

# Association Between Wait Time and 30-Day Mortality in Adults Undergoing Hip Fracture Surgery

Daniel Pincus, MD; Bheeshma Ravi, MD, PhD; David Wasserstein, MD, MSc; Anjie Huang, MSc; J. Michael Paterson, MSc; Avery B. Nathens, MD, MPH, PhD; Hans J. Kreder, MD, MPH; Richard J. Jenkinson, MD, MSc; Walter P. Wodchis, PhD

**IMPORTANCE** Although wait times for hip fracture surgery have been linked to mortality and are being used as quality-of-care indicators worldwide, controversy exists about the duration of the wait that leads to complications.

**OBJECTIVE** To use population-based wait-time data to identify the optimal time window in which to conduct hip fracture surgery before the risk of complications increases.

**DESIGN, SETTING, AND PARTICIPANTS** Population-based, retrospective cohort study of adults undergoing hip fracture surgery between April 1, 2009, and March 31, 2014, at 72 hospitals in Ontario, Canada. Risk-adjusted restricted cubic splines modeled the probability of each complication according to wait-time. The inflection point (in hours) when complications began to increase was used to define early and delayed surgery. To evaluate the robustness of this definition, outcomes among propensity-score matched early and delayed surgical patients were compared using percent absolute risk differences (RDs, with 95% CIs).

**EXPOSURE** Time elapsed from hospital arrival to surgery (in hours).

**MAIN OUTCOMES AND MEASURES** Mortality within 30 days. Secondary outcomes included a composite of mortality or other medical complications (myocardial infarction, deep vein thrombosis, pulmonary embolism, and pneumonia).

**RESULTS** Among 42 230 patients with hip fracture (mean [SD] age, 80.1 years [10.7], 70.5% women) who met study entry criteria, overall mortality at 30 days was 7.0%. The risk of complications increased when wait times were greater than 24 hours, irrespective of the complication considered. Compared with 13 731 propensity-score matched patients who received surgery earlier, 13 731 patients who received surgery after 24 hours had a significantly higher risk of 30-day mortality (898 [6.5%] vs 790 [5.8%]; % absolute RD, 0.79; 95% CI, 0.23-1.35) and the composite outcome (1680 [12.2%]) vs 1383 [10.1%]; % absolute RD, 2.16; 95% CI, 1.43-2.89).

**CONCLUSIONS AND RELEVANCE** Among adults undergoing hip fracture surgery, increased wait time was associated with a greater risk of 30-day mortality and other complications. A wait time of 24 hours may represent a threshold defining higher risk.

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+ Supplemental content

**Author Affiliations:** Department of Surgery, University of Toronto, Toronto, Ontario, Canada (Pincus, Ravi, Wasserstein, Nathens, Kreder, Jenkinson); Institute for Clinical Evaluative Sciences, Toronto, Ontario, Canada (Pincus, Ravi, Paterson, Nathens, Kreder, Wodchis); Institute of Health Policy, Management and Evaluation, University of Toronto, Toronto, Ontario, Canada (Pincus, Huang, Paterson, Nathens, Kreder, Jenkinson, Wodchis); Sunnybrook Health Sciences Centre, Department of Surgery, Toronto, Ontario, Canada (Ravi, Wasserstein, Nathens, Kreder, Jenkinson); Toronto Rehabilitation Institute-University Health Network, Toronto, Ontario, Canada (Wodchis).

**Corresponding Author:** Daniel Pincus, MD, Division of Orthopaedic Surgery, Department of Surgery, University of Toronto, 149 College St, Room 508-A, Toronto, ON M5T 1P5, Canada (d.pincus@utoronto.ca).

**E**xpedited hip fracture surgery for increasing numbers of patients<sup>1</sup> who may be medically complex and most commonly receive surgery outside regular working hours<sup>2</sup> involves several different medical and surgical specialists, hospital administrators, and allied staff.<sup>3</sup> Despite resources expended toward performing surgery earlier<sup>4</sup> and extensive research on the topic,<sup>5</sup> controversy remains about the acceptable waiting time for treatment. Guidelines from the United States<sup>6</sup> and Canada<sup>7</sup> recommend surgery within 48 hours. The proportion of patients receiving surgery within 36 hours is the quality-of-care indicator used in the United Kingdom, but hospital adherence ranges from 14.7% to 95.3%.<sup>8</sup>

Variable policy and adherence to guidelines are the result, in part, of inconsistent empirical evidence for a time-to-surgery threshold.<sup>3</sup> Confounding by indication may exaggerate the effect of early surgery,<sup>9</sup> with medically complex patients being predisposed to both complications and awaiting optimization prior to surgery. Wait times have also been measured imprecisely in days<sup>10,11</sup> and arbitrarily divided into early and delayed groups,<sup>12-14</sup> decreasing statistical power to find differences.<sup>15</sup> The calculation of precise inpatient surgical wait times, in hours rather than days, is possible in Ontario, Canada, for all surgical procedures in the province. The objective of this study was to use these data at the population level to establish a time-to-surgery threshold before the risk of complications increases.

## Methods

### Data Sources and Setting

A population-based cohort study was conducted using health administrative databases in Ontario, Canada. Ontario residents have their medically necessary health care services, physician and hospital information, and demographic characteristics recorded in these databases. These data are held and linked at the Institute for Clinical Evaluative Sciences (ICES; <http://www.ices.on.ca>) and have been used previously to study patients with hip fractures (eAppendix A in the [Supplement](#)).<sup>2</sup> The study protocol was approved by the Research Ethics Board at Sunnybrook Health Sciences Centre, Toronto, Ontario. Individual patient informed consent is not required for use of encoded administrative health data in Ontario.

### Patients

Adults undergoing hip fracture surgery in Ontario between April 1, 2009, and March 31, 2014, were eligible. The beginning of the accrual period was selected when a variable measuring exact surgical wait times was introduced.<sup>16</sup> Accrual ended to allow for 1 year of follow-up (up to the final date March 31, 2015) after the date of initial hospitalization (index date). Similar diagnostic and procedure codes previously used to identify patients with a hip fracture who had experienced complications after orthopedic surgery were retained (eAppendix B in the [Supplement](#)).<sup>2</sup>

Non-Ontario residents, those dead on or before their index date, elective hospital admissions, those with prior hip fracture(s) back to 2002, and patients without hospital arrival time

## Key Points

**Question** What is the association between wait time and 30-day mortality in patients undergoing hip fracture surgery?

**Findings** In this retrospective cohort study that included 42 230 adults, wait time longer than 24 hours was associated with higher risk-adjusted likelihood of 30-day mortality (6.5% vs 5.8%).

**Meaning** A wait time of 24 hours may represent a threshold of increased risk for delaying hip fracture surgery.

data were excluded due to their missing data, potential for misclassification, or both. Other exclusion criteria identified rare cases, unrepresentative of most hip fractures from a clinical perspective: age younger than 45 years,<sup>3</sup> extreme surgical delays (>10 days), and surgery performed by a nonorthopedic surgeon or at a hospital with fewer than 5 hip fracture surgeries during the study period. Hip fractures occurring while patients were in the hospital also were excluded because surgical delays for these patients could not be operationalized using available data ([Table 1](#)).

### Main Exposure

The primary independent variable was the wait time for surgery and defined as the total time elapsed from emergency department arrival until surgery (in hours). To capture the time that elapsed during transfer between hospitals, all contiguous hospitalizations from the earliest hospital arrival time to the date and time of surgery were assessed.<sup>17</sup>

### Covariates

Patient characteristics previously shown to explain most of the variation in mortality after hip fracture surgery were measured including age, sex, and medical comorbidity ([Table 2](#)).<sup>18</sup> Medical comorbidity was estimated using 3 validated tools based on each patient's health care utilization in the 5 years prior to the index date: (1) the Deyo-Charlson Comorbidity Index classified hospital discharge diagnoses,<sup>19</sup> (2) the Johns Hopkins Collapsed Aggregated Diagnosis Groups categorized hospitalizations and outpatient physician visits,<sup>20</sup> and (3) previously validated algorithms that identified patients with a specific diagnoses (ie, frailty, diabetes, hypertension, chronic obstructive pulmonary disease [COPD], congestive heart failure [CHF], coronary artery disease [CAD], or dementia [eAppendix A in the [Supplement](#)]). Associated conditions at the time of hospital presentation also were assessed: osteomyelitis, bone cancer, other fractures, total hip arthroplasty in the prior 5 years, and multiple trauma (defined as an Injury Severity Score  $\geq 16$ ).

Median neighborhood household income quintile was used as a proxy for socioeconomic status.<sup>21</sup> Patients directly transferred from other health care institutions (long-term care, for example), each patient's discharge disposition, and those residing in rural areas were identified.<sup>22</sup> Each procedure's type, duration, and timing (working hours, weekdays between 7 AM and 5 PM; evening or weekend, 5 PM to 12 AM on a weekday or 7 AM to 12 PM over the weekend; or overnight, any day from 12 AM to 7 AM) were recorded.<sup>2</sup>

**Table 1. Assembly of the Study Cohort in Ontario, Canada Between 2009 and 2014**

Inclusion and Exclusion Criteria	No.
Inclusion criteria	
Hip fracture surgical procedures in Ontario during study period	48 627
Exclusion criteria	
Non-Ontario resident	31
Dead before or on index date	8
Nonorthopedic surgeon	351
Prior hip fracture	1997
Missing emergency presentation time data	1460
Hip fracture occurring in-hospital	440
Elective hospital admission	1002
Low-volume hospital (<5 hip fracture procedures during study period)	34
Patients aged <45 y	746
Hip fracture surgery delayed >10 d	328
Eligible hip fracture fixation procedures (total study cohort size)	42 230
Eligible treating surgeons	522
Eligible treating hospitals	72

Index surgeon- and hospital-related factors were assigned at time of each patient's operation. These included (1) years since each surgeon's Canadian orthopedic certification (surgeon experience) and (2) the number of hip fracture procedures performed in the year preceding the index event (surgeon and hospital volume). Each hospital's capacity for performing nonelective surgery was operationalized as the mean daily number of any nonelective (or urgent) procedures performed at the hospital, orthopedic or otherwise, in the year preceding the index event. Hospitals were also categorized as either academic or community based on their membership in the Council of Academic Hospitals of Ontario (<http://www.cahohospitals.com>). Community hospitals were further classified as large ( $\geq 400$  beds) or small to medium ( $< 400$  beds).<sup>23</sup>

### Outcomes

The primary outcome was mortality within 30 days of being admitted for hip fracture surgery. A 30-day observation window is the most common follow-up period measured in literature<sup>3,5,24</sup> and considers the temporal association between surgical delay and the development of complications. Longer follow-up at 90 and 365 days was considered in secondary analyses.

Medical complications within 30, 90, and 365 days, as well as a composite of mortality or any medical complication, were assessed as secondary outcomes. Medical complications considered were myocardial infarction, deep vein thrombosis, pulmonary embolism, and pneumonia. Surgical complications (hardware removal and postoperative hip dislocation) presumed to be unrelated to wait times were assessed as negative tracer outcomes intended to test the specificity of the findings (see the Sensitivity Analyses section).<sup>25</sup>

### Statistical Analysis

Risk-adjusted, restricted cubic splines with 4 knots<sup>26</sup> were used to model the probability of complications according to the time elapsed from emergency department arrival to surgery. Any nonlinear relationship between surgical delay and each outcome could be assessed using spline regression, which makes no underlying assumptions about a functional form. Rather than arbitrarily dividing patients into early and delayed surgery groups,<sup>15</sup> the association between surgical delay and mortality was graphically represented to visualize an inflection point (in hours), if one existed, when complications began to rise. At time thresholds around the area of inflection, the area under the receiver operating characteristic curve was calculated for adjusted logistic regression models relating surgical delay to 30-day mortality. The time (in hours) producing the maximum area under the curve increase was selected as the threshold to dichotomize time and classify patients as receiving either early or delayed surgery.<sup>27</sup> To further evaluate the robustness of this definition, early and delayed patients were matched 1:1 without replacement<sup>28</sup> on the logit of propensity scores.<sup>29</sup>

Restricted cubic spline, logistic regression, and propensity score models were all adjusted for the same covariates: age, sex, year, income quintile, rurality, transfer from any health care institution, medical comorbidity, fracture and surgery type, Injury Severity Score, surgeon volume and experience, hospital volume and type, and surgery duration. Variables thought to be confounders based on existing literature<sup>18</sup> and clinical judgment were included. Mediators of delay unrelated to mortality (such as surgery timing)<sup>2</sup> and common effects of the relationship between delay and mortality (such as discharge disposition) were not included as variables in the models.<sup>30</sup> Missing data, which was less than 1% for all variables considered, were excluded from regression models.

Baseline cohort characteristics were reported as means (SDs) and proportions as appropriate and compared using standardized mean differences to avoid identifying spurious statistical associations in the large administrative data set. Standardized differences of more than 0.1 were considered indicative of imbalance.<sup>31</sup> The McNemar test compared outcomes in early and delayed groups after matching and generalized estimating equations (GEEs) calculated percent absolute risk differences (% absolute risk difference [RD], with 95% CIs).

### Sensitivity Analyses

Several prespecified sensitivity analyses were conducted. Splines were generated in patient subgroups stratified by sex, medical comorbidity, hospital type, and timing of presentation to determine whether the identified time threshold was consistent across patient subgroups.<sup>17,18</sup> Prespecified falsification hypotheses tested specificity of the findings.<sup>25</sup> Because medication data were only available for patients older than 65 years in the Ontario databases, a sensitivity analysis restricted to these patients adjusted for blood thinner prescriptions within the year before surgery.<sup>32</sup>

Two post hoc sensitivity analyses were also conducted. Prolonged wait times may indicate medical, rather than administrative, reasons for delay and even greater confounding. Therefore, an analysis restricted to patients' receiving

**Table 2. Baseline Characteristics of 42 230 Patients Undergoing Hip Fracture Surgery in Ontario Between 2009-2014**

	Before Matching, No. (%)			After Matching, No. (%)		
	≤24 Hours (n = 14 174)	>24 Hours (n = 28 056)	Standardized Mean Difference <sup>a</sup>	≤24 Hours (n = 13 731)	>24 Hours (n = 13 731)	Standardized Mean Difference <sup>a</sup>
ED to surgery, mean (SD), h	15.7 (6.16)	50.4 (28.8)		15.7 (6.15)	48.5 (27.3)	
<b>Demographics</b>						
Age, mean (SD), y	79.9 (11.5)	81.2 (10.2)	0.12	80.1 (11.3)	80.1 (10.7)	0.01
Women	10 172 (71.8)	19 587 (69.8)	0.04	9866 (71.9)	9806 (71.4)	0.01
<b>Income Quintile</b>						
Lowest	3145 (22.2)	6358 (22.7)	0.01	3040 (22.1)	3054 (22.2)	0
2	2873 (20.3)	5719 (20.4)	0	2807 (20.4)	2793 (20.3)	0
3	2715 (19.2)	5276 (18.8)	0.01	2657 (19.4)	2654 (19.3)	0
4	2698 (19.0)	5388 (19.2)	0	2624 (19.1)	2609 (19.0)	0
Highest	2679 (18.9)	5174 (18.4)	0.01	2603 (19.0)	2621 (19.1)	0
Missing	64 (0.5)	141 (0.5)	0.01	0	0	0
Rural residence	1123 (7.9)	2488 (8.9)	0.03	1098 (8.0)	1056 (7.7)	0.01
Missing	86 (0.6)	199 (0.7)	0.01			
<b>Comorbidity</b>						
<b>Associated conditions</b>						
Injury severity score ≥16 <sup>b</sup>	129 (0.9)	200 (0.7)	0.02	108 (0.8)	107 (0.8)	0
Bone cancer	50 (0.4)	126 (0.4)	0.02	47 (0.3)	60 (0.4)	0.02
Osteomyelitis	NR	17 (0.1)	0.02	NR	NR	0.02
Other fractures	655 (4.6)	1391 (5.0)	0.02	625 (4.6)	671 (4.9)	0.02
Total hip arthroplasty within 5 y prior	111 (0.8)	250 (0.9)	0.01	107 (0.8)	111 (0.8)	0
<b>Specific comorbidities</b>						
Frail	2141 (15.1)	5079 (18.1)	0.08	2102 (15.3)	2069 (15.1)	0.01
Diabetes	3831 (27.0)	8626 (30.7)	0.08	3733 (27.2)	3726 (27.1)	0
Hypertension	10 711 (75.6)	22 593 (80.5)	0.12	10 448 (76.1)	10 489 (76.4)	0.01
Chronic obstructive pulmonary disease	2437 (17.2)	5702 (20.3)	0.08	2380 (17.3)	2305 (16.8)	0.01
Congestive heart failure	2396 (16.9)	7171 (25.6)	0.21	2347 (17.1)	2359 (17.2)	0
Coronary artery disease	848 (6.0)	2271 (8.1)	0.08	831 (6.1)	851 (6.2)	0.01
Dementia	3962 (28.0)	8384 (29.9)	0.04	3872 (28.2)	3719 (27.1)	0.02
<b>Deyo-Charlson score<sup>c</sup></b>						
0	2298 (16.2)	4514 (16.1)	0	2237 (16.3)	2194 (16.0)	0.01
1	1910 (13.5)	4056 (14.5)	0.03	1865 (13.6)	1855 (13.5)	0
2	1093 (7.7)	2692 (9.6)	0.07	1071 (7.8)	1095 (8.0)	0.01
3 or more	1628 (11.5)	4595 (16.4)	0.14	1595 (11.6)	1555 (11.3)	0.01
No admission within 5yrs prior	7245 (51.1)	12 199 (43.5)	0.15	6963 (50.7)	7032 (51.2)	0.01
<b>John Hopkins CADG</b>						
Acute minor	12 150 (85.7)	24 675 (87.9)	0.07	11 796 (85.9)	11 857 (86.4)	0.01
Acute major	12 768 (90.1)	25 857 (92.2)	0.07	12 384 (90.2)	12 463 (90.8)	0.02
Likely to recur	10 591 (74.7)	21 509 (76.7)	0.05	10 284 (74.9)	10 235 (74.5)	0.01
Asthma	897 (6.3)	1991 (7.1)	0.03	875 (6.4)	854 (6.2)	0.01
Chronic medical unstable	9766 (68.9)	21 170 (75.5)	0.15	9502 (69.2)	9767 (71.1)	0.04
Chronic medical stable	11 508 (81.2)	23 484 (83.7)	0.07	11 199 (81.6)	11 185 (81.5)	0
Chronic specialty stable	1542 (10.9)	3249 (11.6)	0.02	1510 (11.0)	1595 (11.6)	0.02
Eye dental	4113 (29.0)	8641 (30.8)	0.04	4002 (29.1)	4073 (29.7)	0.01
Chronic specialty unstable	3556 (25.1)	7369 (26.3)	0.03	3458 (25.2)	3490 (25.4)	0.01
Psychosocial	8079 (57.0)	16 789 (59.8)	0.06	7867 (57.3)	7838 (57.1)	0
Prevention, administration	7079 (49.9)	14 645 (52.2)	0.05	6874 (50.1)	6918 (50.4)	0.01
Pregnancy	48 (0.3)	94 (0.3)	0	45 (0.3)	51 (0.4)	0.01

(continued)

Table 2. Baseline Characteristics of 42 230 Patients Undergoing Hip Fracture Surgery in Ontario Between 2009-2014 (continued)

	Before Matching, No. (%)			After Matching, No. (%)		
	≤24 Hours (n = 14 174)	>24 Hours (n = 28 056)	Standardized Mean Difference <sup>a</sup>	≤24 Hours (n = 13 731)	>24 Hours (n = 13 731)	Standardized Mean Difference <sup>a</sup>
<b>Fracture Characteristics</b>						
Fracture type						
Femoral neck	7039 (49.7)	14 169 (50.5)	0.02	6796 (49.5)	6809 (49.6)	0
Intertrochanteric	6275 (44.3)	12 269 (43.7)	0.01	6102 (44.4)	6078 (44.3)	0
Subtrochanteric	860 (6.1)	1618 (5.8)	0.01	833 (6.1)	844 (6.1)	0
Fixation						
Sliding hip screw or cannulated screws	6754 (47.7)	12 362 (44.1)	0.07	6476 (47.2)	6501 (47.3)	0
Arthroplasty	5068 (35.8)	11 180 (39.8)	0.08	4958 (36.1)	4950 (36.0)	0
Intramedullary nail	2352 (16.6)	4514 (16.1)	0.01	2297 (16.7)	2280 (16.6)	0
Surgery duration, mean (SD), min	102.16 (45.41)	107.68 (42.83)	0.13	102.00 (41.19)	102.73 (38.98)	0.02
Timing of surgery, No. (%)						
Evening or weekend	10 388 (73.3)	19 426 (69.2)	0.09	10 071 (73.3)	9800 (71.4)	0.04
Working hours	3668 (25.9)	8307 (29.6)	0.08	3547 (25.8)	3788 (27.6)	0.04
Overnight	118 (0.8)	323 (1.2)	0.03	113 (0.8)	143 (1.0)	0.02
<b>Hospital and Surgeon Characteristics</b>						
Hospital type						
Academic	3479 (24.5)	8688 (31.0)	0.14	3379 (24.6)	3387 (24.7)	0
Large community (≥400 beds)	4991 (35.2)	10 949 (39.0)	0.08	4963 (36.1)	4945 (36.0)	0
Medium community (<400 beds)	5603 (39.5)	8138 (29.0)	0.22	5389 (39.2)	5399 (39.3)	0
Missing	101 (0.7)	281 (1.0)	0.03	0	0	0
Hospital hip fracture volume the prior year, mean (SD)	243.9 (106.6)	253.4 (115.0)	0.09	252.8 (139.2)	253.8 (138.1)	0.01
Hospital daily urgent surgery volume in the prior year, mean (SD)	4.28 (2.47)	4.64 (2.67)	0.14	4.27 (2.44)	4.33 (2.61)	0.02
Surgeon years in practice, mean (SD)	12.6 (9.36)	12.6 (9.76)	0.01	12.6 (9.36)	12.6 (9.72)	0
Surgeon hip fracture volume in the prior year, mean (SD), y	40.20 (22.09)	39.90 (22.21)	0.01	40.32 (22.15)	40.40 (22.44)	0
<b>Other Characteristics</b>						
Transfer from any health care institution	3608 (25.5)	8824 (31.5)	0.13	3529 (25.7)	3515 (25.6)	0
Discharge disposition						
Home	3690 (26.0)	5407 (19.3)	0.16	3527 (25.7)	3000 (21.8)	0.09
Long-term or complex continuing care	3680 (26.0)	7668 (27.3)	0.03	3606 (26.3)	3498 (25.5)	0.02
Palliative or deceased	526 (3.7)	1657 (5.9)	0.1	515 (3.8)	689 (5.0)	0.06
Rehabilitation	5044 (35.6)	9941 (35.4)	0	4912 (35.8)	5032 (36.6)	0.02
Other	1234 (8.7)	3383 (12.1)	0.11	1171 (8.5)	1512 (11.0)	0.08
Year						
2009	2590 (18.3)	5258 (18.7)	0.01	2555 (18.6)	2398 (17.5)	0.03
2010	2552 (18.0)	5587 (19.9)	0.05	2498 (18.2)	2657 (19.4)	0.03
2011	2703 (19.1)	5592 (19.9)	0.02	2535 (18.5)	2608 (19.0)	0.01
2012	2998 (21.2)	5645 (20.1)	0.03	2909 (21.2)	2875 (20.9)	0.01
2013	3331 (23.5)	5974 (21.3)	0.05	3234 (23.6)	3193 (23.3)	0.01

Abbreviation: CADG, collapsed aggregated diagnosis groups; ED, emergency department; NR, not reportable according to privacy guidelines.

<sup>a</sup> Differences of 0.1 or more represent meaningful differences in covariates between groups.

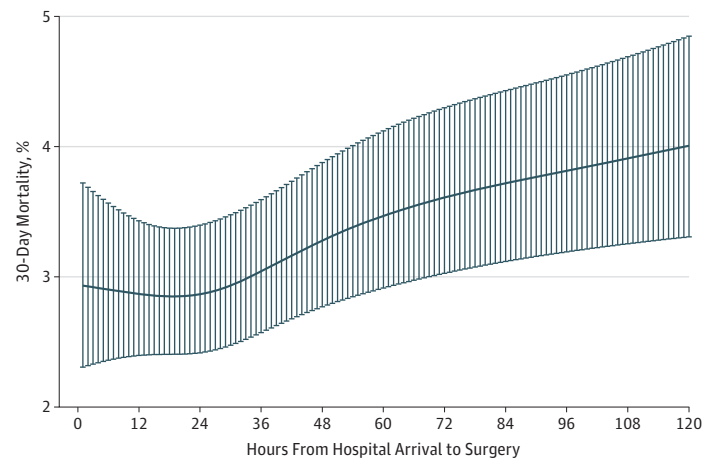
<sup>b</sup> The Injury Severity Score is a measure of the severity of traumatic injury and ranges from 0 (least severe) to 75 (most severe).

<sup>c</sup> Deyo-Charlson score is a measure of patient comorbidity (prior to their hip fracture) and ranges from 0 (lowest mortality risk) to 3 or more (highest mortality risk). Patients may also be classified as having no prior hospital admissions.

surgery within 36 hours was conducted to assess the association between wait times and complications in a subgroup with less potential for unmeasured confounding. As an indi-

cator of residual confounding in the delayed group, the relationship between matching status (matched or unmatched) and mortality in delayed group patients was also explored.

Figure 1. Probability of the Primary Outcome According to Wait Times for Surgery as a Continuous Variable



Probabilities (95% CIs) models used restricted cubic splines adjusting for age, sex, calendar year, income quintile, rurality, transfer from any health care institution, Deyo-Charlson score, history of frailty, diabetes, heart failure, chronic obstructive pulmonary disease, myocardial infarction, or hypertension, fracture and surgery type, Injury Severity Score, surgeon volume and experience, hospital volume and type, and surgery duration. Analysis

conducted among 41 186 of 42 230 patients. C statistic was 0.756. Variance inflation factors were 4 or less for included variable included, indicating an absence of collinearity. Probabilities of the primary outcome according to wait-times for surgery are presented for patients with average fracture, physician, and hospital system characteristics in the cohort.

All analyses were performed at ICES using SAS statistical software version 9.3 and Enterprise Guide version 6.1 (SAS Institute Inc) and a 2-sided type I error probability of .05.

## Results

There were a total of 42 230 patients who met inclusion (Table 1) and were treated by 522 orthopedic surgeons at 72 Ontario hospitals. Their mean (SD) age was 80.1 (10.7) years, and 70.5% were women (Table 2). The mean (SD) time to surgery was 38.8 (28.8) hours. Adjusted splines modeled an area of inflection around 24 hours when the risk of developing complications began to increase, irrespective of the outcome or follow-up period assessed (Figure 1 and Figure 2). Surgical complications (dislocation, hardware removal) were not related to wait-time (Figure 2). The maximum area under the curve increase occurred when using 24 hours to classify patients into early or delayed surgery groups compared with 6-, 12-, 18-, 30- and 36-hour thresholds (eAppendix D in the Supplement). *Delayed hip fracture surgery* was therefore defined as surgery occurring more than 24 hours after emergency department arrival.

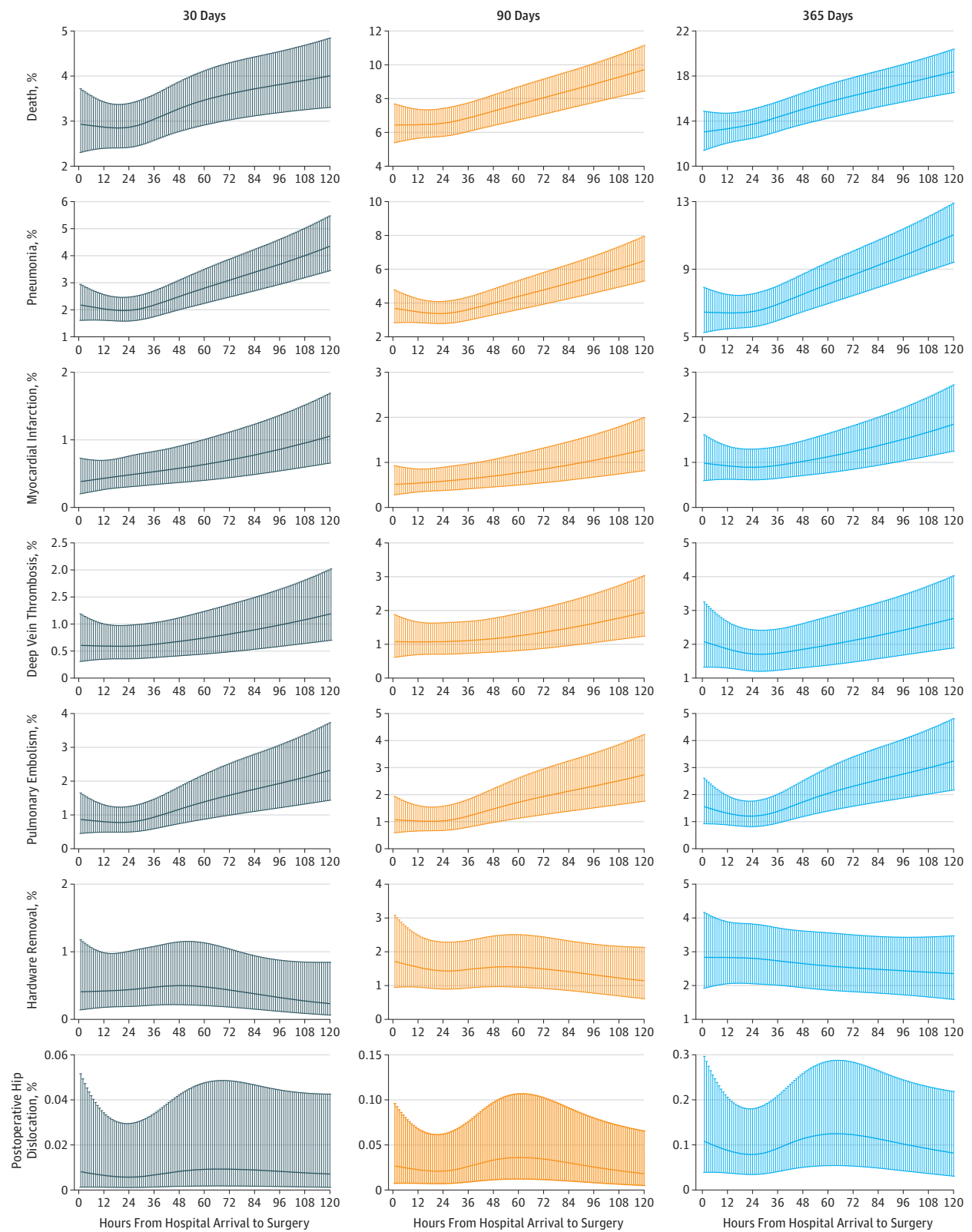
According to this definition, 14 174 patients (33.6%) received early surgery and 28 056 patients (66.4%) received delayed surgery. Before matching, patients receiving delayed surgery were significantly more likely to be men, have medical comorbidity, arrive from other health care institutions, and be treated at academic or higher-volume centers (Table 2). There were 13 731 ( $\approx 97\%$ ) patients in the early surgery group matched to those in the delayed group, and covariates were balanced between groups after matching (including those variables with missing categories).

Of the 13 731 matched patients who received hip fracture surgery after 24 hours, 898 patients (6.5%) died within 30 days vs 790 patients (5.8%) of 13 731 who received surgery within 24 hours, for an absolute risk difference of 0.79% (95% CI, 0.23%-1.35%); 166 (1.2%) vs 96 (0.7%) had pulmonary embolism, for an absolute risk difference of 0.51% (95% CI, 0.28%-0.74%); 160 (1.2%) vs 107 (0.8%) had myocardial infarction, for an absolute risk difference of 0.39% (95% CI, 0.15%-0.62%); and 637 (4.6%) vs 506 (3.7%) had pneumonia, for an absolute risk difference of 0.95% (95% CI, 0.48%-1.43%). For the composite outcome, 1680 patients (12.2%) vs 1383 (10.1%) died within 30 days for an absolute risk difference of 2.16% (95% CI, 1.43%-2.89%). Outcomes remained significant at 90 and 365 days (Table 3).

Mortality due to deep venous thrombosis was not significantly different between groups at 30 days with 136 patients (1.0%) who did not undergo surgery for more than 24 hours vs 111 patients (0.8%) who received it within 24 hours for an absolute risk difference of 0.18% (95% CI, -0.04% to 0.40%). The same held true at 90 days with 190 patients (1.4%) vs 169 patients (1.2%) for an absolute risk difference of 0.15% (95% CI, -0.11% to 0.42%) and at 365 days 259 (1.9%) vs 255 (1.9%) for an absolute risk difference of 0.03% (95% CI, -0.29% to 0.35%).

The relationships between wait times and complications were robust to stratification among different patient subgroups, including among patients without comorbidity and those receiving surgery within 36 hours, for whom confounding by indication should not play a role (eAppendices C and G in the Supplement). There was no significant difference in surgical complications (negative tracer outcomes) between groups (Table 3). Sensitivity analysis restricted to patients older than 65 years and adjusting for antiplatelet or anticoagulant medications also produced equivalent results (eAppendix E in the

Figure 2. Probability of the Primary, Secondary, and Negative Tracer Outcomes (Involving Hardware Removal and Hip Dislocation)



Probabilities (95% CIs) models used restricted cubic splines. Variables in the adjusted models are listed in the "Outcomes" section of the Methods and in Figure 1. Analysis conducted among 41 186 of 42 230 patients.

Probabilities of each outcome according to wait times for surgery are presented for the patient with average fracture, physician, and hospital system characteristics in the cohort.

Table 3. Primary and Secondary Outcomes After Matching<sup>a</sup>

Outcome	No. (%) of Patients		Absolute Risk Difference, % (95% CI)	P Value <sup>b</sup>
	≤24 Hours (n = 13 731)	>24 Hours (n = 13 731)		
<b>Primary Outcome</b>				
30-d Mortality	790 (5.8)	898 (6.5)	0.79 (0.23 to 1.35)	.006
<b>Secondary Outcomes</b>				
<b>Mortality, d</b>				
90	1463 (10.7)	1649 (12.0)	1.35 (0.61 to 2.10)	<.001
365	2654 (19.3)	2971 (21.6)	2.31 (1.47 to 3.25)	<.001
<b>Pulmonary embolism, d</b>				
30	96 (0.7)	166 (1.2)	0.51 (0.28 to 0.74)	<.001
90	118 (0.9)	191 (1.4)	0.53 (0.28 to 0.78)	<.001
365	152 (1.1)	228 (1.7)	0.55 (0.28 to 0.83)	<.001
<b>Deep venous thrombosis, d</b>				
30	111 (0.8)	136 (1.0)	0.18 (-0.04 to 0.40)	.11
90	169 (1.2)	190 (1.4)	0.15 (-0.11 to 0.42)	.26
365	255 (1.9)	259 (1.9)	0.03 (-0.29 to 0.35)	.86
<b>Pneumonia, d</b>				
30	506 (3.7)	637 (4.6)	0.95 (0.48 to 1.43)	<.001
90	671 (4.9)	800 (5.8)	0.94 (0.41 to 1.47)	<.001
365	1101 (8.0)	1245 (9.1)	1.05 (0.39 to 1.71)	.002
<b>Myocardial infarction, d</b>				
30	107 (0.8)	160 (1.2)	0.39 (0.15 to 0.62)	.001
90	126 (0.9)	181 (1.3)	0.40 (0.15 to 0.65)	.002
365	184 (1.3)	231 (1.7)	0.34 (0.06 to 0.63)	.02
<b>Composite outcome, d<sup>c</sup></b>				
30	1383 (10.1)	1680 (12.2)	2.16 (1.43 to 2.89)	<.001
90	2153 (15.7)	2492 (18.1)	2.47 (1.59 to 3.34)	<.001
365	3568 (26.0)	4009 (29.2)	3.21 (2.17 to 4.25)	<.001
<b>Negative tracer outcomes, d<sup>d</sup></b>				
<b>Hardware removal</b>				
30	54 (0.4)	47 (0.3)	-0.05 (-0.19 to 0.09)	.49
90	156 (1.1)	140 (1.0)	-0.12 (-0.36 to 0.13)	.35
365	384 (2.8)	347 (2.5)	-0.27 (-0.65 to 0.11)	.16
<b>Postoperative hip dislocation</b>				
30	24 (0.2)	28 (0.2)	0.05 (-0.07 to 0.13)	.58
90	43 (0.3)	43 (0.3)	0 (-0.13 to 0.13)	>.99
365	59 (0.4)	54 (0.4)	-0.04 (-0.19 to 0.12)	.64

<sup>a</sup> Greedy matching occurred 1:1 on the logit of a propensity score with a caliper of 0.2 × SD; 96.9% of eligible patients who found matches.

<sup>b</sup> P values were calculated using the McNemar test.

<sup>c</sup> Mortality and other medical complications.

<sup>d</sup> Surgical complications presumed to be unrelated to wait-times were assessed as negative tracer outcomes intended to test the specificity of the findings.

Supplement). Although unmatched patients in the delayed group were more medically complex than matched patients, adjusted regression found no significant association between matching status and 30-day mortality indicating no residual confounding in the matched delayed group (eAppendix F in the Supplement).

## Discussion

Among adults undergoing hip fracture surgery in Ontario, Canada, increased wait time was associated with a greater risk of 30-day mortality and other complications. Although several studies have linked wait times for hip fracture surgery to mortality and morbidity,<sup>5</sup> inconsistent evidence

for a time-to-surgery threshold has translated to variable guideline recommendations and compliance with wait-time benchmarks.<sup>6-8</sup>

This is the first study, to our knowledge, to analyze time as a continuous variable in hours and empirically identify a time-to-surgery threshold associated with increased complications after hip fracture. The primary finding pertains to increasing numbers of patients experiencing hip fractures and the different medical and surgical specialists treating them: a wait time of 24 hours may represent a threshold defining higher risk because complications increased when surgery was delayed after this time, irrespective of the complication, follow-up period, or patient subgroup assessed. Preoperative optimization is often required for patients with a hip fracture and can feasibly be performed within the



proposed timeframe. Because wait times for hip fracture surgery are already used worldwide as quality indicators to assess hospital performance, the results of this study may inform existing hip fracture care guidelines and policies.<sup>6-8</sup>

Targeting surgery within 24 hours represents a significant change in practice because 66% of the patients in this study did not receive surgery within this timeframe. Hip fracture prioritization must also be balanced with the needs of patients on waiting lists for other surgical procedures. Because time to surgery rather than timing of surgery is associated with increased risk,<sup>2</sup> continuing to conduct hip fracture operations during evenings and weekends may help reduce wait times for hip fracture surgery without conflicting with elective operations. However, other performance improvement efforts will be required, as well as future work that identifies where these efforts would be most successfully targeted. Although effect modification was not observed in subgroup analyses, given the practical challenges of further reducing existing thresholds, future work may continue trying to identify a subset most in need of urgent surgery.

This study has several strengths. First, a population-based sample from Ontario's diverse population of approximately 13.5 million was used. Findings are generalizable to other jurisdictions, including the United States<sup>11</sup> and Europe,<sup>14</sup> where operating room resources are limited and patients are required to wait for hip fracture surgery. Second and third, the study was conducted in a public health care system where patients can be followed up for complications even if they present elsewhere in the system and surgical delays are mostly related to administrative rather than patient factors.<sup>33</sup>

Fourth, rather than arbitrarily dividing patients into early and delayed surgery groups,<sup>12-14,34</sup> exact time-to-surgery data (in hours) and spline regression were used to empirically define a threshold for increased risk. Observational research is required to determine a time-to-surgery threshold because investigators likely consider it unethical and impractical to allocate patients to increasing thresholds of delayed surgery in this way.<sup>5</sup> The Hip Fracture Accelerated Surgical Treatment and Care Track (HIP ATTACK) trial will compare standard of care treatment to surgery performed much earlier than this (ie, within 6 hours of hospital arrival)<sup>3</sup> and may provide important estimates of the effect of early surgery in the absence of confounding by indication. However, the study will not assess whether delays greater than 6 hours but less than the standard of care are acceptable.

## Limitations

This study also has several limitations. First, since medically complex patients are predisposed to both complications and awaiting optimization prior to surgery, several analyses were performed to mitigate the influence of confounding. Comparisons between early and delayed surgery groups after matching were balanced across more than 30 covariates, which included detailed measures of preexisting medical comorbidity. The absence of effect modification in several important clinical scenarios was also demonstrated in subgroup analyses, including those restricted to patients without comorbidity and those receiving surgery within 36 hours for whom surgical delays should be administrative. However, the finding that increased wait time is associated with increased risk may still be influenced by unmeasured factors.

Second, other complications were not considered that may be clinically important in this population and potentially related to waiting for surgery, such as major bleeding.<sup>3</sup> Outcomes were chosen based on their being (1) important clinical priorities, (2) plausibly related to the primary exposure,<sup>35</sup> and (3) identifiable by validated codes (see eAppendix B in the Supplement).<sup>36</sup> Future study is required to assess whether misclassification of fat embolism as pulmonary embolism, the more salient diagnosis, may explain the significant difference observed in pulmonary embolism between groups, whereas a difference in deep vein thrombosis was not detected. Although patient reported outcomes were not assessed, it may be assumed that expedited hip fracture surgery is patient centered and would be appreciated by patients and their families, other processes of care being equal.<sup>37</sup> Third, patients with nonoperative hip fracture were also not considered because those who died waiting for surgery could not be distinguished from those for whom nonoperative treatment was indicated. However, experiencing a major complication while waiting for surgery precluded the former patients from entering the cohort, leading to more conservative estimates of the effect of waiting for surgery.

## Conclusions

Among adults undergoing hip fracture surgery, increased wait time was associated with a greater risk of 30-day mortality and other complications. A wait time of 24 hours may represent a threshold defining higher risk. Because two-thirds of patients did not receive surgery within this timeframe, performance improvement is warranted.

### ARTICLE INFORMATION

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**Concept and design:** Pincus, Ravi, Wasserstein, Paterson, Kreder, Jenkinson, Wodchis.

**Acquisition, analysis, or interpretation of data:** Pincus, Ravi, Huang, Paterson, Nathens, Kreder, Jenkinson, Wodchis.

**Drafting of the manuscript:** Pincus, Jenkinson, Nathens.

**Critical revision of the manuscript for important intellectual content:** Pincus, Ravi, Wasserstein, Huang, Paterson, Kreder, Jenkinson, Wodchis.

**Statistical analysis:** Pincus, Ravi, Wasserstein, Huang.

**Administrative, technical, or material support:**

Wasserstein, Paterson, Nathens, Kreder.

**Supervision:** Ravi, Wasserstein, Nathens, Kreder, Jenkinson, Wodchis.

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