

Costs of cervical cancer treatment: population-based estimates from Ontario

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ABSTRACT

Objectives The objectives of the present study were to estimate the overall and specific medical care costs associated with cervical cancer in the first 5 years after diagnosis in Ontario.

Methods Incident cases of invasive cervical cancer during 2007–2010 were identified from the Ontario Cancer Registry and linked to administrative databases held at the Institute for Clinical Evaluative Sciences. Mean costs in 2010 Canadian dollars were estimated using the arithmetic mean and estimators that adjust for censored data.

Results Mean age of the patients in the study cohort (779 cases) was 49.3 years. The mean overall medical care cost was \$39,187 [standard error (SE): \$1,327] in the 1st year after diagnosis. Costs in year 1 ranged from \$34,648 (SE: \$1,275) for those who survived at least 1 year to \$69,142 (SE: \$4,818) for those who died from cervical cancer within 1 year. At 5 years after diagnosis, the mean overall unadjusted cost was \$63,131 (SE: \$3,131), and the cost adjusted for censoring was \$68,745 (SE: \$2,963). Inpatient hospitalizations and cancer-related care were the two largest components of cancer treatment costs.

Conclusions We found that the estimated mean costs that did not account for censoring were consistently undervalued, highlighting the importance of estimates based on censoring-adjusted costs in cervical cancer. Our results are reliable for estimating the economic burden of cervical cancer and the cost-effectiveness of cervical cancer prevention strategies.

Key Words Cervical cancer, cost estimates, censoring, Ontario, population-based

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INTRODUCTION

Cancer is the leading cause of death in Canada, accounting for nearly 30% of all mortality¹. Cancer is one of the most costly diseases², and its economic burden is substantial in Canada. The direct cost of cancer care in Canada in 2008 was estimated at \$4 billion³.

Cervical cancer is the 2nd leading cause of cancer death among Ontario women 20–44 years of age⁴, and the 4th most common cause of cancer death among women worldwide⁵. Of every 145 Ontario women, 1 will be diagnosed with cervical cancer during her lifetime, and each year in Ontario, approximately 610 women are diagnosed with cervical cancer, and approximately 150 die from the disease¹.

Treatment for cervical cancer is complex and can include surgery, chemotherapy, and radiation therapy. Of Ontario women diagnosed with cervical cancer in

2003–2004, more than 30% received chemotherapy, and an estimated 55% received radiation therapy⁶. More than half of Ontario's cervical cancer patients had a cancer-related surgical procedure, and each patient had an average of 1.5 hospital admissions within 12 months of diagnosis⁶. In the United States, resource consumption for cancer patients is highest during the initial phase of treatment and the terminal phase before death⁷, because in the 1st year after diagnosis, patients undergo primary treatment and experience the greatest mortality^{8,9}.

Accurate estimates of the cost of cancer treatment are crucial for economic evaluations, policy decisions, and forecasting future medical care expenditures relating to cancer treatment. Although a prior study estimated the costs of cervical cancer treatment in Canada¹⁰, no Canadian study has, to the best of our knowledge, examined cervical cancer costs beyond the 1st year after diagnosis

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or accounted for censoring. In addition, prior publications using Ontario data for cost estimates failed to capture costs associated with visits to cancer clinics or dialysis clinics or those associated with mental health admissions, because those data were not available before 2007. The objective of the present study was therefore to fill those important gaps by using the most recent Ontario data and by accounting for censoring, thereby providing estimates of the total direct medical care costs of treating cervical cancer during the first 5 years after diagnosis. We estimated costs from the perspective of the Ontario Ministry of Health and Long-Term Care.

METHODS

Ontario women 35–69 years of age with incident primary cases of cervical cancer (*International Classification of Diseases*, 9th revision, code group 180.x) diagnosed between 1 January 2007 and 31 December 2010 were identified from the Ontario Cancer Registry. Records of those cervical cancer cases were linked with several population-based administrative databases held at the Institute for Clinical Evaluative Sciences (ICES). The linkages used unique encoded identifiers and were analyzed at ICES. Demographic data were obtained from the Registered Persons Database, and dates and causes of death were obtained from the Vital Statistics Registry. Patients without a valid Ontario Health Insurance Plan number or whose date of death preceded the date of diagnosis were excluded.

Data about direct medical care costs were obtained from the ICES administrative databases using the costing methodology developed at ICES¹¹; Table I describes in detail the data sources and costing methodologies for all health care services included in the present study. We captured the costs of all health care services covered by the province that were provided to our patient cohort: inpatient hospitalizations, same-day surgeries, emergency department visits, ambulatory visits to hospital (for example, to cancer clinics and dialysis clinics), stays in long-term care, inpatient rehabilitation stays, physician services, home care services, and community laboratory services. We captured the costs of publicly insured prescription drugs for patients 65 years of age and older or meeting other eligibility criteria for the Ontario Drug Benefit. Costs from a patient's index date (date of diagnosis) to date of death or 31 December 2012 were included. Costs for each year were adjusted for inflation and are presented in 2010 Canadian dollars (adjusted using Statistics Canada's Consumer Price Index for health care).

We estimated overall and specific costs during the first 5 years after diagnosis. Annual costs were estimated for patients who survived longer than 1 year and for patients who died in a given year from any cause, from a cervical cancer-related cause, and from another cancer cause of death. Overall and cancer-clinic costs were also estimated by year of diagnosis. First, we used the arithmetic mean (that is, a simple mean) to estimate costs. However, the simple mean estimation is likely to be inaccurate because length of follow-up varied for the patients. To account for censored data because of the varying follow-up, we used the Bang and Tsiatis (B&T) estimator for weighted and

improved estimates^{12–14}. All analyses were conducted using the SAS software application (version 9.2; SAS Institute, Cary, NC, U.S.A). Appendix A presents the details of the statistical methods.

RESULTS

The women in the study cohort, representing 779 cases of cervical cancer, had been diagnosed between 2007 and 2010. Mean age at diagnosis was 49 years (95% confidence interval: 47 years to 53 years). About 36% of the patients ($n = 279$) died within 5 years of diagnosis, and of those 279 deaths, 79% ($n = 221$) were caused by cervical cancer. The entire cohort was observed for a minimum of 2 years after diagnosis or until death, and therefore no cases were censored during years 1 or 2 after diagnosis. In the 3rd year after diagnosis, 21% of the cohort had censored cost data, and by the end of year 5, 52% of patients were censored.

Table II reports mean costs for the study cohort overall and by 1-year vital status without taking censoring into account. Overall mean cost during the 1st year post-diagnosis was \$39,187 [standard error (SE): \$1,327]. The mean cost was much higher for patients who died within 1 year of diagnosis (\$66,790; SE: \$4,482) than for those who survived for longer than 1 year (\$34,648; SE: \$1,275). The cost was higher for patients who died from cervical cancer (\$69,142; SE: \$4,483) than for those who died from other causes (\$56,824; SE: \$11,338). For patients who survived 1 year or longer, the highest cost category was cancer clinic costs; for patients who died within 1 year, it was inpatient hospitalization (Table II). Cancer clinic costs were lower for patients who died within 1 year of diagnosis from non-cervical-cancer causes (\$5,238; SE: \$1,365) than for patients who died from cervical cancer (\$12,440; SE: \$1,143) or who survived at least 1 year (\$14,130; SE: \$516).

Table III reports mean cumulative costs in cervical cancer patients (simple arithmetic mean and weighted and improved estimates). Annual costs were highest during year 1 (\$39,187; SE: \$1,327) and declined during subsequent years (year 2: \$14,425; SE: \$1,346; year 3: \$11,280; SE: \$1,677; year 4: \$8,444; SE: \$1,023; year 5: \$5,480; SE \$1,074).

Mean 1-year costs varied greatly by year of diagnosis, ranging from \$35,519 (SE: \$2,257) in 2010 to \$45,369 (SE: \$3,383) in 2009 (Table IV). Table V reports costs by year after diagnosis and survival during that year. Our results showed that the estimated mean costs without accounting for censoring were consistently lower than the B&T estimates. Mean cumulative 3- and 4-year costs were \$58,702 (SE: \$2,710) and \$63,131 (\$3,131) respectively when estimated using the simple mean. Using the improved estimator, the corresponding cumulative 3- and 5-year costs were \$59,768 (\$3,016) and \$68,745 (\$2,963) respectively. Estimates using weighted and improved estimators were similar, but the variance with the improved estimator was generally smaller and thus more efficient.

DISCUSSION

In the present study, we estimated the direct medical care costs of cervical cancer treatment in Ontario during the first 5 years after a diagnosis of cervical cancer.

TABLE I Data sources and costing methodology

Resource	Source database and costing methodology
Cancer clinic visits	National Ambulatory Care Reporting System <ul style="list-style-type: none"> Case costs are estimated by multiplying a patient's resource intensity weight^a by hospital- and year-specific cost per weighted case: $RIW \times CPWC$
Hospital-based care	
Inpatient hospitalizations	Discharge Abstract Database (maintained by CIHI) <ul style="list-style-type: none"> Estimated using $RIW \times CPWC$.
Same-day surgery	National Ambulatory Care Reporting System <ul style="list-style-type: none"> Estimated using $RIW \times CPWC$.
Emergency department visits	National Ambulatory Care Reporting System <ul style="list-style-type: none"> Estimated using $RIW \times CPWC$.
Dialysis clinic visits	National Ambulatory Care Reporting System <ul style="list-style-type: none"> Estimated using $RIW \times CPWC$.
Tertiary care	
Rehabilitation admissions	National Rehabilitation Reporting System <ul style="list-style-type: none"> Estimated using rehabilitation cost weight multiplied by the CPWC.
Complex continuing care	Continuing Care Reporting System <ul style="list-style-type: none"> Weighted days are based on case mix index and length of stay; case costs are estimated by multiplying weighted days by cost per weighted day: $(CMI \times LOS) \times CPWD$
Long-term care	
FY2007–FY2008	Ontario Health Insurance Plan and Ontario Drug Benefit <ul style="list-style-type: none"> LOS is derived from claims data and costs are based on LOS multiplied by the cost per diem set by the Ministry of Health: $LOS \times \text{cost per diem}$
FY2009–2010	Continuing Care Reporting System <ul style="list-style-type: none"> CMI and LOS information are used to calculate weighted days, which are multiplied by the Ministry of Health cost per diem: $(CMI \times LOS) \times CPWD$
Mental health admissions	Ontario Mental Health Reporting System <ul style="list-style-type: none"> Mental health-specific CMIs assigned during each phase of care (admission, acute, long-term) are multiplied by the associated LOS and CPWD. Costs in each phase are summed to estimate the overall cost of care: $\Sigma[(CMI \times LOS) \times CPWD]$
Home care services	Home Care Database <ul style="list-style-type: none"> Home care costs are estimated by multiplying the year-specific provincial-average cost per service by the number of visits or hours of service.
Physician services	
Fee-for-service billings	Ontario Health Insurance Plan <ul style="list-style-type: none"> Costs are based on the number and type of physician visits and services billed and the fee-for-service rates set by the Ministry of Health for a given year.
Shadow billings	Ontario Health Insurance Plan <ul style="list-style-type: none"> Costs associated with services provided by physicians who are in capitation models or alternative payment plans, or who receive salaries are estimated using shadow billing claims, which base costs on the visit or service provided and fee-for-service rate in a given year.
Primary care capitation	Client Agency Program Enrolment <ul style="list-style-type: none"> Primary-care mode enrolment tables are used to identify patients of physicians receiving age- and sex-adjusted capitation payments.
Prescription drugs	Ontario Drug Benefit <ul style="list-style-type: none"> Costs of outpatient prescription drugs, including oral chemotherapy, are based on the total amount paid by the provincial drug plan to pharmacies for eligible patients (≥ 65 years or meeting other eligibility criteria).
Other	
Non-physician OHIP billings	Ontario Health Insurance Plan <ul style="list-style-type: none"> Costs of services billed by non-physician health professionals (e.g. nurse practitioners, chiropractors, physiotherapists) for insured services.
Laboratory billings	Ontario Health Insurance Plan <ul style="list-style-type: none"> The laboratory component of tests is estimated using set fees. The physician component (interpretation of results) is included in physician billings.

^a Adjusted for several factors including age and flagged intervention groups, including chemotherapy and radiotherapy.

CIHI = Canadian Institute for Health Information.

Cumulative 5-year cancer clinic and overall costs per patient were \$17,294 and \$68,745 respectively. Cost accumulation was greatest during the 1st year after diagnosis,

an unsurprising observation given that treatment is most aggressive during that period^{7,8,10}. Annual total medical care costs declined from \$39,187 per patient in year 1 after

TABLE II Costs associated with cervical cancer in the first year after diagnosis

Variable	Cost ^a by patient group (\$)		
	Survived >1 year (n=669)	Died within 1 year (n=110)	Overall (n=779)
Total cost	34,648±1,275	66,790±4,482	39,187±1,327
Cancer clinic	14,130±416	11,065±998	13,697±386
Hospital-based care			
Inpatient hospitalization	7,912±608	33,597±3,181	11,539±760
Same day surgery	957±42	466±82	887±39
ED visits	702±46	1,723±141	846±46
Dialysis clinic	75±62	764±755	172±119
Tertiary care			
Rehabilitation admissions	197±118	0±0	170±102
Complex continuing care	800±588	4,138±1,494	1,272±549
Long-term care	15±13	258±257	49±38
Mental health admissions	152±133	0±0	131±114
Home care	1,670±184	4,271±562	2,037±180
Physician services	6,640±171	8,494±482	6,902±164
Prescription drugs	1,148±174	1,836±275	1,245±155
Other ^b	249±10	178±20	239±9

^a Average ± standard error.

^b Includes laboratory costs and nonphysician services covered by the Ontario Health Insurance Plan.

TABLE III Medical care costs associated with cervical cancer during years 1–5 after diagnosis

Interval	Sample		Mean costs (\$) ^a			Mean follow-up (days) ^a
	At interval start (n)	Censored during interval (%)	Simple ^b	By weighted method	By improved method	
Year 1	779	0.0	39,187±1,327	39,187±1,327	39,187±1,327	340±3
Years 1–2	779	0.0	51,515±2,059	51,515±2,059	51,515±2,059	637±8
Years 1–3	779	21.1	58,702±2,710	62,017±3,514	59,768±3,016	882±13
Years 1–4	779	37.2	62,035±3,110	63,088±3,011	65,436±3,166	1,118±18
Years 1–5	779	52.4	63,131±3,131	67,074±5,127	68,745±2,963	1,140±24
Year 2	669	0.0	14,425±1,347	14,425±1,347	14,425±1,347	335±4
Years 2–3	669	24.5	22,674±2,285	25,541±3,054	23,967±2,617	631±9
Years 2–4	669	43.4	26,561±2,846	27,869±2,462	30,566±2,947	906±14
Years 2–5	669	61.0	27,838±2,872	31,687±4,219	34,419±2,889	1,164±20
Year 3	570	28.8	9,685±1,372	11,973±1,894	11,280±1,677	348±3
Years 3–4	570	50.9	14,249±2,113	16,564±1,738	19,025±2,147	670±8
Years 3–5	570	71.6	15,748±2,148	20,052±2,921	23,548±2,290	974±14
Year 4	365	34.5	7,154±1,352	7,600±991	8,444±1,023	352±4
Years 4–5	365	66.8	9,504±1,470	11,926±1,981	13,375±1,438	683±9
Year 5	223	49.8	3,682±915	6,104±1,357	5,480±1,074	354±4

^a All ± standard error.

^b Not accounting for censoring.

TABLE IV Average 1-year total medical care and cancer clinic costs by year of diagnosis (uncensored cost estimates)

Year of diagnosis	Pts (n)	Mean cost ^a (\$)	
		Total	Cancer clinic
2007	161	39,763±2,773	13,462±716
2008	198	36,647±2,016	12,907±672
2009	198	45,369±3,373	14,364±759
2010	222	35,519±2,257	13,976±862

^a ± Standard error.

TABLE V Average annual total medical care costs by year and vital status (uncensored cost estimates)

Vital status at year end	Pts (n)	Mean value ^a	
		Total cost (\$)	Follow-up (days)
Survived >1 year	669	34,648±1,275	365±0
Died during year 1			
All causes	110	66,790±4,482	186±10
Cervical cancer	89	69,142±4,818	199±11
Other causes	21	56,824±11,338	132±17
Survived >2 years	570	11,550±1,472	365±0
Died during year 2			
All causes	99	30,508±2,715	157±11
Cervical cancer	77	34,535±3,205	171±12
Other causes	22	16,413±3,436	109±21
Survived >3 years	529	9,012±1,699	365±0
Died during year 3			
All causes	41	36,943±5,722	148±15
Cervical cancer	36–40 ^b	30,342±4,482	137±15
Other causes	≤5	— ^c	— ^c
Survived >4 years	344	6,794±951	365±0
Died during year 4			
All causes	21	32,013±5,087	156±23
Cervical cancer	16–20 ^b	34,084±5,695	166±26
Other causes	≤5	— ^c	— ^c
Survived >5 years	225	4,564±982	362±3
Died during year 5			
All causes	8	25,729±7,997	182±32
Cervical cancer	≤5	— ^c	— ^c
Other causes	≤5	— ^c	— ^c

^a ± Standard error.

^b Sample size range reported because of small sample size.

^c Data not reported because of small sample size.

diagnosis to \$14,425 during year 2, \$11,280 during year 3, \$8,444 during year 4, and \$5,480 during year 5. The 1-year costs were much higher for patients who died from cervical cancer within the year after diagnosis (\$69,142) than for patients who survived at least 1 year (\$34,648). That finding is unsurprising, given that patients who die from cervical cancer are more likely to have late-stage disease and to

receive more intensive treatment, which incurs greater costs. Average 1-year costs varied significantly by year of diagnosis; however, those differences are likely the result of differences in the proportion of deaths in the given years.

Our results showed that cancer clinic and hospital admissions were the two largest drivers of costs in the 1st year after diagnosis, corroborating the findings of a prior study¹⁰. Those cost categories capture costs associated with cancer-related treatments such as chemotherapy, radiation therapy, and cancer-related surgeries. Our estimated cost of inpatient admissions (\$11,539) was nearly double that reported by de Oliveira *et al.*¹⁰ (\$6,761), and our estimated cost of cancer-related care (\$13,697) was much higher than their estimates of chemotherapy (\$804) and radiation therapy (\$3,468) combined. Those differences likely reflect the fact that our estimates included all cancer clinic visits, which are not limited to chemotherapy and radiation therapy and can include services such as palliative care, surgical oncology, and supportive services. Furthermore, de Oliveira *et al.*¹⁰ might have underestimated the costs of radiation therapy, because their cost per fraction of radiation was estimated using data from the 1990s.

To the best of our knowledge, our study of medical care costs for Canadian cervical cancer patients is the first to take censoring into account. An earlier Ontario study reported 1-year average costs of \$18,055 (2009 Canadian dollars) for cervical cancer patients who survived 1 year and \$41,536 for those who died within 1 year¹⁰, which are lower than our mean estimates. The discrepancy might be a result of the fact that our estimates captured all cancer-related costs, including costs associated with rehabilitation, mental health admissions, dialysis clinic visits, and all Ontario Health Insurance Plan billings. To the best of our knowledge, no Canadian studies have described costs for cervical cancer beyond year 1, thus permitting a comparison with our results. In our study, resource consumption was highest during year 1, accounting for 67% of cumulative 3-year costs. That result resembles U.S. findings by Insinga *et al.*⁹, who concluded that 69% of 3-year costs were incurred during year 1⁹. As in other studies of cervical and other cancer patients, we found that mean costs were much higher for patients who died than for those who survived^{8,10}.

Our study also has several limitations. First, the costs were highly skewed, and estimates of mean cost are influenced by high-cost users. Second, cancer staging data were not available for the study cohort; thus, we were unable to produce stage-specific cost estimates. Third, we were unable to exclude medical care costs unrelated to cancer. However, we expect that costs unrelated to cancer are likely to be small for this patient population. Fourth, our estimates of outpatient prescription drug costs were based on data from the Ontario Drug Benefit program. Because the Ontario Drug Benefit provides coverage only to patients 65 years of age and older or to those meeting other eligibility criteria, our outpatient prescription drug costs could be slightly underestimated. However, chemotherapy, representing the largest pharmacotherapy cost, is administered in hospital and is captured by our estimates of cancer clinic costs. Finally, data limitations precluded us from estimating the costs of treatment beyond 5 years after diagnosis.

Our study has several strengths. First, we estimated the overall and specific medical care costs of cervical cancer treatment for the 1st year and beyond the 1st year after diagnosis. Second, we accounted for censoring to produce accurate estimates of treatment costs beyond 1 year. Our simple mean costs were much lower than those estimated using the weighted and improved estimators, which suggests that earlier published studies of average costs underestimated the true treatment costs. Third, we included all medical care costs covered by the Ontario Ministry of Health and Long-Term Care. Estimates of overall resource utilization might be useful to decision-makers. Finally, our cost estimates are reliable for economic evaluations of interventions to prevent cervical cancer and for calculation of lifetime cervical cancer-related costs.

CONCLUSIONS

We analyzed the overall and specific medical care costs of treating cervical cancer in the first 5 years after a diagnosis of cervical cancer in Ontario. By taking censoring into account, our estimates are more likely to reflect the true medical care costs of cervical cancer treatment in Ontario. Overall medical care costs were approximately \$40,000 in year 1, \$14,000 in year 2, \$11,000 in year 3, \$9,000 in year 4, and \$5,500 in year 5.

We found that costs associated with cancer clinic visits and inpatient admissions were the two largest sources of cervical cancer treatment costs. However, physician services and home care were also significant drivers of costs. Our estimates could be of use for future economic evaluations of human papillomavirus vaccines, screening strategies, or other preventive interventions. Decision-makers might also find our estimates useful for policy planning or projecting future costs.

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CONFLICT OF INTEREST DISCLOSURES

We have read and understood *Current Oncology's* policy on disclosing conflicts of interest, and we declare that we have none.

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APPENDIX A

Equation 1

The simple mean for estimating the costs for a cohort of patients is

$$\hat{\mu} = \frac{1}{n} \sum_{i=1}^n M_i \quad \text{[Equation 1]},$$

where $\hat{\mu}$ is the estimated arithmetic mean cost, M_i is the cost accumulated by patient i during a given time period. Estimates based on Equation 1 will bias the mean downward because costs accrued after observed follow-up are equated to zero^{15,16}. Estimates derived solely from complete observations will be biased upward to patients with a shorter survival time¹⁶. Applying standard survival analysis techniques to costing analyses is also invalid because censoring and cost are not independent^{15,17,18}. Censoring is more likely for patients who accumulate costs slowly than for high-cost users; the mean is therefore biased upward^{17,18}. Given that censoring increases with follow-up, appropriate statistical methods that address censoring are required to reduce bias in estimates of costs.

Assumptions of the B&T Estimator

The random variable M represents the costs accumulated by a patient during a specified time T , which is bounded by maximum time L . T is assumed to follow a continuous distribution ($0 \leq T \leq L$); if all costs are available, it corresponds to survival time—otherwise, to the period during which costs are observed. If all patients have cost data available for time period L or longer, then the mean cost is the simple arithmetic mean. However, because of staggered dates of diagnosis, costs for all patients are not completely observed. Given the censored nature of the data, we consider a potential time to censoring C , which is assumed to be completely random. C is also assumed to be continuous, and the probability of a censoring time of at least time L is assumed to be greater than zero [$\Pr(C_i \geq L) > 0$]. The latter assumption is necessary to ensure that, to calculate mean, costs for some patients are observed for the defined study period.

The B&T estimator weights costs using the Kaplan–Meier survival curve and therefore includes the associated assumptions. The Kaplan–Meier estimate assumes non-informative censoring or the independence of censoring from the probability of the outcome of interest. Survival probabilities are also assumed to be the same for patients with early study entry as for those with later entry, and the probability of survival within a time interval is assumed to be constant.

Equation 2

The weighted estimator for estimating costs for a cohort of patients is

$$\hat{\mu}_{WT} = \frac{1}{n} \sum_{i=1}^n \frac{\Delta_i M_i}{\hat{R}(T_i)} \quad \text{[Equation 2].}$$

Equation 2 is the weighted estimator for time-restricted costs as proposed by Bang and Tsiatis¹², in which complete cases consist of patients who die during the study period or who are observed until the end of the study period (L). Costs of complete cases are weighted by the inverse probability of the Kaplan–Meier estimate not being censored at the end of the interval. Estimates based on Equation 2 allow for continuous death and censoring times and provide a consistent estimate of mean cumulative medical care costs^{12,14,15}. However, this estimator is inefficient because it relies on costs from patients with complete data and could be unstable with heavy censoring^{12,15}.

In Equation 2, is the estimated mean cost based on the simple weighted estimator, T_i indicates a failure time, and C_i indicates a censored time. Observed follow-up time is $X_i = \min(T_i, C_i)$, $\Delta_i = I(T_i \leq C_i)$. $I(\cdot)$ is the indicator function, with $I = 1$ indicating a failure and $I = 0$ indicating a censored observation. T is bounded by the maximum follow-up time L , where $T_i \leq L$ and $\Pr(C_i \geq L) > 0$. $K(T_i)$ is the Kaplan–Meier estimate of the probability of not being censored at failure time T_i or censoring time C_i .

Equation 3

The improved estimator for estimating the costs for a cohort of patients is

$$\hat{\mu}_{IMP} = \frac{1}{n} \sum_{i=1}^n \frac{\Delta_i M_i}{\hat{R}(T_i)} + \frac{1}{n} \sum_{i=1}^n \frac{(1-\Delta_i)\{M_i - \overline{M}(C_i)\}}{\hat{R}(T_i)} \quad \text{[Equation 3(a)]}$$

and

$$\overline{M}(C_i) = \frac{\sum_{j=1}^n I(X_j \geq M_j(C_j))}{\sum_{j=1}^n I(X_j \geq C_i)} \quad \text{[Equation 3(b)].}$$

Equation 3 is the improved estimator proposed by Pfeifer and Bang¹³, which attempts to improve efficiency relative to the simple estimator by using data from censored cases¹². In Equation 3, is the estimated mean cost based on the improved estimator, $M(C_i)$ is the mean cost for all individuals still under observation at censoring time C_i , X_j indicates that individual j is still under observation beyond individual i 's censoring time, and $M_j(C_j)$ is the cost accumulated by individual j at time C_j . The improved estimator has two parts¹³:

- Mean cost of complete cases estimated by the simple weighted B&T estimator
- An efficiency term that estimates the costs of censored cases

Censored costs are adjusted by subtracting the mean cost for all other cases still under observation at that censoring time. Adjusted censored costs are then weighted by the Kaplan–Meier inverse probability of not being censored at that time. The efficiency term is the average of the weighted censored costs.