Annals of Epidemiology 24 (2014) 575–580

Contents lists available at ScienceDirect

Annals of Epidemiology

journal homepage: www.annalsofepidemiology.org

Original article

Mortality inequality in populations with equal life expectancy: Arriaga's decomposition method in SAS, Stata, and Excel

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ARTICLE INFO

Article history:
Received 4 December 2013
Accepted 7 May 2014
Available online 27 May 2014

Keywords:
Demography
Inequality
Life expectancy
Mortality
Tobacco

ABSTRACT

Purpose: Life expectancy is used to measure population health, but large differences in mortality can be masked even when there is no life expectancy gap. We demonstrate how Arriaga's decomposition method can be used to assess inequality in mortality between populations with near equal life expectancy.
Methods: We calculated life expectancy at birth for Quebec and the rest of Canada from 2005 to 2009 using life tables and partitioned the gap between both populations into age and cause-specific components using Arriaga's method.
Results: The life expectancy gap between Quebec and Canada was negligible (<0.1 years). Decomposition of the gap showed that higher lung cancer mortality in Quebec was offset by cardiovascular mortality in the rest of Canada, resulting in identical life expectancy in both groups. Lung cancer in Quebec had a greater impact at early ages, whereas cardiovascular mortality in Canada had a greater impact at older ages.
Conclusions: Despite the absence of a gap, we demonstrate using decomposition analyses how lung cancer at early ages lowered life expectancy in Quebec, whereas cardiovascular causes at older ages lowered life expectancy in Canada. We provide SAS/Stata code and an Excel spreadsheeet to facilitate application of Arriaga's method to other settings.

Introduction

Life expectancy is a useful measure of population health for its capacity to summarize mortality in a single measure. Life expectancy has unique mathematical properties that often go unrecognized which can be tapped to facilitate population comparisons by epidemiologists. The difference in life expectancy between two groups is an algebraic function of underlying age and cause-specific mortality rates [1–6]. Recent methods proposed in demography have taken advantage of these relationships to show that life expectancy gaps can be partitioned into age and cause-specific components. Such methods have successfully identified the age groups and causes of death resulting in socioeconomic [7–11], ethnocultural [8,12–15], and temporal [7,8,10,11,13–16] inequalities in life expectancy in several countries.

Although there is an abundance of decomposition analyses in the literature, such studies are rarely performed in the absence of a life expectancy gap. Populations can have large inequalities in age or cause-specific mortality, yet very similar life expectancy—in such settings, decompositions can still be undertaken to determine the reason for the absence of a gap. No matter how small, the difference in life expectancy between two populations is the sum of positive and negative contributions of age and cause-specific mortality rates [2–5]. Contributions can be quite large, yet be in opposite directions that cancel each other when summed, potentially yielding little or no life expectancy gap (i.e., equal life expectancy in both groups). For example, life expectancy in a population with mortality that is high at younger and low at older ages could be very similar to another with mortality low at younger and high at older ages, despite the large inequality in age-specific mortality. Decomposition methods are ideal for determining whether life expectancy gaps that appear negligible are in fact

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http://dx.doi.org/10.1016/j.annepidem.2014.05.006

associated with large differences in mortality. If the ages or causes of death are sensitive to preventive interventions, such as tobacco cessation, decomposition approaches can provide public policy initiatives with evidence on which age groups or causes of death to target for reducing mortality.

Our primary objective was to demonstrate the utility of decomposition methods for unmasking potentially hidden mortality inequalities among populations with similar life expectancies. Doing so could provide evidence on whether specific age groups or causes of death could be targeted to increase life expectancy. We analyzed mortality data from Canada. Life expectancy of Canadians is high at 79 years for men and 83 years for women, and gaps between provinces are negligible [17]. Yet the province of Quebec has an exceptionally high prevalence of tobacco consumption [17], and higher smoking-related mortality should intuitively lead to lower life expectancy in this province. Decomposition analysis can determine whether tobacco-related mortality indeed affects life expectancy between Quebec and the rest of Canada. Our secondary objective was to encourage similar analyses by researchers and policy makers in other milieus through readily adaptable syntax and an easy-to-use spreadsheet containing formulae for the decomposition of a life expectancy gap.

Methods

Data and variables

We obtained data on all deaths in men and women in Quebec and the rest of Canada (hereafter, Canada) for 2005 through 2009 from the Quebec Health and Social Services Ministry and Statistics Canada. Death counts were available in 5-year age blocks (<1, 1–4, 5–9, …, 85–89, and ≥90 years). Population counts were obtained from the Census of Canada (administered in 2006, with estimates for 2005 and 2007–2009) for ages 1 year or more, and birth registration certificates for infants younger than 1 year.

Principal cause of death was determined using the 10th revision of the International Classification of Diseases. We identified tobacco-related causes of death using International Classification of Diseases codes published by the United States Center for Diseases Control and the Canadian Center for Addiction and Mental Health (Appendix 1) [18,19].

Life expectancy gap

We calculated life expectancy at birth for Quebec and Canada from abridged life tables for men and women separately [20]. We converted age-specific mortality rates to life-table probabilities of dying, using a probability of death of 1 for the last age group (≥90 years). We computed the absolute difference in life expectancy between Quebec and Canada and 95% confidence intervals for life expectancy and the gap [20].

Decomposing the life expectancy gap

We partitioned the absolute difference in life expectancy between Quebec and Canada into age and cause components using Arriaga's method [2,3] and calculated 95% confidence intervals for each component using Monte Carlo simulation [21]. Although various decomposition approaches exist, Arriaga's method accounts for all age groups including the last, and is easy to apply to traditional life table data [22]. Other decomposition methods, such as those proposed by Pollard [4,5] or Andreev [1], generally yield results similar to Arriaga's [23]. There are essentially two steps in Arriaga's method, the first a decomposition by age group [2] and the second by cause of death within an age group [3]. The mathematical formulae describing this procedure are described in the following, although these are not strictly necessary to understand the results. It suffices to know that a gap of zero years between Quebec and Canada could be obtained, for example, if mortality in Quebec is high enough in young people to lower life expectancy by 1 year, but mortality in Canada is high enough in older people to also lower life expectancy by 1 year (or vice versa). These opposing 1-year contributions equal zero when summed.

Step 1—decomposing by age

The total contribution of an age group to the life expectancy gap (in years) is the sum of two mathematical terms [2,22], the first corresponding to a direct effect and the second to indirect and interaction effects, as follows:

$$
\begin{aligned}
{}_nC_x = & \left[\frac{l_x^{\text{Quebec}}}{l_0} \times \left(\frac{{}_nL_x^{\text{Canada}}}{l_x^{\text{Canada}}} - \frac{{}_nL_x^{\text{Quebec}}}{l_x^{\text{Quebec}}}\right)\right] \\
& + \left[\frac{T_{x+n}^{\text{Canada}}}{l_0} \times \left(\frac{l_x^{\text{Quebec}}}{l_x^{\text{Canada}}} - \frac{l_{x+n}^{\text{Quebec}}}{l_{x+n}^{\text{Quebec}}}\right)\right]
\end{aligned}
\qquad [1]
$$

where ${}_nC_x$ is the total contribution between ages x and $x+n$, l_x is the number of individuals left alive at age x in a fictitious cohort, l_0 is the cohort size at the start (commonly 100,000 in a life table), ${}_nL_x$ is the number of person-years lived between ages x and $x+n$, and T_{x+n} is the total number of person-years lived above age $x+n$. The first term of equation 1 represents the direct effect of age, which consists of the number of years an age group adds to a life expectancy differential, due to higher mortality in that specific age group in one population. To illustrate, if mortality between Quebec and Canada is equal at all ages except is higher in Quebec for the age interval 40–44 years, life expectancy in this province would be lowered by a direct effect of mortality of that age group, thereby widening the gap.

However, there is also an indirect effect of the 40–44 years age group because the higher mortality in Quebec leaves fewer survivors at age 45 years, affecting all later age groups in the life table [2,22]. The second term of equation 1 represents this indirect effect. Furthermore, if mortality between Quebec and Canada differs at many ages, interaction effects are introduced, reflecting the continuously changing number of survivors and mortality rates of later age groups. The second term of equation 1 also captures these interaction effects. The last age group, however, has only a direct effect, because there is no later age group on which indirect or interaction effects can act.

The next step is to sum the direct, indirect, and interaction effects to obtain the total contribution of an age group [2,22]. The sum of contributions from all age groups should equal the total life expectancy gap in years. It is also possible to calculate the ratio of the number of years contributed by an age group to the total gap, to estimate inequality on the relative scale.

Step 2—decomposition by cause of death within an age group

The second step is to compute the contribution of causes of death to the life expectancy gap. To do so, the total contribution of a given age group is further partitioned into the number of years contributed by each cause [3,22], as follows:

$$
{}_nC_x^i = {}_nC_x \times \left[\frac{{}_nR_x^{i,\text{Canada}} \times {}_nm_x^{\text{Canada}} - {}_nR_x^{i,\text{Quebec}} \times {}_nm_x^{\text{Quebec}}}{{}_nm_x^{\text{Canada}} \times {}_nm_x^{\text{Quebec}}}\right] \qquad [2]
$$

where ${}_nR_x^i$ is the proportion of deaths between ages x and $x+n$ due to cause i, and ${}_nm_x$ is the all-cause mortality rate between ages x and $x+n$. The total contribution of any given cause to the life expectancy

Table 1
Life expectancy at birth in Quebec and Canada, 2005–2009

	Men	Women
Life expectancy (95% confidence interval)		
Quebec	78.4 (78.4, 78.5)	83.1 (83.1, 83.2)
Canada	78.5 (78.5, 78.5)	83.1 (83.0, 83.1)
Difference (95% confidence interval)*	0.1 (0.0, 0.2)	0.1 (0.0, 0.1)

* Absolute difference in life expectancy between Quebec and the rest of Canada.

gap is obtained by summing cause-specific contributions across age groups. Similar to age, the sum of contributions from all causes should equal the total life expectancy gap. This means that a cause with lower mortality in Quebec at young ages and higher mortality in Canada at older ages could potentially have equal but opposing contributions that cancel out, yielding no life expectancy gap when summed. Furthermore, the contribution of one cause with higher mortality in Quebec could be completely offset by a different cause that has higher mortality in Canada.

Finally, we used mortality rates as a supplementary tool to interpret results of the decomposition. We calculated directly standardized cause-specific mortality rates for men and women using the 2006 population of Canada as reference.

Data were anonymized, and ethics approval for this study was waived by the Institutional Review Board of the University of Montreal Hospital Centre. We used SAS version 9.2 for statistical analyses and provide consolidated code for calculating life expectancy [24] and decomposing the gap between two populations by age and cause of death in SAS and Stata (Appendix 2). In addition, we provide a sample decomposition in an Excel spreadsheet with formulae embedded (Appendix 3). Instructions for use of the Appendices are provided, and we strongly encourage researchers wishing to reproduce this method to adapt the syntax or spreadsheet using their own data.

Results

There was essentially no gap in life expectancy between Quebec and Canada (Table 1). The difference was only 0.1 years, for both men and women. There were differences in age and tobacco-related mortality between Quebec and Canada, but the reason why life expectancy was similar between the two areas was not readily apparent from the rates alone (Table 2).

There was no clear pattern in age-specific contributions to the life expectancy gap between Quebec and Canada for women, although higher mortality among infants and women aged 90 years

Table 2
Age and cause-specific mortality rates and contributions to the life expectancy gap, Quebec versus Canada, 2005–2009

	Men			Women		
	Mortality rate*		Ratio (95% CI)†	Mortality rate*		Ratio(95% CI)†
	Quebec	Canada		Quebec	Canada	
Age, y						
<1	505.2	566.8	−0.6 (−0.7, −0.5)	442.3	489.0	−0.6 (−0.8, −0.5)
1–19	26.4	28.4	−0.2 (−0.3, −0.1)	14.7	17.0	−0.4 (−0.5, −0.4)
20–44	104.7	107.8	−0.4 (−0.5, −0.3)	52.9	58.3	−0.9 (−1.1, −0.8)
45–64	544.1	533.2	0.1 (−0.1, 0.2)	356.8	335.0	1.2 (1, 1.4)
65–89	3916.5	3951.8	2.4 (2.2, 2.5)	2944.6	3000.3	0.7 (0.4, 0.9)
≥90	21899.0	22340.1	−0.2 (−0.3, −0.1)	18093.2	18694.8	−0.8 (−1, 0.7)
Malignant neoplasms						
Lip, oral cavity, pharynx	5.0	4.8	0 (0, 0.1)	1.8	1.8	0 (−0.1, 0)
Esophagus	6.6	8.8	−0.3 (−0.4, −0.3)	1.5	2.2	−0.2 (−0.2, −0.1)
Larynx	3.4	2.1	0.2 (0.1, 0.2)	0.6	0.4	0.1 (0, 0.1)
Trachea, bronchus, lung	92.8	62.9	4.4 (4.2, 4.6)	52.2	41.9	3 (2.7, 3.3)
Stomach	9.6	7.7	0.3 (0.2, 0.3)	4.8	3.6	0.3 (0.2, 0.3)
Pancreas	13.4	12.2	0.2 (0.1, 0.3)	10.8	9.7	0.3 (0.2, 0.4)
Cervix uteri	—	—	—	1.6	2.3	−0.2 (−0.3, −0.1)
Kidney	6.8	6.5	0 (0, 0.1)	3.2	2.9	0 (0, 0.1)
Bladder	9.7	9.1	0.1 (0, 0.1)	2.9	2.6	0.1 (0, 0.1)
Myeloid leukemia	3.2	3.8	−0.1 (−0.2, −0.1)	2.0	2.4	−0.1 (−0.2, 0)
Circulatory						
Ischemic heart disease	135.3	155.0	−2.5 (−2.7, −2.2)	71.8	81.0	−2.2 (−2.4, −1.9)
Other heart diseases	43.0	42.6	0.3 (0.1, 0.4)	32.4	33.3	−0.2 (−0.4, 0)
Cerebrovascular disease	36.3	46.5	−1 (−1.2, −0.9)	31.8	41.2	−2.2 (−2.4, −2)
Atherosclerosis	1.9	3.6	−0.2 (−0.2, −0.1)	1.1	2.9	−0.4 (−0.5, −0.4)
Aortic aneurysm, dissection	8.4	7.7	0 (0, 0.1)	3.3	3.3	0 (−0.1, 0.1)
Other arterial diseases	3.0	3.7	−0.1 (−0.1, to 0)	2.2	2.7	−0.1 (−0.2, −0.1)
Respiratory						
Influenza, pneumonia	18.3	20.5	−0.3 (−0.4, −0.2)	12.3	14.4	−0.6 (−0.7, −0.4)
Bronchitis, emphysema	3.2	3.1	0 (0, 0)	2.0	1.7	0.1 (0, 0.1)
Other chronic obstructive	45.0	36.1	0.8 (0.7, 0.9)	24.0	21.2	0.7 (0.5, 0.8)
Digestive/mental-behavioral/injury						
Ulcer	0.9	1.7	−0.1 (−0.1, −0.1)	0.6	1.1	−0.1 (−0.2, −0.1)
Mental-behavioral disorders	0.2	0.1	0 (0, 0)	0.1	0.1	0 (0, 0)
Exposure to smoke, fire, flames	0.7	1.0	−0.1 (−0.1, 0)	0.4	0.5	0 (−0.1, 0)
Perinatal						
Length of gestation, fetal growth	1.0	0.7	0.2 (0.1, 0.3)	0.9	0.7	0.2 (0.1, 0.4)
Sudden infant death syndrome	0.2	0.4	−0.2 (−0.3, −0.1)	0.1	0.3	−0.3 (−0.3, −0.2)
Residual unrelated to tobacco	417.3	410.4	−0.6 (−1, −0.2)	313.8	303.2	0.8 (0.3, 1.3)
Absolute total	865.2	851.0	1.0	578.1	577.5	1.0

* Directly standardized mortality rates per 100,000 (2006 population of Canada as referent).
† The ratio is obtained by dividing the contribution of the age or cause by the life expectancy gap. A positive value indicates a contribution from Quebec and a negative value a contribution from Canada.

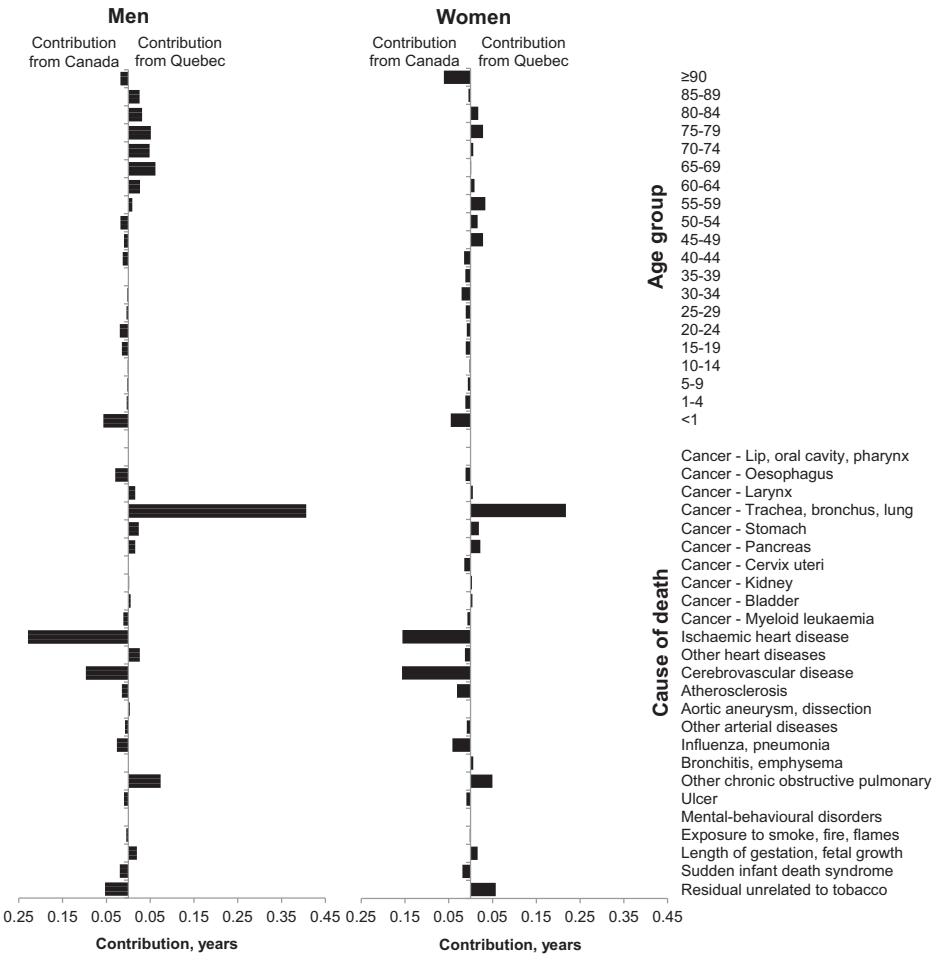

Fig. 1. Number of years contributed by age and cause to the life expectancy gap, Quebec and Canada, 2005–2009. The figure shows the contributions of age (upper half) and cause (lower half).

or older in Canada appeared to offset higher mortality among from women aged 45–85 years in Quebec (Fig. 1, upper half). The age-specific pattern was, however, more apparent for men. Higher mortality rates in Quebec men made a large contribution to the gap after 60 years of age, but this was also somewhat offset by higher male infant mortality in Canada. Furthermore, a few specific tobacco-related causes made large opposing contributions to the gap (Fig. 1, lower half). Contributions from elevated lung cancer predominated in Quebec, equivalent to 4.4 times the size of the gap in men and 3 times the size in women (Table 2), although other chronic obstructive pulmonary diseases also contributed. Contributions from these causes in Quebec were in large part offset in Canada by higher mortality from ischemic heart disease (men 2.5, women 2.2 times the size of the gap) and cerebrovascular disease (men 1.1, women 2.2 times the size of the gap). Overall, tobacco-related causes played a large role in masking the offsetting differences in mortality between Quebec and Canada that generated the small overall gap in life expectancy. For men, the contribution was larger in Quebec, at roughly 1.6 times the size of the life expectancy gap. For women, the contribution was larger in Canada, at roughly 1.8 times the size.

Joint partitioning of the gap by age and cause suggested that tobacco-related causes in Quebec made larger contributions at lower ages, with causes unrelated to tobacco overtaking at older ages (Fig. 2). This pattern was more prominent for women than men. In contrast, tobacco-related causes in Canada contributed more to the gap at older ages, especially for women. Thus, deaths related to tobacco consumption occurred at an earlier age overall for Quebec than for Canada, particularly among women. A closer look at specific tobacco-related causes indicated that contributions from lung cancer mortality in Quebec after 50 years in men and at 40–69 years in women were offset by ischemic heart disease in Canada after 60 years in men and 70 years in women (Fig. 3).

Discussion

In this study, we decomposed the life expectancy gap between Quebec and Canada into age and tobacco-related causes of deaths. We selected these two populations for their similar life expectancy, despite differences in prevalence of major risk factors for mortality including tobacco [17]. We aimed to demonstrate that, no matter how small, life expectancy gaps can be partitioned to determine whether risk factors such as tobacco indeed influence life expectancy. Using Quebec and Canada as an example, we illustrated the potential for decomposition analyses to determine avenues for extending life expectancy. We found that, despite a negligible gap, lung cancer at early ages had a large impact on life expectancy in Quebec. By extension, this finding suggests that public health initiatives aimed at reducing tobacco consumption in young adults have the potential to increase life expectancy for this population. We also found that cardiovascular mortality at older ages in Canada offset the gap, implying that competing causes of death can prevent life expectancy from extending further. To increase accessibility of this methodology, we provide researchers and policy makers with

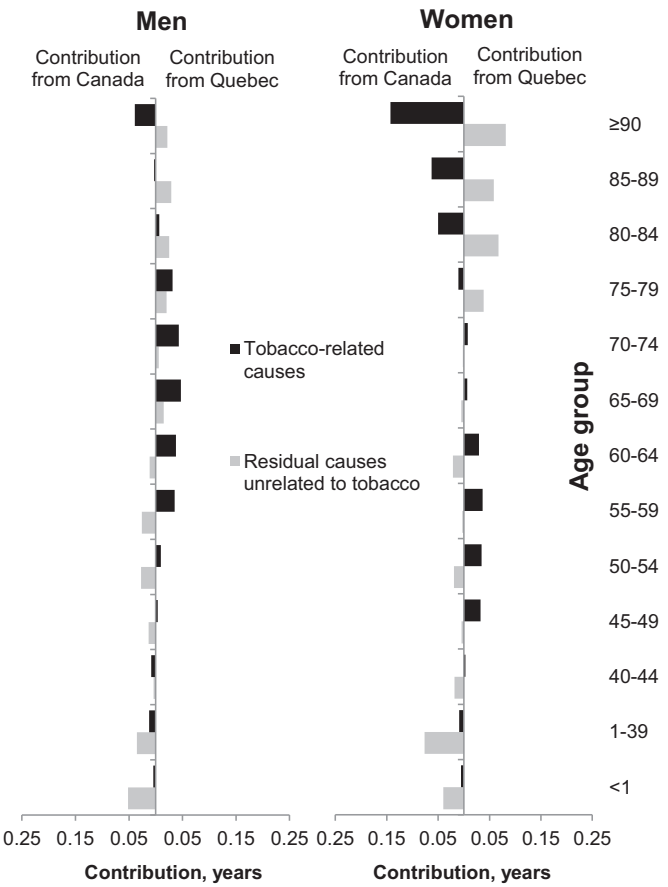

Fig. 2. Contribution of tobacco-related versus other causes to the life expectancy gap by age group, Quebec and Canada, 2005–2009. The figure shows the contribution of tobacco-related causes as a whole versus all other causes, stratified by age group. Ages 1–39 years were combined because contributions for tobacco-related causes of death were low.

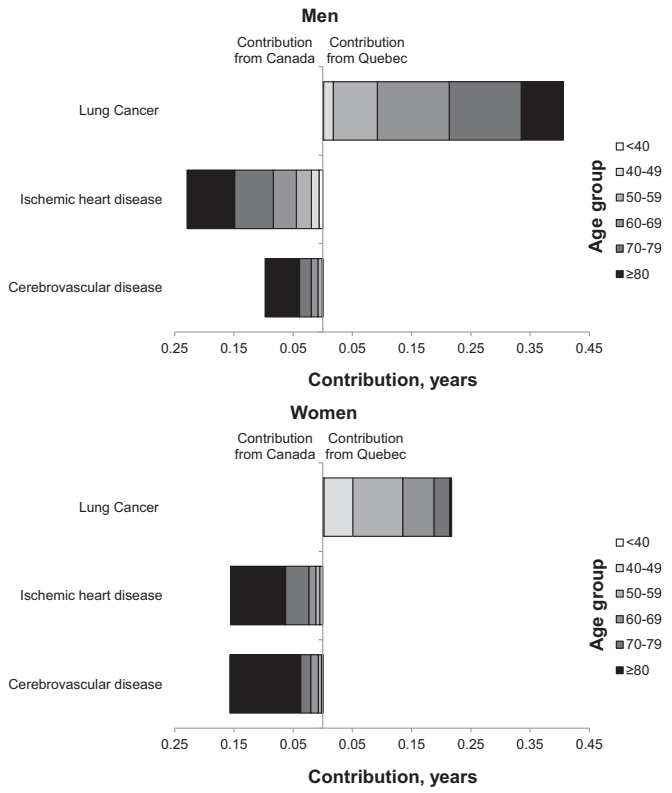

Fig. 3. Contribution of the three leading causes of tobacco-related mortality to the life expectancy gap by age, Quebec and Canada, 2005–2009. The figure shows the contributions of lung cancer, ischemic heart, and cerebrovascular disease by age group. Contributions from other causes were smaller and are not shown.

SAS/Stata code and an Excel spreadsheet for easy application of decomposition analyses to any life expectancy gap.

Life expectancy is commonly used to measure differences in health between populations [25]. However, use of this indicator is limited in high-income countries because life expectancy can plateau in very healthy populations, becoming less sensitive to differences between groups when overall mortality is low. Furthermore, measures of life expectancy can mask large inequality in age or cause-specific mortality, particularly when no gap is apparent. Although decomposition of life expectancy gaps can help address these limitations, most analyses of this nature have focused on relatively larger gaps [7–16], ranging from 0.8 years in Spain [16] to 6.5 years in the United States [13]. A novel contribution of our study was to demonstrate that decomposition analyses can yield useful information for health policy even when a gap is absent.

Canada is very diverse, and most prominent is the province of Quebec which is largely Francophone and socially distinct from the rest of the country [8,12]. In addition to Canadian tobacco regulation [26], Quebec has extensive legislation regulating marketing to children and adults [27,28], as well as a public health law mandating health promotion [29]. Tobacco consumption nonetheless is particularly high in Quebec, making the similarity in life expectancy with Canada surprising. In 2007–2008, 26.5% of men and 22.0% of women smoked in Quebec, whereas rates were lower in provinces such as Ontario (men 23.6% and women 17.1%) and British Columbia (men 20.9% and women 15.6%) [17]. Our decomposition showed that smoking did indeed lower life expectancy in Quebec, through higher lung cancer mortality at young ages. Evidence suggests that approximately 90% of deaths from lung cancer are attributable to tobacco, whereas the proportion is lower for cardiovascular disease (9%), particularly after 80 years [30]. Thus, the greater contribution of cardiovascular mortality at older ages in Canada may reflect lower smoking rates and potentially delayed mortality. Although ultimately differences in life expectancy were negligible, the impact of tobacco in Quebec may be substantial because more health care resources may be needed to care for tobacco-related diseases in young people, and economic impacts from loss of productivity early in life may be large [31].

Decomposition methods such as Arriaga's have advantages. A standard population is not needed, unlike directly standardized mortality rates. Comparability of mortality studies that rely on rates alone is limited when different standards are used. Moreover, decomposition analyses use only observed data, precisely quantifying the importance of all age groups and causes of death. Finally, these methods facilitate identification of public health problems in populations, providing relevant input to policy questions by determining which specific age groups or causes of death have substantial impacts on life expectancy. Thus, decomposition analyses complement methods based on regression such as Preston's that aim to identify risk factors for shorter life expectancy [32].

There are limitations of Arriaga's methodology. Decomposition analyses assume that the contribution to a life expectancy gap of each cause of death within an age group is proportional to the proportion of deaths from each cause [3]. Although recent evidence suggests that this assumption is valid [23,33], Arriaga's method may underestimate the contribution of causes of death more common at older ages [23,33]. Although this problem arises because of the initial decomposition by age required before decomposing by cause,

alternative methods that decompose by cause of death only have recently been developed for research questions that do not require partitioning by age [23,33]. Furthermore, decomposition analyses focus on leading cause of death, and not secondary causes, which may be problematic for smoking-related deaths attributable to several causes. There may be differences in classification of cause of death on registration certificates across provinces. Decomposition analyses are based on aggregated population data—inference to individuals can lead to ecologic bias. Finally, life expectancy measures mortality rather than health status of the living—methods to decompose gaps in healthy life expectancy are merited.

Decompositions of life expectancy gaps can provide useful policy information even when there appears to be little or no gap between populations. We showed that despite the negligible gap between Quebec and Canada, there were major differences in ages and causes of death that could be targeted to reduce mortality. In particular, tobacco policies aimed at reducing lung cancer mortality at young ages in Quebec are warranted, even if competing causes such as cardiovascular mortality overtake at older ages. We provide SAS/Stata syntax and an Excel spreadsheet to facilitate decomposition of life expectancy gaps, whether large or small, between any two populations.

Acknowledgment

This work was supported by a grant from the Research Center of the University of Montreal Hospital Center. N.A. and S.H. acknowledge career awards from the Fonds de recherche du Québec. The authors thank Karine Garneau for programming the Arriaga formulae in Excel.

Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.annepidem.2014.05.006.

References

[1] Andreev E, Shkolnikov VM, Begun AZ. Algorithm for decomposition of differences between aggregate demographic measures and its application to life expectancies, healthy life expectancies, parity progression ratios and total fertility rates. Demogr Res 2002;7:499–522.
[2] Arriaga EE. Measuring and explaining the change in life expectancies. Demography 1984;21:83–96.
[3] Arriaga EE. Changing trends in mortality declines during the last decades. In: Ruzicka L, Wunsch G, Kane P, editors. Differential mortality: methodological issues and biosocial factors. Oxford, England: Clarendon, Press. International Studies in Demography; 1989. pp. 105–29.
[4] Pollard JH. The expectation of life and its relationship to mortality. J Inst Actuaries 1982;109:225–40.
[5] Pollard JH. On the decomposition of changes in expectation of life and differentials in life expectancy. Demography 1988;25:265–76.
[6] United Nations. Sex differentials in life expectancy and mortality in developed countries: an analysis by age groups and causes of death from recent and historical data. Popul Bull UN 1988;25:65–107.
[7] Adam-Smith J, Harper S, Auger N. Causes of widening life expectancy inequalities in Quebec, Canada, 1989-2004. Can J Public Health 2011;102:375–81.
[8] Auger N, Harper S, Barry AD. Diverging socioeconomic inequality in life expectancy of Francophones and Anglophones in Montréal, Québec: tobacco to blame? J Public Health 2013;21:317–24.
[9] Khang YH, Yang S, Cho HJ, Jung-Choi K, Yun SC. Decomposition of socioeconomic differences in life expectancy at birth by age and cause of death among 4 million South Korean public servants and their dependents. Int J Epidemiol 2010;39:1656–66.
[10] Martikainen P, Valkonen T, Martelin T. Change in male and female life expectancy by social class: decomposition by age and cause of death in Finland 1971-95. J Epidemiol Community Health 2001;55:494–9.
[11] Tarkiainen L, Martikainen P, Laaksonen M, Valkonen T. Trends in life expectancy by income from 1988 to 2007: decomposition by age and cause of death. J Epidemiol Community Health 2012;66:573–8.
[12] Auger N, Harper S, Barry AD, Trempe N, Daniel M. Life expectancy gap between the Francophone majority and Anglophone minority of a Canadian population. Eur J Epidemiol 2012;27:27–38.
[13] Harper S, Rushani D, Kaufman JS. Trends in the black-white life expectancy gap, 2003-2008. JAMA 2012;307:2257–9.
[14] Na'amnih W, Muhsen K, Tarabeia J, Saabneh A, Green MS. Trends in the gap in life expectancy between Arabs and Jews in Israel between 1975 and 2004. Int J Epidemiol 2010;39:1324–32.
[15] Yang S, Khang YH, Chun H, Harper S, Lynch J. The changing gender differences in life expectancy in Korea 1970-2005. Soc Sci Med 2012;75:1280–7.
[16] Gispert R, Serra I, Bares MA, Puig X, Puigdefabregas A, Freitas A. The impact of avoidable mortality on life expectancy at birth in Spain: changes between three periods, from 1987 to 2001. J Epidemiol Community Health 2008;62:783–9.
[17] Statistics Canada. In: CANSIM. 2013. http://www5.statcan.gc.ca/cansim/. Accessed 7 Nov 2013.
[18] Baliunas D, Patra J, Rehm J, Popova S, Kaiserman M, Taylor B. Smoking-attributable mortality and expected years of life lost in Canada 2002: conclusions for prevention and policy. Chronic Dis Can 2007;27:154–62.
[19] Rostron B. Smoking-attributable mortality by cause in the United States: revising the CDC's data and estimates. Nicotine Tob Res 2013;15:238–46.
[20] Chiang CL. The life table and its applications. Malabar: Robert E. Krieger Publishing Company; 1984.
[21] Robert CP, Casella G. Monte Carlo statistical methods. 2nd ed. New York: Springer; 2010.
[22] Preston S, Heuveline P, Guillot M. Demography-measuring and modeling population processes. Oxford: Blackwell Publishing; 2001.
[23] Beltrán-Sánchez H, Preston SH. A new method for attributing changes in life expectancy to various causes of death, with application to the United States. PSC Working Paper Series PSC 07-01. 2007.
[24] Yang Z, Sun X. SAS macros for generating abridged and cause-eliminated life tables. Cary: SAS Institute Inc.; 2006. In: http://www2.sas.com/proceedings/sugi31/047-31.pdf.
[25] Silcocks PB, Jenner DA, Reza R. Life expectancy as a summary of mortality in a population: statistical considerations and suitability for use by health authorities. J Epidemiol Community Health 2001;55:38–43.
[26] Department of Justice, Canada. Tobacco act. 1997, c.13. http://laws.justice.gc.ca/en/T-11.5/. Accessed 19 April 2014.
[27] Office de la protection du consommateur. Loi sur la protection du consommateur: Publicité destinée aux enfants. 1978. http://www.opc.gouv.qc.ca/commercant/pratique-commerce/publicite-loi/publicite-enfant/Accessed 19 April 2014.
[28] Breton E, Richard L, Gagnon F, Jacques M, Bergeron P. Health promotion research and practice require sound policy analysis models: the case of Quebec's Tobacco Act. Soc Sci Med 2008;67:1679–89.
[29] Ministère de la Santé et des Services sociaux du Québec. Public health act, chapter S-2.2. Government of Québec. 2001. http://www2.publicationsduquebec.gouv.qc.ca/dynamicSearch/telecharge.php?type=2&file=/S_2_2/S2_2_A.html. Accessed 7 Nov 2013.
[30] World Health Organization. WHO global report: mortality attributable to tobacco. Geneva: WHO Press; 2012.
[31] Rehm J, Baliunas D, Brochu S, Fischer B, Gnam W, Patra J, et al. The costs of substance abuse in Canada 2002: highlights. Ottawa, ON: Canadian Center on Substance Abuse; 2006. Accessed 7 November 2013, www.ccsa.ca.
[32] Mackenback JP, Looman C. Life expectancy and national income in Europe, 1900-2008: an update of Preston's analysis. Int J Epidemiol 2013;42:1100–10.
[33] Beltran-Sanchez H, Preston SH, Canudas-Romo V. An integrated approach to cause-of-death analysis: cause-deleted life tables and decompositions of life expectancy. Demogr Res 2008;19:1323–47.

Appendix 1

International Classification of Disease (ICD-10) codes for tobacco-related causes of death

	ICD-10
Malignant neoplasms	
Lip, oral cavity, pharynx	C00–C14
Esophagus	C15
Larynx	C32
Trachea, bronchus, lung	C33–C34
Stomach	C16
Pancreas	C25
Cervix uteri	C53
Kidney	C64–C65
Bladder	C67
Myeloid leukemia	C92
Circulatory system	
Ischemic heart disease	I20–I25
Other heart diseases	I00–I09, I26–I51
Cerebrovascular disease	I60–I69
Atherosclerosis	I70
Aortic aneurysm, dissection	I71
Other arterial diseases	I72–I79
Respiratory	
Influenza, pneumonia	J10–J18
Bronchitis, emphysema	J40–J42, J43
Other chronic obstructive	J44
Digestive/mental-behavioral/injury	
Ulcer	K25–K28
Mental-behavioral disorders	F17
Exposure to smoke, fire, flames	X00–X09
Perinatal	
Length of gestation, fetal growth	P05–P07
Sudden infant death syndrome	R95