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.	not available for any reference period
..	not available for a specific reference period
...	not applicable
0	true zero or a value rounded to zero
0^s	value rounded to 0 (zero) where there is a meaningful distinction between true zero and the value that was rounded
^{p}	preliminary
^{r}	revised
x	suppressed to meet the confidentiality requirements of the *Statistics Act*
^{E}	use with caution
F	too unreliable to be published
*	significantly different from reference category ($p < 0.05$)

Health-adjusted potential years of life lost due to treatable causes of death and illness

Sara Allin, Erin Graves, Michel Grignon, Diana Ridgeway and Li Wang

Abstract

Background

Summary measures based on potential years of life lost (PYLL) to death and to illness would complement population health measures such as health-adjusted life expectancy. These measures can be applied to deaths and to conditions that are considered amenable to treatment by the health care system.

Data and methods

Life tables for 2007 to 2009 were used to calculate health-adjusted potential years of life lost (HAPYLL) for males and females from birth to age 75 for Canada and the provinces. Mortality rates for all causes were adjusted using the Health Utility Index 3 (HUI3) as a measure of the average value of a year in ill health. Average HUI3 was calculated for each age group for selected health conditions self-reported in the 2009/2010 Canadian Community Health Survey. HAPYLL was estimated by adding the average number of years lost due to treatable causes of death (treatable PYLL) to the average number of years lost because of ill health (HUI3 gap).

Results

More years of life are lost because of ill health than are lost because of premature death. During the 2007-to-2009 period, age-/sex-standardized PYLL due to treatable causes of death was 1,257 years lost per 100,000 person-years, while the age-/sex-standardized HUI3 gap was 6,477 years. Provincial rankings change when information on deaths is combined with information on ill health.

Interpretation

The impact of treatable conditions is greater in terms of quality of life lost than in life-years lost.

Key words

Health Utility Index, summary measures of health, treatable mortality

Authors

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In 1996, Wolfson proposed a method of measuring health-adjusted life expectancy (HALE), based on vital statistics and survey data.[1] The concept of HALE had been introduced in Canada in 1993 by Berthelot et al.[2] and applied worldwide by Romieu and Robine.[3] The proposal was in response to a recommendation by the 1991 National Task Force on Health Information that Canada should use a synthetic measure of average population health, which combined mortality and morbidity, to examine trends in population health, inform health policy, and monitor health system performance. Any synthetic measure of average population health is a function of many determinants beyond health care, but it is possible that deterioration in the measure could signal a problem in the health care system of a country.

HALE builds on life expectancy, which is based only on age-specific death rates, by using survey data to describe the distribution of health states at each age. Each health state receives a weight reflecting its value relative to perfect health: a year of life in perfect health is valued at 1.00; a year lived in a state valued at 0.5 is the equivalent of half a year lived in perfect health. To estimate HALE, the average weights of health states at each age are combined with age-specific death rates.

HALE, therefore, summarizes the health of a population as the equivalent number of years in perfect health individuals can expect if they live through the health and death conditions observed at a given time. For example, if life expectancy is 78 years and HALE is 72 years, the equivalent of 6 of the 78 years are "lost" because of less-than-perfect health.

Health Utility Index

A critical aspect of HALE is determining the values of health states. Two approaches can be used to generate such values: one relies on clinical judgment (a consensus of physicians provides values for a variety of health states). The other approach relies on the general public; these measures are "preference-based." The preference-based approach is routinely used to measure HALE in Canada and employs the Health Utility Index 3 (HUI3) to assign a value to health states.[1,2]

HUI3 embodies societal preferences for alternative health states. These health states are represented as various combinations of levels of functioning on eight domains (vision, hearing, speech, mobility, emotional state, thinking and memory, dexterity, and level of pain and discomfort). Each domaine has five or six levels, ranging from normal to severely limited (or the complete absence of) functioning. Societal preferences are defined as an average of the preferences of individuals, insofar as they form a representative sample of the population.

The HUI was developed in the 1990s by Feeney, Torrance and Furlong at McMaster University. It was derived from a survey of 504 respondents in the Hamilton (Ontario) region who were asked to imagine that they lived with functional impairments at various levels of severity.[4] Respondents provided standard gamble scores for selected HUI health states. In the standard gamble, an individual can choose between a lottery consisting of a probability "p" of perfect health and a probability "1-p" of the all-worst HUI health state, and an intermediate HUI health state for sure. A series of questions was asked to identify the probability "p" for which the respondent was indifferent between the lottery and the sure thing—the more desirable the intermediate sure-thing health state, the higher the indifference probability. These stated preferences allowed the HUI researchers to calibrate a formula for the calculation of scores for each impairment and combinations of impairments.[4]

The preference-based value of health for a given population is based on results of a survey that asked respondents in that population if they suffered from these impairments (and to what degree). Values for each level within each domain permit the calculation of a score with 0.00 representing death, and 1.00, perfect health. This makes it possible to calculate a level of functional health for each survey respondent, and then to estimate the mean functional health of all respondents of a given age—in other words, a HUI value by age or age group. Because the HUI questions in the survey were explicitly framed as comparisons between a year of life with the given level of functional health versus a year of life in perfect health, the HUI value attributed to an individual reflects the equivalent number (0 to 1) of years in perfect health that a year lived in the health state of the respondent would represent.

Health gaps

HALE is only one synthetic measure of average population health. Another option is to report a health gap.

Rather than estimating an equivalent number of years lived under current conditions of death and health, a health gap calculates the number of potential years in perfect health that are lost to premature death and to ill-health.[5] However, the first gap measure—Potential Years of Life Lost (PYLL)—was based only on deaths, with no adjustment for years lived in poor health.[6]

This limitation was recognized by the World Health Organization in the 1990s. Global burden of disease measures such as Disability-Adjusted Life Years (DALY) were created as the sum of PYLL and Years Lived with Disability (YLD). However, YLD is a binary measure: if health is a continuous indicator between 0 and 1, a threshold is arbitrarily defined, below which the individual is considered to be "in disability," and each year lived in that state adds a value of 1 to YLD. All years in less-than-good health ("good" being arbitrarily defined) are lost, exactly as if they were not lived at all.

The objective of the present study is to develop a measure of population health that addresses some of the shortcomings of DALY by combining a measure of years of life lost due to death with a continuous measure of quality of life for years lived—health-adjusted PYLL or HAPYLL.

Comparing health gaps with HALE

Although health gaps look similar to HALE, the difference between them is important.[7] Health gaps are additive, whereas health expectancy makes a false assumption of multiplicativity.

A health gap measures the number of healthy years "lost" in a population—the sum of years "lost" either to being dead or to being ill.[5] If death is State A, and illness, State B, a health gap estimates $\sum_x P_x(AUB)$ (over all ages x). The gap is naturally additive because $P(AUB) = P(A) + P(B)$, when A and B are mutually exclusive, which is the case here, as no one can be dead and ill at the same time.

A health expectancy estimates $\sum_x P_x(\bar{A} \cap \bar{B})$, where $\bar{A}$ is non$-$A (survival), and $\bar{B}$ is non$-$B (being well).[5] Health expectancy is the probability of an intersection of two states—being alive and being well. An empirical estimation would require knowledge of the joint distribution of the two states. Because, in practice, the joint distribution is not known, most HALE measures use a multiplicative approximation: $P(\bar{A} \cap \bar{B}) = (1\text{-}P(A))\ x\ (1\text{-}P(B))$. However, the approximation holds only when the two states are independent (being well does not change the probability of dying). Because the approximation is erroneous, health expectancies are less accurate than health gaps.

This limitation is important for the analysis of population health. HALE estimates the number of healthy years an individual is expected to live at birth by subtracting years of poor health, weighted according to severity, from overall life expectancy. However, because the multiplicative assumption is likely false, it is not possible to separate the effect of exogenous gains in longevity from the indirect effect of full health on the change of mortality. For that reason, HALE is ill-suited for predicting or for simulating counterfactuals. It is not possible to answer questions such as "What effect would a decline in morbidity have on HALE?" because the formula for calculating HALE does not incorporate an effect of better health on mortality. For example, in HALE, a decline in morbidity in the population would not have an impact on mortality because morbidity and mortality are treated independently. However, this is not likely to be the case, since a decline in morbidity would likely reduce mortality.

Another advantage of the additive nature of health gaps is that gaps attributable to specific conditions can be calculated. Such calculations are similar to calculations of healthy years of life saved as a result of specific interventions (for instance, routine use of aspirin to prevent strokes and heart attacks,[8] or the effect of the elimination of cardiovascular diseases on life expectancy[9]). The present analysis measures the equivalent years "lost" due to a set of treatable conditions. The implicit counterfactual is a situation where nobody would die or suffer from these conditions. In most simulations of the effect of an intervention, only one or two conditions are considered, and weights attributed to health states with or without the illness come from expert evaluations. By contrast, in this analysis, the set of treatable conditions is larger, and population-based weights are used to estimate years in less-than-perfect health due to those conditions.

The aim is to calculate a "treatable" health gap: how many years are lost due to deaths and to living in less-than-perfect health because of conditions that are considered treatable? In accordance with the current convention,[10-12] a reference age of 75 was used to calculate years of life lost. By focusing on treatable conditions, the measure of population health can be more closely linked to the performance of health care systems.[10,12]

Methods

Based on 2007-to-2009 life tables for Canada and the provinces, mortality rates for all causes were adjusted using the HUI3 as a measure of the average value of a year of life. The steps used to calculate health-adjusted potential years of life lost (HAPYLL) for the 2007-to-2009 period are described below.

For each individual, PYLL was calculated by subtracting age at death from the reference age of 75. For instance, PYLL for a death at age 60 is 15 (75 - 60 = 15). (For people who were older than the reference age when they died, PYLL is set at 0.) PYLL in the population is obtained by summing PYLLs for all individuals, and calculating per 100,000 person-years. For treatable PYLL, only deaths from causes that are considered amenable to medical intervention (Appendix Table A) were included in the calculation.[10-13] This guaranteed that the estimate of HAPYLL is consistent with measures of PYLL published by Statistics Canada.

Based on the prevalence of health states and their HUI3 value as reported to the 2009/2010 Canadian Community Health Survey (CCHS), the average value of a year of life for individuals in a given age category was estimated. HUI3 scores were set at 1.0 for people *not* suffering from any of the conditions considered "treatable." Although it is unlikely that everyone who does *not* have any of these conditions would be in perfect health,[14] this does not affect the analysis, because the objective is to measure the gain in HUI3 that would result from the hypothetical situation in which no one suffered from any of these conditions before age 75. The estimated HUI3 of the individual was used as the value of their year of life. This is an overestimation of the gap, because respondents with one of the listed conditions and another condition not included on the list will have lower HUI3 scores than the HUI3 generated from the treatable condition alone. The age-specific value of the years of life lost (h_x) was estimated at five-year intervals, and then, h_x by single year of age was estimated by linear interpolation.

Age-specific mortality rates and h_x were combined for each age group, separately for men and women.

The standard approach was used to calculate life expectancy and health-adjusted life expectancy by sex and for each age. To be consistent with the calculation of PYLL, the reference age was set at 75—person-years lived beyond 75 were not counted.

The HUI3 gap between life expectancy and health-adjusted life expectancy at each age until 75 was aggregated for each individual. The age-standardized HUI3 gap and the age-/sex-standardized HUI3 gap were calculated. The age-/sex-standardized estimates are reported.

PYLL per 100,000 person-years and the HUI3 gap were estimated to determine the total equivalent years lost due to treatable causes of death and to treatable conditions among the survivors.

Appendix Table B illustrates how HAPYLL was calculated for males. For example, at age 20, the average Canadian man could lose the equivalent of 2.48 life years (HUI3 gap) because of treatable conditions.

Results

For the 2007-to-2009 period, treatable HUI3 gaps were substantially larger than treatable PYLL. The overall age-/sex-standardized treatable HUI3 gap was the equivalent of 6,477 years of life lost per 100,000 person-years, compared with 1,257 years of life lost per 100,000 person-years for treatable PYLL (Table 1).

Variation among the provinces was greater for the treatable HUI3 gap than for treatable PYLL. As well, provincial rankings differed when equivalent years of life lost due to morbidity from treatable causes were considered along with mortality from treatable causes (Table 2) (ranking first indicates the fewest potential years of life lost; ranking tenth indicates the most potential years of life lost). For example, Quebec ranked fourth in treatable PYLL, but first in treatable HAPYLL. Similarly, Alberta, Saskatchewan and Manitoba rose in the ranking when years lost to morbidity were incorporated in the measure. Conversely, the addition of equivalent years of life lost to morbidity resulted in lower rankings for Nova Scotia and New Brunswick.

The treatable HUI3 gap was larger for women than for men overall (7,623 versus 5,330 years of life lost per 100,000 person-years), and in all provinces except Newfoundland and

Table 1
Age-/Sex-standardized HUI3 gap, treatable PYLL and HAPYLL, by province, Canada, 2007 to 2009

Province	HUI3 gap	Treatable PYLL	Treatable HAPYLL (HUI3 gap + treatable PYLL)
Canada	**6,477**	**1,257**	**7,733**
Newfoundland and Labrador	8,730	1,610	10,340
Prince Edward Island	11,618	1,294	12,911
Nova Scotia	11,746	1,193	12,939
New Brunswick	9,154	1,171	10,325
Quebec	3,733	1,196	4,929
Ontario	7,316	1,281	8,597
Manitoba	7,040	1,682	8,722
Saskatchewan	6,711	1,479	8,190
Alberta	5,833	1,288	7,121
British Colombia	4,850	1,029	5,879

PYLL = potential years of life lost per 100,000 person-years
HAPYLL = health-adjusted potential years of life lost per 100,000 person-years
Sources: Statistics Canada, CANSIM, Tables 102-0122 and 102-4311.

Table 2
Provincial rankings of age-/sex-standardized treatable PYLL and treatable HAPYLL, Canada, 2007 to 2009

Rank	Treatable PYLL	Treatable HAPYLL
1	British Colombia	Quebec
2	New Brunswick	British Colombia
3	Nova Scotia	Alberta
4	Quebec	Saskatchewan
5	Ontario	Ontario
6	Alberta	Manitoba
7	Prince Edward Island	New Brunswick
8	Saskatchewan	Newfoundland and Labrador
9	Newfoundland and Labrador	Prince Edward Island
10	Manitoba	Nova Scotia

PYLL = potential years of life lost per 100,000 person-years
HAPYLL = health-adjusted potential years of life lost per 100,000 person-years
Note: Ranked from lowest to highest PYLL and HAPYLL
Sources: Statistics Canada, CANSIM, Tables 102-0122 and 102-4311.

Labrador (Table 3). By contrast, the well-known difference in mortality between men and women (higher rates for men) was apparent for treatable PYLL—1,316 years lost per 100,000 person-years for men, compared with 1,198 years lost per 100,000 person-years for women.

Discussion

HALE measures morbidity and mortality simultaneously. HAPYLL provides additional insight—it can be used to measure years of life lost owing to deaths and to years lived in less-than-perfect health because of treatable conditions. The results of this study suggest that, before age 75, more years are "lost" because of morbidity (quality of life) than are lost through death (quantity of life).

Nonetheless, HAPYLL has a number of limitations. The first is the need to set a reference age beyond which no death is considered amenable to treatment, which clearly varies with individuals and over time. This analysis employed publicly available estimates of treatable causes of death, which are calculated using a reference age of 75.

The second limitation involves the coverage of the CCHS. The survey targets the household population aged 12 or older. Therefore, HUI3 data are missing for children, Aboriginal populations living on reserves, and residents of institutions. For simplicity in this

Table 3
Age-standardized HUI3 gap, treatable PYLL and treatable HAPYLL at age 75, by sex and province, Canada, 2007 to 2009

	HUI3 gap		Treatable PYLL		Treatable HAPYLL (HUI3 gap + treatable PYLL)	
Province	Female	Male	Female	Male	Female	Male
Canada	**7,623**	**5,330**	**1,198**	**1,316**	**8,821**	**6,646**
Newfoundland and Labrador	7,330	10,129	1,499	1,721	8,829	11,850
Prince Edward Island	12,255	10,980	1,063	1,529	13,318	12,509
Nova Scotia	13,505	9,987	1,161	1,229	14,666	11,216
New Brunswick	9,884	8,423	969	1,367	10,853	9,790
Quebec	4,207	3,259	1,180	1,216	5,387	4,475
Ontario	8,791	5,841	1,201	1,361	9,992	7,202
Manitoba	8,009	6,070	1,581	1,786	9,590	7,856
Saskatchewan	7,957	5,465	1,444	1,518	9,401	6,983
Alberta	6,611	5,055	1,242	1,335	7,853	6,390
British Colombia	5,464	4,235	1,002	1,057	6,466	5,292

PYLL = potential years of life lost per 100,000 person-years
HAPYLL = health-adjusted potential years of life lost per 100,000 person-years
Sources: Statistics Canada, CANSIM, Tables 102-0122 and 102-4311.

analysis, it was assumed that the average HUI3 of children younger than 12 was the same as at age 12.

Third, the CCHS disease/condition categories are broad and not easily mapped to the ICD codes used to calculate treatable PYLL (Appendix Table A). Some conditions on the list of treatable causes of death, such as asthma, diabetes and hypertension, are included as separate questions in the CCHS; others, such as cancer, are included in all types of cancer, although the definition of "treatable" includes only some cancers.

Finally, it is not possible to determine the specific HUI3 loss due to an illness on the list of treatable causes of death for respondents with co-morbidities, one of which is on the list; the other, not on the list. Therefore, the approach overestimates the HUI3 lost from treatable conditions. However, considering the HUI3 of those with only the conditions considered treatable would lead to an underestimate. While this is a limitation, it is not a severe one in comparisons of HAPYLL across jurisdictions or over time. It is unlikely that co-morbidities evolve in such a way that all differences in HAPYLL between two populations would be the result of differences in the joint distributions of illnesses that are treatable causes of death and illnesses that are not. ■

What is already known on this subject?

- Health-adjusted life expectancy (HALE) is a widely used summary measure of health that combines information on mortality and morbidity.
- Health gaps are alternative summary measures that allow calculation of the gap attributable to specific health problems.

What does this study add?

- This study addresses the key limitations of both HALE and disability-adjusted life years by developing a new summary measure of health—health-adjusted potential years of life lost from causes of death and from conditions that are considered treatable.
- The advantage of this measure is that it draws on the Health Utility Index 3 to allow for a continuous measure of morbidity.

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Appendix

Table A
Conditions selected to measure deaths from treatable causes and prevalence of treatable conditions

Causes of death for treatable PYLL from Health Indicators, Canadian Institute for Health Information	Variable in Canadian Community Health Survey
Tuberculosis	..
Selected invasive bacterial infections	..
Sepsis	..
Malaria	..
Meningitis	..
Cellulitis	..
Pneumonia	..
Colorectal cancer	
Malignant neosplasm of breast (female only)	
Cervical cancer	
Uterus cancer	
Testicular cancer	CCC_131 Has cancer
Bladder cancer	
Thyroid cancer	
Hodgkin's disease	
Leukemia (younger than 45)	
Benign neoplasms	..
Hypertensive diseases	CCC_071: High blood pressure
Cerebrovascular diseases (50% counted as treatable)	CCC_151 Suffers from effects of stroke
Ischemic heart disease (50% counted as treatable)	..
Other atherosclerosis (50% counted as treatable)	..
Asthma and bronchiectasis	CCC_031 Has asthma
Acute lower respiratory infection	..
Upper respiratory infections	..
Adult respiratory distress syndrome	..
Pulmonary oedema	..
Abscess of lung and mediastinum pyothorax	..
Other pleural disorder	..
Other respiratory disorders	CCC_091 Has COPD
Peptic ulcer disease	..
Diseases of appendix; hernia; disorders of gallbladder, biliary tract and pancreas	..
Nephritis and nephrosis	..
Renal failure	..
Obstructive uropathy, urolithiasis and prostatic hyperplasia	..
Inflammatory diseases of genitourinary system	..
Disorders resulting from impaired renal tubular function	..
Complications of perinatal period (selected diagnoses)	..
Congenital malformations, deformations and chromosomal anomalies	..
Pregnancy, childbirth and the puerperium	..
Thyroid disorder	..
Diabetes mellitus (50% counted as treatable)	CCC_101 Has diabetes
Adrenal disorders	..
Congenital metabolic disorder	..
Epilepsy	..
Osteomyelitis	..

.. not available for specific reference period
PYLL = potential years of life lost
Sources: Canadian Institute for Health Information, Health Indicators, 2012; 2009/2010 Canadian Community Health Survey Data dictionary of Master file.

Table B
Calculation of HUI3 gap for males, by selected ages, Canada, 2007 to 2009

Age	l_x	q_x	L_x	T_x	e_x	h_x	$L_{x\text{-perfect}}$	$T_{x\text{-perfect}}$	$e_{x\text{-perfect}}$	$L_x - L_{x\text{-perfect}}$	$e_x - e_{x\text{-perfect}}$	*HGAP*
0	100,000	0.005	99,520	7,075,059	70.75	0.011	98,425	6,804,183	68.04	1,095	2.71	2,965
10	99,330	0.000	99,325	6,081,090	61.22	0.011	98,232	5,821,148	58.60	1,093	2.62	2,859
20	98,999	0.001	98,960	5,088,848	51.40	0.012	97,772	4,843,800	48.93	1,188	2.48	2,939
30	98,237	0.001	98,199	4,102,764	41.76	0.016	96,589	3,869,606	39.39	1,610	2.37	3,822
40	97,252	0.001	97,184	3,124,850	32.13	0.027	94,541	2,910,189	29.92	2,643	2.21	5,835
50	95,268	0.003	95,115	2,160,952	22.68	0.039	91,444	1,977,234	20.75	3,671	1.93	7,080
60	90,509	0.008	90,134	1,228,582	13.57	0.076	83,302	1,107,554	12.24	6,832	1.34	9,136
70	79,188	0.022	78,329	372,423	4.70	0.123	68,734	327,903	4.14	9,595	0.56	5,395
74	71,498	0.032	70,357	70,357	0.98	0.123	61,738	61,738	0.86	8,619	0.12	1,039

x: Age
q_x: Mortality rate at age x and $x+1$
$L_x=(l_x + l_{x+1}) / 2$: Person years lived between age x and $x+1$
$T_x = (Sum\ (L_x)) - L_{x-1}$: *Total number of person years lived above age x*
$e_x = T_x / l_x$: Life expectancy at age x
h_x: Per capita HUI3 lost at age x
$L_{x\text{-perfect}} = L_x*(1-h_x)$: Person years lived with perfect health between age x and $x+1$
$T_{x-perfect} = (Sum\ (L_{x\text{-perfect}})) - L_{x-1}$: Total number of person years lived with perfect health above age x
$e_{x\text{-perfect}} = T_{x\text{-perfect}} / l_x$: Life expectancy with perfect health at age x
$HGAP_x = (e_x - e_{x-perfect})*(L_x-L_{x\text{-perfect}})$: HUI3 gap at age x