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Canada's Population Health Model (POHEM): a tool for performing economic evaluations of cancer control interventions

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Abstract

This paper describes the Population Health Model (POHEM) developed by Statistics Canada and shows its usefulness in the evaluation of cancer control interventions and policy decision-making. Models of the costs of diagnosis and treatment of lung and breast cancer were developed and incorporated into POHEM. Then, POHEM was used to evaluate the economic impact of chemotherapy for advanced non-small cell lung cancer; reduced length of hospital stay following breast cancer surgery; and the provision of preventive tamoxifen to women at high risk of breast cancer. A lung cancer chemotherapy treatment decision framework was developed to rank order currently available chemotherapy regimens according to relative cost-effectiveness and cost-utility. Reducing post-surgical breast cancer hospitalisation with optimal home care support could produce major healthcare savings. However, the provision of preventive tamoxifen was estimated to have no population health benefit. This paper demonstrates that POHEM is an effective tool for performing economic evaluations of cancer control interventions and to inform healthcare policy decisions. © 2001 Elsevier Science Ltd.

Keywords: Economic evaluation; Cancer control; Microsimulation model

1. Introduction

Healthcare decision-makers are burdened with increasing healthcare costs from expensive new treatment approaches, growing financial constraints, increasing caseloads from an ageing population and demands from a sophisticated patient population. As a result, there is increasing need for tools that can aid in both clinical and administrative decision-making within the current healthcare environment. The purpose of this paper is to describe Statistics Canada's microsimulation model, the Population Health Model (POHEM) and to provide examples of its usefulness in supporting clinical and health care administrative policies.

Numerous interventions have been evaluated using POHEM [1–9]. However, due to space limitations, it is beyond the scope of this paper to describe all of them. Consequently, in addition to outlining the 'base case' estimates of current practice patterns for lung and breast cancer, we have chosen to present three policy relevant examples [10–14]. They are:

- the cost-effectiveness of chemotherapeutic interventions for advanced non-small cell lung cancer (NSCLC);
- an analysis of the impact of reduced length of hospital stay following breast cancer surgery; and
- a cost-effectiveness analysis of the provision of 'preventive' tamoxifen for women in Canada at high risk of developing breast cancer.

2. Patients and methods

2.1. The Population Health Model (POHEM)

POHEM is a microsimulation framework for integrating diverse data and analytical results in the health area. Information is drawn together on risk factors, disease onset and progression, consequential effects on health and functional status, and on resource utilisation. Using Monte Carlo microsimulation methods, POHEM generates and then ages over time, a sample of synthetic individuals to whom demographic and labour force characteristics, health risk factors, and individual

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health histories typical of Canadians are assigned. In other words, POHEM uses random number generators to simulate specific events, by comparing the results of random draws to known distributions. POHEM creates a virtual synthetic longitudinal data set, which represents the full life cycle of a birth cohort, and produces statistics from this cohort. Progression and case fatality are simulated in continuous time. That is, the time to an event is simulated, rather than the probability of a transition. This allows for the implementation of a competing risk framework, by which the event with the shortest time to a transition is deemed to happen.

In the case of health outcomes, co-morbidities and competing risks from multiple disease processes are explicitly modelled in order to obtain the impact on populations, rather than disease-specific impacts [16,17]. The flexibility of using microsimulation and continuous time allows the incorporation of higher order Markov processes. As an example, a risk function for lung cancer can be incorporated which takes into account a specific individual's smoking history up to 10 years prior to the current date, rather than using current mean smoking values at the population level. The simulation sample size typically used is one million individuals, in order to assure that the Monte Carlo error is small relative to the model outputs of interest.

Lung cancer was chosen as the first disease to be modelled comprehensively, since it is the major cause of cancer death in Canada often associated with poor prognosis. The POHEM lung cancer model was developed in collaboration with oncologists at the Ottawa Regional Cancer Centre (ORCC). The objective in developing an individual disease model was to document 'typical' Canadian diagnostic and therapeutic practice to be used as a baseline scenario against which to evaluate new diagnostic or therapeutic interventions [18–20].

As a result of the demonstrated usefulness of the lung cancer model, Statistics Canada collaborated with other ORCC oncologists to develop a breast cancer model for Canada. The breast cancer model was designed to reflect current Canadian risk factors, incidence, diagnostic and therapeutic cancer management practices and costs [21–23].

In addition to the lung and breast cancer models, a Canadian colorectal model is currently in the final phase of development. In parallel with the development of these cancer models, work has been done in the areas of coronary heart disease, osteoporosis, arthritis and fractures [24].

2.2. Data requirements and sources

2.2.1. Typical practice patterns for lung and breast cancer

In order to realistically simulate the 'typical' practice patterns for lung and breast cancer in the Canadian population, it is necessary to collect information on: risk factors; disease incidence by age, gender and cell-type; stage distribution at the time of diagnosis; and the 'standard' or typical diagnostic and therapeutic approaches used. Data on disease progression after initial diagnosis (depending upon age, gender and stage at diagnosis) are required, in addition to follow-up patterns of practice, treatment at relapse and terminal care.

The costs associated with all of these phases of diagnosis and care are estimated, based on resource utilisation and estimates of average national or provincial unit costs. The data requirements and sources used to develop our cancer costing models have previously been reported [18,19,22,23] and will not be discussed in detail in this report. The appendix provides a list of the data sources used for the breast cancer model, which are very similar to those for the lung cancer model.

2.2.2. The cost-effectiveness of chemotherapeutic interventions for advanced non-small cell lung cancer (NSCLC)

The lung cancer model was developed at a time when best supportive care was the standard of care for metastatic non-small cell lung cancer (NSCLC). Since then, numerous chemotherapy regimens have been shown to increase survival modestly.

The survival data for patients with stage IV disease treated with each regimen were extracted from the original clinical trials [2–4]. The stage-specific survival was incorporated into POHEM, using a piecewise Weibull survival function for each regimen.

The cost of the chemotherapy drugs and their administration, including the cost of associated toxicities, has been previously reported for vindesine plus cisplatin, etoposide plus cisplatin, vinblastine plus cisplatin, vinorelbine (Navelbine) plus cisplatin, paclitaxel (Taxol) plus cisplatin, as well as gemcitabine and vinorelbine alone [2–4]. Drug acquisition costs, as well as the cost of nursing and pharmacy/chemotherapy preparation time, were provided by staff of the Chemotherapy Treatment Unit of the ORCC. The rates and costs of the treatment-associated complications were estimated on the basis of trial data, where available [10].

POHEM's results for these different interventions were used to develop an advanced decision framework based on the concept of extended dominance used in health economics [25]. This framework has been used to evaluate and rank order these ambulatory chemotherapeutic interventions by cost-effectiveness and cost-utility ratios against best supportive care and against each of the other regimens for stage IV NSCLC.

2.2.3. An analysis of the impact of reduced length of hospital stay following breast cancer surgery

The breast cancer model was developed to reflect current Canadian practice patterns. In 1995, the average

length of hospital stay (ALOS) in Canada for women undergoing breast conserving surgery (BCS) was 4.5 days (<50 years of age) and 5.2 days ($\geqslant 50$ years). For mastectomy, the ALOS was 5.6 and 6.7 days, respectively.

To implement an out-patient/early discharge strategy comparable to the best practice reported in the medical literature, POHEM was used to estimate the cost impacts in the acute care setting and the required investment in the home care setting.

The model incorporated the following assumptions: that BCS would be performed on an ambulatory basis, mastectomy would require a 2-day hospital stay, and that appropriate home care services would be provided. It assumed that this strategy would be appropriate for 90% of operable (stage I/ II) patients, that there would be a 5% re-admission rate for complications and that home care costs would be $453 per patient. Cost per case, total cost burden, investment in home care, savings in acute care, and net savings were calculated. All costs were determined in 1995 Canadian dollars.

2.2.4. A cost-effectiveness analysis of the provision of 'preventive' tamoxifen for women in Canada at high risk of developing breast cancer

In a preliminary report of the National Surgical Adjuvant Breast and Bowel Project's Breast Cancer Prevention Trial (BCPT- P-1), tamoxifen was shown to reduce the overall risk of invasive breast cancer by 49% [26]. However, a careful examination of the trial's results suggested that there were both beneficial and adverse effects from administering preventive tamoxifen. (The term 'preventive' tamoxifen is used throughout the manuscript in the same context as was used in the Breast Cancer Prevention Trial. The authors acknowledge that the FDA approval of tamoxifen was as a drug to reduce the incidence of breast cancer in high risk women and *not* as a breast cancer preventive agent.)

The 'base case' POHEM breast cancer model was modified to incorporate the eligibility criteria used in the BCPT-P-1 with the objective of simulating the impact of preventive tamoxifen on the overall health of cohorts of women 35–70 years of age, including the impact on breast cancer, coronary heart disease, endometrial cancer, pulmonary embolism, deep vein thrombosis, stroke, fractures, cataracts and on direct medical costs.

While the main intervention scenario conformed as closely as possible to the eligibility criteria in the BCPT-P-1 protocol, additional scenarios were simulated to compare the health impacts of tamoxifen on different sub-populations of women with different levels of risk of developing breast cancer. The Gail algorithm was used to assess a woman's risk of developing breast cancer [27]. Simulations were performed for a set of 5-year predicted risks (1.66, 3.32 and 4.15%) as thresholds for determining those women 35–70 years of age who might benefit from tamoxifen as a preventive agent.

The eligibility criteria and relative risks of women entered in the BCPT-P-1 were applied to a cohort of Canadian women, using Canadian incidence and mortality rates and breast cancer management patterns.

All cost-effectiveness and cost-utility analyses performed with POHEM are from the perspective of a provincial government payer in a universal healthcare system.

3. Results

3.1. Lung cancer

Table 1 provides details of the cost components associated with diagnosing and treating lung cancer patients in Canada in 1995. The total cost is estimated at approximately $545 million. The largest cost components are initial hospitalisation (41.4%) followed by terminal care (37.9%). Since most terminal care costs are associated with hospitalisation, these results highlight the large burden of lung cancer on the hospital system [19,20].

The results of the cost-effectiveness analysis of chemotherapeutic interventions for advanced non-small cell lung cancer (NSCLC) are presented in Table 2. It has been shown that treatment with chemotherapy reduces the cost of terminal care hospitalisation, compared with best supportive care. As shown in Table 2, the use of vinblastine/cisplatin chemotherapy (VLB-P) in metastatic NSCLC decreased the cost of care per treated patient, while increasing survival. Table 3 shows how the various regimens have been rank-ordered against each other, by cost per life year saved and by

Table 1
Summary of 5-year cumulative lung cancer costs[a] in Canada (1995 Canadian $000)

Component	Cost ($000)	%
Diagnosis	15 709	2.9
Pre-operative tests/staging	9070	1.7
Surgery	7469	1.3
Hospitalisation	225 720	41.4
Chemotherapy	11 446	2.1
Radiotherapy	25 967	4.8
Follow-up in 1st year	9736	1.8
Follow-up after 1st year	10 315	1.9
Diagnosis of relapse	23 290	4.2
Terminal care	206 657	37.9
Total	$545 379	100.0

[a] Costs include all diagnostic, staging and therapeutic procedures for all stages of lung cancer.

Table 2
Incremental cost per life year saved and incremental cost per QALY gained: comparison between individual therapies for Stage IV non-small cell lung cancer[a,b]

	VLB + P	BSC	NVB	NVB + P	VP-16 + P	Gem	VDS + P[c]	T + P 135	T + P 200
Incremental cost per life year saved									
BSC	D								
NVB	99 700	1900							
NVB + P	15 200	4100	8000						
VP-16 + P	WD	7500	D	D					
Gem	25 200	6800	17 400	D	5600				
VDS + P	D	17 600	D	D	WD	D			
T + P 135 mg/m^2	31 600	15 400	28 400	52 800	22 400	37 400	13 400		
T + P 200 mg/m^2	43 200	21 500	40 500	79 300	33 900	59 200	25 000	WD	
T + P 250 mg/m^2	53 500	27 000	51 300	103 000	44 300	78 800	35 300	WD	WD
Incremental cost per QALY gained									
BSC	D								
NVB	19 769	2658							
NVB + P	15 982	6036	13 254						
VP-16 + P	124 702	12 762	D	D					
Gem	18 933	86 26	18 468	36 083	4778				
T + P 135 mg/m^2	35 048	21 545	40 110	62 982	27 016	72 048			
T + P 200 mg/m^2	47 859	30 146	57 166	94 562	40 975	114 272		WD	
T + P 250 mg/m^2	59 320	37 841	72 424	122 815	53 463	152 048		WD	WD

D, dominant strategy (i.e. the therapy in the top row is both less expensive and more effective); WD, weakly dominant (i.e. the therapy in the top row is less expensive with the same survival); BSC, best supportive care; NVB, vinorelbine (Navelbine); P, cisplatin; VP-16, etoposide; Gem, gemcitabine; VDS, vindesine; VLB, vinblastine; T, paclitaxel (Taxol).

[a] This table is reproduced with the permission of the *Journal of the National Cancer Institute* (see Ref. [10]).

[b] The tables show the incremental cost per life year and cost per quality-adjusted life year (QALY) gained of each regimen in the first column compared with the regimen in the top row.

[c] VDS + P is not shown in the second section as a utility value was not estimated.

Table 3
Ranking of lung cancer chemotherapy regimens by cost per life year saved and per QALY, based on alternative threshold values[a,b]

Regimen	Threshold value (Canadian $000)						
	$0	$5	$10	$25	$50	$75	$100
Ranking of chemotherapy regimens by cost per life year saved							
VLB + P	1	1	1	2	5	6	7
BSC	2	4	6	9	10	10	10
NVB	3	2	3	4	6	7	6
NVB + P	4	3	2	1	1	2	3
VP-16 + P	5	5	5	6	8	8	8
Gemcitabine	6	6	4	3	3	4	5
VDS + P	7	7	7	8	9	9	9
T + P 135 mg/m^2	8	8	8	5	2	1	1
T + P 200 mg/m^2	9	9	9	7	4	3	2
T + P 250 mg/m^2	10	10	10	10	7	5	4
Ranking of chemotherapy regimens by cost per QALY gained							
VLB + P	1	1	1	4	6	7	7
BSC	2	3	5	7	9	9	9
NVB	3	2	3	3	4	6	6
NVB + P	4	4	2	1	2	3	4
VP-16 + P[c]	5	6	6	5	7	8	8
Gemcitabine	6	5	4	2	1	2	2
T + P 135 mg/m^2	7	7	7	6	3	1	1
T + P 200 mg/m^2	8	8	8	8	5	4	3
T + P 250 mg/m^2	9	9	9	9	8	5	5

VLB, vinblastine; P, cisplatin; BSC, best supportive care; NVB, vinorelbine (Navelbine); VP-16, etoposide; VDS, vindesine; T, paclitaxel (Taxol).

[a] This table is reproduced with the permission of the *Journal of the National Cancer Institute* (see Ref. [10]).

[b] For each threshold value of the cost willing to be paid per life-year saved or cost per quality-adjusted life-year (QALY) gained, this table shows the ranking of chemotherapy regimens that would maximise survival.

[c] VDS + P not shown in lower table, as utility values were not estimated.

quality-adjusted life year (QALY) gained. Assuming a threshold of $25 000, our analysis supported the use of the current Canadian clinical standard of vinorelbine plus cisplatin as the most cost-effective of the new chemotherapeutic regimens. At higher threshold levels, other regimens would be preferred, either because of higher utility or greater survival [10].

3.2. Breast cancer

Table 4 provides details of the cost components associated with diagnosing and treating breast cancer in Canada. The cost per case increases with the stage at diagnosis, ranging from $23 275 for stage I to $36 340 for stage IV. The lifetime cost for the cohort of women diagnosed in 1995 is estimated to be approximately $454 million. Even though stage I has the lowest cost per case, it accounts for 41% of the lifetime cost, since it has the largest number of cases.

The costs of the 'initial treatment' of stage I and II women diagnosed in 1995 were estimated to be $127.6 million, with hospitalisation for breast cancer surgery comprising 53% of the costs. The reduced length of stay intervention following breast cancer surgery, as specified in this study, estimated a potential saving of $47.2 million for the acute care cost of initial breast cancer management, with an investment in home care of $14.5 million, resulting in an overall net saving of $32.7 million. Under this strategy, the total cost of initial breast cancer care would be $94.9 million, with hospitalisation, home care and day surgery contributing to 21, 6 and 9% of the total, respectively. The adoption of a predominantly ambulatory approach to the surgical management of breast cancer would result in a saving of $20.3 million for breast conserving surgery alone and $12.7 million for mastectomy [11,12].

The POHEM simulation of the provision of 'preventive' tamoxifen for women in Canada at high risk of developing breast cancer showed an increase in healthcare costs without a significant net benefit in life expectancy. The analysis suggests that the detrimental effects of tamoxifen such as endometrial cancer, coronary heart disease, stroke and deep vein thrombosis would likely outweigh the protective effect tamoxifen has on breast cancer for the majority of the women meeting the eligibility criteria of the BCPT-P-1. Tamoxifen appeared to be beneficial only for women with a 5-year predicted risk of 3.32% or greater. We have estimated that only 4.0% of Canadian women would meet this risk level at any time in their lives. The results of the tamoxifen analysis have been presented previously [13,14] and have recently been submitted for publication.

4. Discussion

In this paper, we have briefly described POHEM and examples of its use. The data generated by POHEM simulations are useful in informing health policy- and decision-makers. It is often difficult to assess how much impact health economics has on the delivery of healthcare services. However, POHEM data have been used to influence several specific policy issues as described below.

Based on POHEM-derived knowledge of the costs of the components of care for lung cancer, a business case was made by the CEO of the Ottawa Regional Cancer Centre to establish a lung cancer diagnostic unit to provide timely, efficient, high quality cost-effective diagnostic care at a regional hospital. This information has also led to the incorporation of the concept of diagnostic assessment units in Cancer Care Ontario's strategic plan.

Table 4
Components of breast cancer cost and lifetime cost by stage at presentation (1995 Canadian $000)[a,b,c]

Cost component	Stage I ($)	Stage II ($)	Stage III ($)	Stage IV[d] ($)	Average—all stages ($)
Initial treatment	8238	9089	9052	9538	8722
Local recurrence	1399	1109	1404	–	1197
Follow-up	2313	1840	1428	–	1918
Rx of metastases[e]	2026	2603	3820	–	2267
Ongoing care	4395	3840	4643	12 634	4679
Terminal care[f]	4905	7177	11 849	14 169	6878
Average cost/case	23 275	25 658	32 197	36 340	25 661
Number of patients	8142	7257	1239	1062	17 700
Lifetime cost ($000)	189 508	186 200	39 892	38 593	454 193

Rx, treatment.

[a] This table is reproduced from a *European Journal of Cancer* article (see Ref. [23]).

[b] Numbers may not add up due to rounding.

[c] The row entitled 'Average cost/case' is a summation of the previous six rows. The last row in the table shows the lifetime cost of breast cancer treatment by stage (number of patients × the average cost per case).

[d] For stage IV, initial treatment includes treatment of stage IV at presentation and of metastatic disease.

[e] Rx of metastases includes treatment initiated within 3 months of diagnosis of the metastases.

[f] Terminal care includes costs in the last 3 months of life.

The decision framework that was developed from the cost-effectiveness data derived from POHEM allows the comparison of different treatment regimens based on various thresholds for the value of a life-year saved. The Policy Advisory Committee of Cancer Care Ontario considered the cost-effectiveness data in concert with evidence-based practice guidelines when reaching a decision to fund vinorelbine and gemcitabine in the province of Ontario. In an era of economic rationalisation, this decision framework can be used effectively to inform the selection of preferred regimens by physicians, patients and policy-makers. Our economic analysis also provides additional support for the abandonment of best supportive care as a standard of care for stage IV NSCLC in Canada.

The analysis of the impact of reduced length of hospital stay following breast cancer surgery identified the need for better co-ordination amongst Canadian surgeons, healthcare administrators and community-based care providers. If resources were redirected to the provision of home-based postoperative care, there would be potential for a large net healthcare saving, while still preserving high quality patient care.

The results of the POHEM 'preventive' tamoxifen analysis are now being incorporated into a decision aid for high risk Canadian women who are attempting to determine whether to take tamoxifen to reduce their risk of breast cancer (A. O'Connor, Loeb Research Institute). As a consequence, the results are having an impact not only on policy-making, but also, on individual decision-making for care.

The main limitation of studies based upon simulation modelling is that a model is only as good as the data that are included in it. Even though we used nationally representative data when they were available, there are many data sources that do not have national coverage. It is implicitly assumed that the provincial or regional data sources used are nationally representative. For example, while we have an excellent national registry for cancer incidence, this registry does not contain data on stage at presentation. The lung cancer stage information was obtained from a provincial registry representing approximately 3% of the Canadian population. In some instances, there were no available databases and we had to rely on medical expertise, as, for example, in estimating the usual diagnostic tests for breast cancer.

The major strength of our simulation model is that it can be used as a policy analysis tool to answer 'what-if' questions that go beyond cost issues to incorporate outcome measures. The availability of information on disease costing is crucial, since it forms the base against which cost reduction strategies and cost-effectiveness analyses can be evaluated. This becomes particularly pertinent in an era of fiscal restraint, where new therapies are generally expensive and difficult policy decisions may need to be made before new therapies can be adopted and paid for through public funding.

In this paper, we have provided an overview of various economic evaluations performed by using POHEM. Hopefully, this summary will reinforce the need for and value of developing sophisticated tools for performing such evaluations of cancer control interventions.

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Appendix. List of data requirements and sources

Data required	Data sources
Incidence of breast cancer	Canadian Cancer Registry, 1995 (Women)
Risk factors	National Breast Screening Study
	Provincial Heart Health Surveys
Stage at diagnosis	Saskatchewan Cancer Foundation—1993[a]
	Manitoba Medical Services Foundation and Manitoba
	Cancer Treatment and Research Foundation—1990
Standard diagnostic work-up	Saskatchewan Cancer Foundation—1993
	Surveys of Canadian Oncologists—1994
	Breast Cancer Experts[b]
Therapeutic algorithms at initial diagnosis	Saskatchewan Cancer Foundation—1993
	Surveys of Canadian Oncologists—1994
	Manitoba Medical Services Foundation and Manitoba
	Cancer Treatment and Research Foundation—1990
	Breast Cancer Experts
Follow-up after initial treatment	Surveys of Canadian Oncologists—1994
	Breast Cancer Experts
Diagnosis and treatment of recurrent or metastatic disease	Saskatchewan Cancer Foundation—Special Chart Reviews—1985–1992
	Ottawa Regional Cancer Centre—Special Chart Reviews—1996–1997
Survival data	Northern Alberta Breast Cancer Registry—1971–1988
	Saskatchewan Cancer Foundation—Special Chart Reviews—1985–1992
	British Columbia Cancer Agency—1989–1994
Fees for physicians' services, diagnostic and surgical tests and procedures	Ontario Fee Schedule—1995 (reliability verified by Canadian Institute for Health Information)
Hospital *per diem* rates by case mix groups	Ontario Case Cost Project—1993–1995
Hospital *per diem* rate for terminal care	Results of 1988 National Cancer Institute of Canada
	Clinical Trial—BR5 (updated with Consumer Price Index)
	Ontario Case Cost Project—1993–1995
Hospital length of stay	Statistics Canada's National Person-oriented
	Database of Hospital Discharges (POD)—1992–1994
	Ottawa General Hospital
Radiotherapy costs	Ottawa Regional Cancer Centre—1997
Chemotherapy costs—drugs and administration	Ottawa Civic Hospital—1995
	Ottawa General Hospital—1995
Facility overhead costs	Results of 1988 NCIC Clinical Trial—BR5 (updated with Consumer Price Index)
Hormonal therapy costs	Ottawa Pharmacies
Monthly costs of ongoing care	Manitoba Health Services Insurance Plan
	Statistics Canada's POD—1992–1994
	Ontario Case Cost Project—1993–1995
Terminal care costs	Manitoba Health Services Insurance Plan
	Statistics Canada's POD—1992–1994
	Ontario Case Cost Project—1993–1995

N.B. Where information was not directly available from a national or provincial database, information was obtained from literature reviews or from breast cancer experts.

[a]Special chart reviews of all patients diagnosed in 1993.

[b]1994 Surveys of Canadian medical, surgical and radiation oncologists.

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