a hospital harm, as the status of these as potentially preventable has been contested. We removed the indicator for postadmission conditions from the models as a final sensitivity analysis.

All analyses were performed using SAS Enterprise Guide 7.1.

Ethics approval
The use of data in this project was authorized under section 45 of Ontario’s Personal Health Information Protection Act, which does not require review by a research ethics board.

Results

We identified a total of 610979 patients eligible for study inclusion. Characteristics of patients who experienced hospital harm and those who did not appear in Table 1. The largest volume of cases was for unplanned medical PCE (32.3%), whereas renal PCE represented the smallest proportion of cases (0.8%). A breakdown of the cohort by PCE category appears in Appendix 1D (Appendix 1).

Of the 610979 patients included in the study, 36004 (5.9%) experienced a hospital harm in their index acute hospital admission. Among patients who experienced a hospital harm, the largest number of patients were admitted for an unplanned medical PCE (24.6%). The incidence of hospital harm within PCEs was highest overall in the trauma PCE (14.1%) and lowest in the mental health PCE (0.6%) (results not shown). Health care– or medication-associated conditions represented the most frequent harm category overall (50.1%).

After adjusting for confounders, we found that the incremental length of hospital stay attributable to hospital harm ranged from 0.4 days (pregnancy PCE) to 24.2 days (mental health PCE). The attributable length of hospital stay related to experiencing a hospital harm was highest in the mental health PCE, at 24.2 days. The attributable length of hospital stay attributable to hospital harm was highest in the trauma PCE, at 30.2 days.

In this population-based study, we measured the attributable length of hospital stay, duration of first PCE, and cost of first PCE in patients who experienced a hospital harm during their acute hospital admission in 1 of 9 PCE categories. Of the 610979 patients included in this study, 36004 (5.9%) experienced a hospital harm. The attributable length of hospital stay related to experiencing a hospital harm was highest in the mental health PCE, at 24.2 days. The incremental cost of PCE attributable to experiencing a hospital harm was highest in the unplanned surgical PCE, at $51,067. Overall, the health system impact of hospital harm amounted to a total of an incremental 407,696 hospital days, 661,646 PCE days and a cost of $1,088,330,376 for the province of Ontario.

Our overall incidence rate of hospital harm of 5.9% is similar to the national incidence rates of 5.6% reported recently by CIHI and 7.5% in 2004 by Baker and colleagues in the Canadian Adverse Events Study.2,7 Our finding that hospital harm significantly increases length of PCE adds to the literature, as the PCE methodology has only recently been developed.18 Its use here is timely, as health care systems are increasingly moving toward value-based care that is based on purchasing not only isolated health provider encounters but the outcome produced by all providers centred around a particular health episode. The PCE methodology enables all acute and postacute care, including hospital, physician, pharmacy and home care re-admissions to be captured in the episode of care, an important advance as many of the studies on the costs of adverse events have treated readmissions as initial admissions, leading to bias.31 More importantly, the use of PCEs highlights that the effects of experiencing harm in hospital extend to the postdischarge period, supporting earlier results from the United States and Denmark.16,37

In our first subgroup analysis by age, hospital harm significantly increased length of hospital stay and costs of PCE for both patients younger than 65 years (p < 0.001) and patients aged 65 years and older (p < 0.001). In patients younger than 65 years, duration of PCE was significantly increased (p < 0.001; p = 0.01 for unplanned surgical PCE) in all PCEs among those who experienced hospital harm, aside from those in the mental health PCE (p = 0.6). Experiencing a hospital harm significantly increased duration of PCE in patients aged 65 years and older (p < 0.001).

When we excluded patients with electrolyte and fluid imbalance and those with sepsis (undertaken as separate analyses), the impact of hospital harm on length of stay, duration of PCE and costs of PCE remained consistent and significant. Finally, on removal of the indicator for postadmission conditions, our results also remained consistent and significant. When included as a covariate, the effect of all other postadmission conditions was significant for all outcomes (p < 0.001) but much smaller than the effect of hospital harm.

Interpretation

In our first subgroup analysis by age, hospital harm significantly increased length of hospital stay and costs of PCE for both patients younger than 65 years (p < 0.001) and patients aged 65 years and older (p < 0.001). In patients younger than 65 years, duration of PCE was significantly increased (p < 0.001; p = 0.01 for unplanned surgical PCE) in all PCEs among those who experienced hospital harm, aside from those in the mental health PCE (p = 0.6). Experiencing a hospital harm significantly increased duration of PCE in patients aged 65 years and older (p < 0.001).

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Table 1: Baseline characteristics of 610 979 patients, by hospital harm status

| Characteristic                               | No. (%) of patients* | Hospital harm n = 36 004 | No hospital harm n = 574 975 | Standardized difference |
|----------------------------------------------|----------------------|--------------------------|-------------------------------|--------------------------|
| Age, yr, mean ± SD                           |                      | 64.88 ± 19.83            | 55.94 ± 21.02                 | 0.44                     |
| Sex, female                                  |                      | 20 282 (56.3)            | 350 975 (61.0)                | 0.10                     |
| Neighbourhood income quintile                |                      |                          |                               |                          |
| Q1 (lowest)                                  |                      | 8571 (23.8)              | 136 070 (23.7)                | 0.00                     |
| Q2                                            |                      | 7972 (22.1)              | 121 293 (21.1)                | 0.03                     |
| Q3                                            |                      | 7150 (19.9)              | 113 086 (19.7)                | 0.00                     |
| Q4                                            |                      | 6231 (17.3)              | 104 643 (18.2)                | 0.02                     |
| Q5 (highest)                                 |                      | 6015 (16.7)              | 98 954 (17.2)                 | 0.01                     |
| Rural residence                              |                      | 4034 (11.2)              | 72 331 (12.6)                 | 0.04                     |
| No. of chronic conditions                    |                      |                          |                               |                          |
| 0                                            |                      | 11 288 (31.4)            | 129 606 (22.5)                | 0.20                     |
| 1                                            |                      | 3170 (8.8)               | 91 936 (16.0)                 | 0.22                     |
| 2                                            |                      | 3441 (9.6)               | 88 306 (15.4)                 | 0.18                     |
| 3                                            |                      | 3959 (11.0)              | 79 057 (13.7)                 | 0.08                     |
| 4                                            |                      | 4152 (11.5)              | 63 977 (11.1)                 | 0.01                     |
| ≥ 5                                          |                      | 9994 (27.8)              | 122 093 (21.2)                | 0.15                     |
| Major clinical category, intervention†       |                      | 18 256 (50.7)            | 224 466 (39.0)                | 0.24                     |
| Hospital Frailty Risk Score‡                 |                      |                          |                               |                          |
| Low risk (< 5)                               |                      | 29 186 (81.1)            | 564 046 (98.1)                | 0.58                     |
| Intermediate (5–15)/high risk (> 15)‡         |                      | 6818 (18.9)              | 10 929 (1.9)                  | 0.58                     |
| Teaching hospital                            |                      | 14 844 (41.2)            | 176 176 (30.6)                | 0.22                     |
| Postadmission conditions, yes                |                      | –                        | 47 025 (8.2)                  | –                       |
| PCE category                                 |                      |                          |                               |                          |
| Pregnancy                                    |                      | 4524 (12.6)              | 117 361 (20.4)                | 0.21                     |
| Trauma                                       |                      | 6175 (17.2)              | 37 774 (6.6)                  | 0.33                     |
| Mental health                                |                      | 229 (0.6)                | 38 404 (6.7)                  | 0.33                     |
| Cancer                                       |                      | 4284 (11.9)              | 34 153 (5.9)                  | 0.21                     |
| Renal                                        |                      | 425 (1.2)                | 4314 (0.7)                    | 0.04                     |
| Planned surgical                             |                      | 6080 (16.9)              | 104 131 (18.1)                | 0.03                     |
| Planned medical                              |                      | 183 (0.5)                | 5359 (0.9)                    | 0.05                     |
| Unplanned surgical                           |                      | 5237 (14.5)              | 45 212 (7.9)                  | 0.21                     |
| Unplanned medical                            |                      | 8867 (24.6)              | 188 267 (32.7)                | 0.18                     |
| Harm category                                |                      |                          |                               |                          |
| Health care– or medication-associated conditions |                 | 18 027 (50.1)          | –                             | –                        |
| Health care–associated infections             |                      | 13 328 (37.0)            | –                             | –                        |
| Patient accidents                            |                      | 967 (2.7)                | –                             | –                        |
| Procedure-associated conditions              |                      | 9819 (27.3)              | –                             | –                        |
| No. of hospital admissions within 1 yr before index admission, mean ± SD |                  | 0.30 ± 0.82              | 0.22 ± 0.70                   | 0.11                     |
| No. of ED visits within 1 yr before index admission, mean ± SD |                  | 1.30 ± 2.36              | 1.31 ± 2.99                   | 0.01                     |

Note: ED = emergency department, PCE = person-centred episodes of care, SD = standard deviation.
*Unless stated otherwise.
†International Statistical Classification of Diseases and Related Health Problems, 10th Revision, Canada diagnosis codes are used to categorize patients into major clinical categories. These broad categories are based on the most responsible diagnosis code. This diagnosis is the one determined to have been responsible for the greatest portion of the patient’s length of stay. Major clinical categories are divided into two partitions: intervention and diagnosis.
‡Because of small cell counts in those deemed high risk based on Hospital Frailty Risk Score, intermediate and high-risk groups were combined.
Limitations

The CIHI hospital harm methodology does not capture all harmful events that occur in hospital; only harms identified as potentially preventable are included.7 A more comprehensive list of the types of harm not captured by the methodology is described elsewhere.7 It should be stressed that while the methodology aims to identify only potentially preventable instances of harm, not all instances of harm actually are preventable. In a recent review on adverse events in health care, it was reported that between one- and two-thirds of hospital adverse events are estimated to be preventable.34 Such estimates have implications for the results of this study. If only two-thirds of cases of the hospital

### Table 2: Impact of hospital harm on incremental length of hospital stay, incremental duration of first person-centred episode of care and incremental costs of first person-centred episode of care*

| PCE category | Hospital harm | No hospital harm | Incremental | Length of hospital stay, d, mean ± SD | p value | Hospital harm | No hospital harm | Incremental | Duration of first PCE, d, mean ± SD | p value | Hospital harm | No hospital harm | Incremental | Cost of first PCE, 2017 Can$, mean ± SD | p value |
|--------------|---------------|-----------------|-------------|----------------------------------------|---------|---------------|-----------------|-------------|-------------------------------------|---------|---------------|-----------------|-------------|----------------------------------------|---------|
| Pregnancy    | 3.5 ± 0.3     | 3.1 ± 0.3       | 0.4 ± 0.3   | < 0.001                                |         | 35.0 ± 1.6    | 34.6 ± 2.0      | 0.3 ± 2.0   | 617 ± 896                           | < 0.001 | 5373 ± 909     | 800 ± 909       | < 0.001 |
| Trauma       | 25.0 ± 10.2   | 21.5 ± 10.4     | 3.5 ± 4.8   | < 0.001                                |         | 82.0 ± 16.3   | 78.8 ± 15.0     | 3.2 ± 15.0 | 27.7 ± 28.0                        | < 0.001 | 70.556 ± 28.03 | 21.7 ± 13.72   | < 0.001 |
| Mental health| 34.3 ± 12.8   | 30.8 ± 12.4     | 3.5 ± 4.4   | < 0.001                                |         | 85.2 ± 23.7   | 80.0 ± 23.4     | 5.2 ± 23.4 | 27.7 ± 42.9                        | < 0.001 | 43.693 ± 16.913 | 25.679 ± 17.5 | < 0.001 |
| Cancer       | 18.0 ± 5.7    | 15.5 ± 5.0      | 2.5 ± 5.0   | < 0.001                                |         | 62.9 ± 8.5    | 58.2 ± 4.5      | 4.7 ± 4.5   | 16.7 ± 5.2                        | < 0.001 | 48.775 ± 15.086 | 21.424 ± 4.686 | < 0.001 |
| Renal        | 19.6 ± 7.9    | 16.0 ± 7.0      | 3.6 ± 7.9   | < 0.001                                |         | 68.2 ± 12.6   | 52.7 ± 16.8     | 15.6 ± 16.4 | 49.732 ± 18.458                   | < 0.001 | 23.421 ± 8.406 | 26.311 ± 9.913 | < 0.001 |
| Planned surgical | 10.6 ± 3.0   | 8.0 ± 2.5       | 2.6 ± 5.0   | < 0.001                                |         | 51.0 ± 6.5    | 37.3 ± 3.7      | 13.6 ± 3.9  | 35.906 ± 11.033                   | < 0.001 | 12.375 ± 2.551 | 23.031 ± 3.699 | < 0.001 |
| Planned medical | 22.2 ± 7.7   | 15.0 ± 6.0      | 7.2 ± 1.7   | < 0.001                                |         | 75.8 ± 11.7   | 49.5 ± 11.6     | 26.3 ± 11.6 | 51.719 ± 10.264                   | < 0.001 | 18.362 ± 5.897 | 33.357 ± 6.495 | < 0.001 |
| Unplanned surgical | 22.4 ± 8.9   | 15.0 ± 6.0      | 7.4 ± 1.7   | < 0.001                                |         | 71.3 ± 13.2   | 46.2 ± 313.5    | 25.1 ± 294.1 | 70.232 ± 28.108                   | < 0.001 | 19.164 ± 23.636 | 51.067 ± 24.216 | < 0.001 |
| Unplanned medical | 19.4 ± 8.2   | 12.7 ± 5.5      | 6.7 ± 2.5   | < 0.001                                |         | 67.1 ± 17.5   | 47.9 ± 88.4     | 19.1 ± 86.3 | 44.353 ± 19.146                   | < 0.001 | 16.909 ± 11.945 | 27.445 ± 12.396 | < 0.001 |
| Total        | 36 004        | 27 166          | 8.8 ± 2.5   | < 0.001                                |         | 131 146       | 90.9 ± 12.3     | 40.2 ± 12.3 | 108 330 ± 330                    | < 0.001 | 1 088 330 ± 330 | 1 088 330 ± 330 | < 0.001 |

Note: PCE = person-centred episodes of care, SD = standard deviation.
*Incremental outcomes and p values are adjusted by all the covariates of interest (Appendix 1, available at www.cmaj.ca/lookup/suppl/doi:10.1503/cmaj.181621/-/DC1).

### Table 3: System impact during episodes of care associated with hospital harm during fiscal year 2015/16*

| PCE category | No. of cases of harm | Incremental acute days | Incremental duration of first PCE | Incremental cost of first PCE, 2017 Can$ |
|--------------|----------------------|------------------------|---------------------------------|----------------------------------------|
| Pregnancy    | 4524                 | 0.38                   | 1700                            | 1468                                   | 800                      | 3 617 540                        |
| Trauma       | 6175                 | 17.27                  | 106 645                         | 186 553                                | 47 824                   | 295 313 077                     |
| Mental health| 229                  | 24.23                  | 5549                            | 6235                                   | 18 014                   | 4 125 135                      |
| Cancer       | 4284                 | 11.50                  | 49 247                          | 71 618                                 | 27 351                   | 117 169 842                    |
| Renal        | 425                  | 11.39                  | 48 42                          | 6619                                   | 26 311                   | 11 182 128                     |
| Planned surgical | 6080              | 6.89                   | 41 875                          | 82 941                                 | 23 031                   | 140 027 325                    |
| Planned medical | 183                 | 15.55                  | 2845                           | 4811                                   | 33 357                   | 6 104 265                      |
| Unplanned surgical | 5237               | 15.80                  | 82 750                          | 131 679                                | 51 067                   | 267 439 974                    |
| Unplanned medical | 8867              | 12.66                  | 112 244                         | 169 722                                | 27 445                   | 243 351 091                    |
| Total        | 36 004               | 11.32                  | 407 696                         | 661 646                                | 30 228                   | 1 088 330 376                  |

Note: PCE = person-centred episodes of care.
*Incremental outcomes are adjusted by all the covariates of interest.
harm measured in this study were preventative, the overall health system impact would be reduced to a total of 271 798 hospital days, 441 097 PCE days and $725 553 584. This highlights that caution must be taken in interpreting these results and drawing conclusions about which events can feasibly be the targets of patient safety initiatives, as the method of defining hospital harm and attributing costs is designed to be inclusive, potentially leading to an overestimate. However, the CIHI hospital harm methodology aims to focus on potentially preventable events and excludes many postadmission hospital events (captured in our measure of other postadmission events). We undertook additional sensitivity analyses by excluding patients with electrolyte and fluid imbalance and those who developed sepsis after their index admission. Our results remained consistent and significant following both of these exclusions. Finally, there is a possibility that there may be unmeasured confounders, such as body mass index. This information is currently unavailable in administrative databases.

**Conclusion**

We found that experiencing hospital harm significantly increases length of hospital stay, length of PCE and costs of PCE. We employed the CIHI hospital harm methodology at a provincial level, which enabled us to estimate the total health system impact of hospital harm in Ontario. Financially, this amounted to $1 088 330 376 in 2017 Canadian dollars and 407 696 acute hospital days or the equivalent of a 1117-bed hospital operating at 100% capacity between Apr. 1, 2015, and Mar. 31, 2016. Substantial investments in strategies to reduce adverse events could result in cost savings and additional benefits to patients. Future research should assess the impact of preventable harm on other outcomes, such as patient-reported outcomes, patient-reported experiences, re-admissions and death.

**References**

1. Institute of Medicine (US) Committee on Quality of Health Care in America. To err is human: building a safer health system. Kohn LT, Corrigan JM, Donaldson MS, editors. Washington (DC): National Academies Press (US); 2000. Available: www.ncbi.nlm.nih.gov/books/NBK225182 (accessed 2018 Oct. 23).

2. Baker GR, Norton PG, Flintoft V, et al. The Canadian Adverse Events Study: the incidence of adverse events among hospital patients in Canada. CMAJ 2004; 170:1678-86.

3. 5 Million Lives Campaign: overview. Boston: Institute for Healthcare Improvement. Available: www.ihi.org/IIT/Engage/Initiatives/Completed/5MillionLivesCampaign/Pages/default.aspx (accessed 2018 Oct. 23).

4. Beyond the quick fix: strategies for improving patient safety. Toronto: Institute of Health Policy, Management and Evaluation, University of Toronto; 2015. Available: http://ihpme.utoronto.ca/wp-content/uploads/2015/11/Beyond-the-Quick-Fix-Baker-2015.pdf (accessed 2018 Apr. 30).

5. Forster AJ, Kyeremanteng K, Hooper J, et al. The impact of adverse events in the intensive care unit on hospital mortality and length of stay. BMC Health Serv Res 2008;8:259.

6. Wong BM, Dyal S, Etchells EE, et al. Application of a trigger tool in near real time to inform quality improvement activities: a prospective study in a general medicine ward. BMJ Qual Saf 2015;24:272-81.

7. Chan B, Cechrane D. Measuring patient harm in Canadian hospitals: What can be done to improve patient safety? Ottawa: Canadian Institute for Health Information, Canadian Patient Safety Institute; 2016. Available: www.cihi.ca/sites/default/files/document/cihi_cpsi_hospital_harm_en.pdf (accessed 2018 Apr. 30).

8. Patient safety indicators overview. Rockville (MD): Agency for Healthcare Research and Quality. Available: www.qualityindicatorsahrq.gov/modules/psi_overview.aspx (accessed 2018 Oct. 22).

9. Zhan C, Miller MR. Excess length of stay, charges, and mortality attributable to medical injuries during hospitalization. JAMA 2003;290:1868-74.

10. Hoogervorst-Schijp J, Langelaan M, Spreeuwenberg P, et al. Excess length of stay and economic consequences of adverse events in Dutch hospital patients. BMC Health Serv Res 2015;15:531.

11. Encinosa WE, Hellinger FJ. What happens after a patient safety event? Medical expenditures and outcomes in Medicare. In: Henrikken K, Battles JB, Marks ES, et al, editors. Advances in patient safety: from research to implementation (volume 1: research findings). Rockville (MD): Agency for Healthcare Research and Quality (US); 2005. Available: www.ncbi.nlm.nih.gov/books/NBK20457 (accessed 2018 May 1).

12. Zhan C, Friedman B, Mosso A, et al. Medicare payment for selected adverse events: building the business case for investing in patient safety. Health Aff (Millwood) 2006;25:1386-93.

13. Kaushal R, Bates DW, Franz C, et al. Costs of adverse events in intensive care units. Crit Care Med 2007;35:2479-83.

14. Encinosa WE, Hellinger FJ. The impact of medical errors on ninety-day costs and outcomes: an examination of surgical patients. Health Serv Res 2008;43: 2067-85.

15. Jackson T. One dollar in seven: scoping the economics of patient safety. Ottawa: Canadian Patient Safety Institute; 2009. Available: www.patientsafetyinstitute.ca/en/toolsResources/Research/commissionedResearch/EconomicsofPatientSafety/Documents/Economics%20of%20PatientSafety%20Literature%20Review.pdf (accessed 2018 Apr. 30).

16. Wardle G, Wodchis WP, Laporte A, et al. The sensitivity of adverse event cost estimates to diagnostic coding error. Health Serv Res 2012;47:984-1007.

17. Kjellberg J, Wolf RT, Kruse M, et al. Costs associated with adverse events among acute patients. BMC Health Serv Res 2017;17:651.

18. Gulicher SJT, Bronskill SE, Guan J, et al. Who are the high-cost users? A method for person-centred attribution of health care spending. PLoS One 2016;11:e0149179.

19. Porter ME. A strategy for health care reform — toward a value-based system. N Engl J Med 2009;361:109-12.

20. Juurlink D, Preya C, Croxford R, et al. Canadian Institute for Health Information Discharge Abstract Database: a validation study — ICES investigative report. Toronto: Institute for Clinical Evaluative Sciences; 2006. Available: www.ices.on.ca/flip-publication/canadian-institute-for-health-information-discharge/index.html (accessed 2018 May 6).

21. Wodchis WP, Austin PC, Henry DA. A 3-year study of high-cost users of health care. CMAJ 2016;188:182-8.

22. Mondor L, Maxwell CJ, Hogan DB, et al. Multimorbidity and healthcare utilization among home care clients with dementia in Ontario, Canada: a retrospective analysis of a population-based cohort. PLoS Med 2017;14:e1002249.

23. Gruneir A, Bronskill SE, Maxwell CJ, et al. The association between multimorbidity and hospitalization is modified by individual demographics and physician continuity of care: a retrospective cohort study. BMC Health Serv Res 2016;16:154.

24. Pincus D, Wasserstein D, Nathens AB, et al. Direct medical costs of motorcycle crashes in Ontario. CMAJ 2017;189:E1410-5.

25. Pincus D, Ravi B, Wasserstein D, et al. Association between wait time and 30-day mortality in adults undergoing hip fracture surgery. JAMA 2017;318: 1994-2003.

26. Data quality study of the 2015-2016 Discharge Abstract Database: a focus on hospital harm. Ottawa: Canadian Institute for Health Information; 2016. Available: https://secure.cihi.ca/free_products/DAD_15_16_Reab_Report_EN.pdf (accessed 2019 Apr. 29).

27. Wodchis WP, Bushmeneva K, Nkirotic M, et al. Guidelines on person-level costing using administrative databases in Ontario. Working Paper Series Vol. 1. Toronto: Health System Performance Research Network; 2013. Available: www.hspmn.ca/activities/papers/hspmn_case_costing_vol1_2013.pdf (accessed 2018 May 7).

28. Tanuseputro P, Wodchis WP, Fowler R, et al. The health care cost of dying: a population-based retrospective cohort study of the last year of life in Ontario, Canada. PLoS One 2015;10:e0121759.
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Data sharing: The data from this study are held securely in coded form at ICES. Although data-sharing agreements prohibit ICES from making the data publicly available, access may be granted to those who meet prespecified criteria for confidential access (available at www.ices.on.ca/DAS).

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