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by Larry F. Ellison

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ABSTRACT

Background

A comprehensive evaluation of progress in cancer survival for all cancer types combined has not previously been conducted for Canada. The cancer survival index (CSI) is superior to age standardization in measuring such progress.

Data and methods

Data are from the population-based Canadian Cancer Registry, record-linked to the Canadian Vital Statistics Death database. CSI estimates for both sexes combined were calculated as the weighted sum of the sex- and cancer-specific age-standardized net survival estimates. Sex-specific CSI estimates were calculated separately using sex-specific cancer type weights.

Results

From the 1992-to-1994 period to the 2015-to-2017 period, the five-year CSI increased 8.6 percentage points to 63.7%. It increased by 8.9 percentage points to 61.8% among males, and by 8.2 percentage points to 65.8% among females. The contribution of a cancer and sex combination to change in the CSI over time is a function of its assigned weight and changes in its age-standardized net survival. Female breast was the most influential cancer and sex combination, contributing 10.1% to the overall increase, followed by prostate (8.2%) and female lung (7.3%). The increase in the index since the 2005-to-2007 period was most impacted by lung cancer among both females (11.1%) and males (9.4%). While prostate cancer survival increased over the entire study period, it has recently decreased, resulting in a counterproductive 8.1% contribution since the 2005-to-2007 period.

Interpretation

Steady progress has been made in overall cancer survival in Canada since the early 1990s. Female breast cancer has contributed the most to this progress overall, but more recently female lung cancer has been the most influential.

Keywords

all cancers, cancer survival index, malignant neoplasms, population surveillance, registries, survival analysis

AUTHOR

Larry F. Ellison (larry.ellison@canada.ca) is with the Centre for Population Health Data at Statistics Canada, Ottawa, Ontario.

What is already known on this subject?

- A comprehensive evaluation of progress in cancer survival for all cancer types combined has not previously been conducted for Canada.
- Progress in cancer survival for all cancers combined has traditionally been examined using age-standardized estimates. A few recent studies have additionally adjusted for cancer type and sex to construct a cancer survival index (CSI).
- The net CSI provides a rigorous summary measure to monitor progress in cancer survival. When interpreted in combination with cancer incidence and mortality time trends, the CSI can more generally be used as an indicator of progress in cancer control efforts.

What does this study add?

- Relatively steady progress has been made in five-year net cancer survival for all cancers combined in Canada since the early 1990s.
- From the 1992-to-1994 period to the 2015-to-2017 period, the five-year CSI increased by 8.6 percentage points to just under 64%. A slightly higher increase was observed among males than among females.
- The cancer and sex combinations that most influenced changes in the five-year net CSI over the study period were female breast cancer, followed by prostate cancer, female lung cancer, male non-Hodgkin lymphoma and male lung cancer.
- The increase in the five-year net CSI since the 2005-to-2007 period was most impacted by lung cancer among both females and males. The contribution of prostate cancer during this period was counterproductive because of a decrease in survival.

Population-based cancer survival estimates permit the monitoring of progress in cancer outcomes over time. When combined with cancer incidence and mortality time trends, they provide an indication of progress in overall cancer control.[1] Estimates of survival for all cancers combined may provide summary measures with which to compare survival across geographic areas or within a geographic area over time. These estimates have routinely been age-standardized to control for differences in the age distribution of cancer cases within the populations being compared.[2,3] However, cancer survival has also been shown to vary widely by cancer type and sometimes by sex within a particular cancer type.[4-8] The distribution of incident cancer cases by cancer type (case-mix) and sex can also vary over time within a population or between populations during a given time period. A relatively new concept, the cancer survival index (CSI), is a summary measure of cancer survival that accounts for all three of these potentially confounding factors (i.e., age, sex and cancer type).[9-12] In doing so, the CSI ensures more valid comparisons of cancer survival across populations for all cancers combined.

The current study is the first comprehensive evaluation of progress in cancer survival for all cancer types combined in Canada. The results span the complete time period of the Canadian Cancer Registry[13] (CCR) and are unaffected by changes in the age, sex and case-mix of cancers over this time. Specifically, predicted Canadian net CSI estimates for the three-year period from 2015 to 2017 are presented and compared with corresponding actual estimates dating as far back as the 1992-to-1994 period. Comparisons are made for both sexes combined and for males and females separately. Further insight is provided by the determination of the most influential cancer and sex combinations and the leading cancer types within each sex, in regard to changes in the CSI since the periods of 1992 to 1994 and 2005 to 2007.

Data and methods

Data sources and definitions

Canadian Cancer Registry death-linked analytic file

The data source was a pre-existing analytic file created by linking CCR cases diagnosed from 1992 to 2017 to mortality information complete through December 31, 2017, via Statistics Canada's Social Data Linkage Environment.[14] The CCR is a population-based database comprised of cases diagnosed among Canadian residents since 1992.[13] The mortality information was obtained from the CCR itself, the Canadian Vital Statistics Death (CVSD) database—whose current scope is all deaths in Canada[15]—and T1 personal master files (as reported on tax returns). The use of death information on tax returns facilitated the identification of additional death events of patients on the CCR that may not have been included in the CVSD, such as out-of-country deaths. It was also used to validate the date of death when discrepancies between dates on the CCR and the CVSD were encountered.

The analytic file followed the multiple primary coding rules of the International Agency for Research on Cancer (IARC).[16] Survival time was measured in days. Cases were defined based on the International Classification of Diseases for Oncology, Third Edition,[17] and classified using Surveillance, Epidemiology, and End Results (SEER) Program grouping definitions.[6] Non-melanoma skin cancer cases are not in the scope of the CCR.[13]

Expected survival

Expected survival probabilities, necessary for the calculation of net survival (NS), were mostly obtained from sex-specific complete annual provincial life tables.[18] As complete life tables were not available for Prince Edward Island or the territories, expected survival for these jurisdictions were derived, up to age 99, from abridged life tables for Canada and the affected jurisdictions[19] and from complete Canadian life tables[18] using a method suggested by Dickman et al.[20] For ages 100 to 109, where this wasn't possible for these jurisdictions, complete Canadian life table values were directly used. Expected survival probabilities used in the calculation of NS for prostate and female breast cancer were adjusted for cancer-specific mortality rates in the general population.[21-23] More detail on the general approach for this adjustment can be found elsewhere.[5]

Inclusion and exclusions

All new primary cancers diagnosed in individuals aged 15 to 99 years were initially included. For cancers of the bones and joints, the age range was 20 to 99. Cases from the province of Quebec were excluded because cancer incidence data from this province had not been submitted to the CCR since the 2010 data year. Next, cases for which the diagnosis had been established through autopsy only or death certificate only, or for which a death had been established but the year of death was unknown, were excluded (1.5%). The dataset was then further restricted to first primary cancers per person, per individual cancer,[24-27] resulting in a further exclusion of 0.2% of cases.

Statistical analysis

NS is used as the underlying measure of cancer survival. NS estimates were derived using an algorithm[30] that has been augmented by Ron Dewar of the Nova Scotia Cancer Care Program (Dewar R, 2020, email communication, June 22) to include the Pohar Perme estimator of NS[31] using the hazard transformation approach. NS is the preferred method for comparing cancer survival in population-based cancer studies because it adjusts for the fact that different populations may have different levels of background risk of death.[28] The focus of this report is on five-year survival, though some short-term results in the form of one-year survival are also presented.

Cancer survival index estimates

CSI estimates for the three-year period from 2015 to 2017 are compared with corresponding estimates dating as far back as the 1992-to-1994 period. To highlight recent changes, comparisons for the most recent 10-year period since the 2005-to-2007 period are also provided. CSI estimates for both sexes combined were calculated as the weighted sum of the unrounded sex- and cancer-specific age-standardized NS estimates.[11] Sex-specific CSI estimates were calculated separately as the weighted sum of the unrounded cancer-specific age-standardized NS estimates for each sex. Weights were derived from the proportionate distribution of incident cases diagnosed from 2010 to 2014 using the IARC version of the CCR tabulation file (excluding cases diagnosed in Quebec) released on January 29, 2018. This version of the CCR file has previously been used to construct both the Canadian cancer survival standard weights[5] and the weights used to derive a Canadian childhood cancer survival index.[29] Only cases diagnosed between the ages of 15 and 99 years (20 to 99 years for bone cancer) with malignant behaviour or in situ neoplasms of the urinary bladder were considered in the calculations. Non-melanoma skin cancer cases were excluded. The weights are a minor refinement on those used in the 2019 Canadian Cancer Statistics publication.[12]

Age-standardized NS estimates for individual cancers were calculated as the weighted sum of the age-specific estimates for a given cancer. The Canadian cancer survival standard weights were used for this process.[5] Fifty-five cancers were considered—the cancers traditionally reported on for cancer incidence, survival and prevalence by Statistics Canada, except the categories corresponding to the corpus uteri and uterus not otherwise specified were combined. Weights for this combined cancer were derived in the same manner as for the standard weights for individual cancers and are as follows: 15 to 44 (0.050), 45 to 54 (0.169), 55 to 64 (0.353), 65 to 74 (0.261) and 75 to 99 (0.167). A five-year age-specific NS estimate could not be derived for 15 of the 11,220 (0.13%) necessary cancer, sex, age group and overlapping three-year time period combinations. In these extremely rare instances, the corresponding five-year NS estimate for the opposite sex was used as a proxy.

Predicted survival

The period method was used to determine predicted NS estimates for 2015 to 2017. The cohort method was used to derive non-predictive (actual) estimates of five-year NS between the periods of 1992 to 1994 and 2010 to 2012, and one-year NS between the periods of 1992 to 1994 and 2014 to 2016. Empirical evaluations of period analysis have shown that this method provides estimates that closely predict the survival that is eventually observed for people diagnosed in the period of interest, particularly when survival is fairly constant.[32-34] When survival is generally increasing (or decreasing), a period estimate tends to be a conservative prediction of the survival that is eventually observed.[33,35] All survival estimates were expressed as percentages. Changes in CSI estimates over time were expressed as percentage point differences.

Table 1
Weights used in case-mix standardization of Canadian net cancer survival index estimates

	Males and females combined		Sex-specific	
Cancer	Male	Female	Male	Female
Lip	0.00149	0.00052	0.00290	0.00108
Tongue	0.00468	0.00204	0.00909	0.00420
Salivary gland	0.00147	0.00110	0.00285	0.00227
Floor of mouth	0.00095	0.00037	0.00185	0.00077
Gum and other mouth	0.00189	0.00146	0.00367	0.00300
Nasopharynx	0.00104	0.00043	0.00202	0.00088
Oropharynx	0.00069	0.00021	0.00135	0.00043
Hypopharynx	0.00105	0.00022	0.00205	0.00045
Other oral cavity and pharynx	0.00350	0.00094	0.00681	0.00194
Esophagus	0.00826	0.00258	0.01605	0.00530
Stomach	0.01152	0.00637	0.02240	0.01312
Small intestine	0.00282	0.00236	0.00549	0.00487
Colon	0.04088	0.03899	0.07949	0.08027
Rectum	0.02505	0.01519	0.04870	0.03128
Anus	0.00127	0.00226	0.00248	0.00466
Liver	0.00846	0.00282	0.01645	0.00580
Gallbladder	0.00094	0.00169	0.00184	0.00348
Pancreas	0.01258	0.01212	0.02445	0.02495
Other digestive organs	0.00574	0.00601	0.01117	0.01238
Larynx	0.00460	0.00086	0.00894	0.00176
Lung and bronchus	0.06658	0.06265	0.12944	0.12900
Other respiratory organs	0.00115	0.00076	0.00224	0.00156
Bones and joints	0.00092	0.00068	0.00178	0.00141
Soft tissue (including heart)	0.00382	0.00286	0.00743	0.00588
Melanoma of the skin	0.02046	0.01751	0.03978	0.03606
Other non-epithelial skin	0.00236	0.00175	0.00459	0.00360
Breast	0.00110	0.12772	0.00213	0.26298
Cervix uteri	...	0.00791	...	0.01628
Ovary	...	0.01477	...	0.03040
Corpus uteri and uterus not otherwise specified	...	0.00554	...	0.01140
Other female genital organs	...	0.03200	...	0.06589
Prostate	0.12348	...	0.24008	...
Testis	0.00557	...	0.01083	...
Penis	0.00114	...	0.00222	...
Other male genital organs	0.00032	...	0.00062	...
Bladder (including in situ)	0.03639	0.01155	0.07076	0.02378
Kidney and renal pelvis	0.01891	0.01061	0.03677	0.02185
Ureter	0.00051	0.00039	0.00099	0.00081
Other urinary organs	0.00144	0.00065	0.00280	0.00134
Eye and orbit	0.00096	0.00084	0.00187	0.00173
Brain	0.00708	0.00518	0.01376	0.01066
Cranial nerves and other nervous system	0.00031	0.00033	0.00061	0.00069
Thyroid	0.00793	0.02498	0.01541	0.05143
Other endocrine including thymus	0.00084	0.00071	0.00164	0.00147
Hodgkin lymphoma	0.00263	0.00213	0.00511	0.00439
Non-Hodgkin lymphoma	0.02433	0.01987	0.04730	0.04091
Myeloma	0.00813	0.00619	0.01581	0.01276
Acute lymphocytic leukemia	0.00068	0.00054	0.00132	0.00111
Chronic lymphocytic leukemia	0.00793	0.00488	0.01541	0.01004
Acute myeloid leukemia	0.00386	0.00314	0.00751	0.00647
Chronic myeloid leukemia	0.00227	0.00152	0.00442	0.00312
Other leukemia	0.00217	0.00161	0.00422	0.00331
Mesothelioma	0.00242	0.00058	0.00470	0.00119
Kaposi sarcoma	0.00039	0.00009	0.00075	0.00019
Miscellaneous	0.01937	0.01719	0.03765	0.03540
Total	...	...	1.00000	1.00000

... not applicable

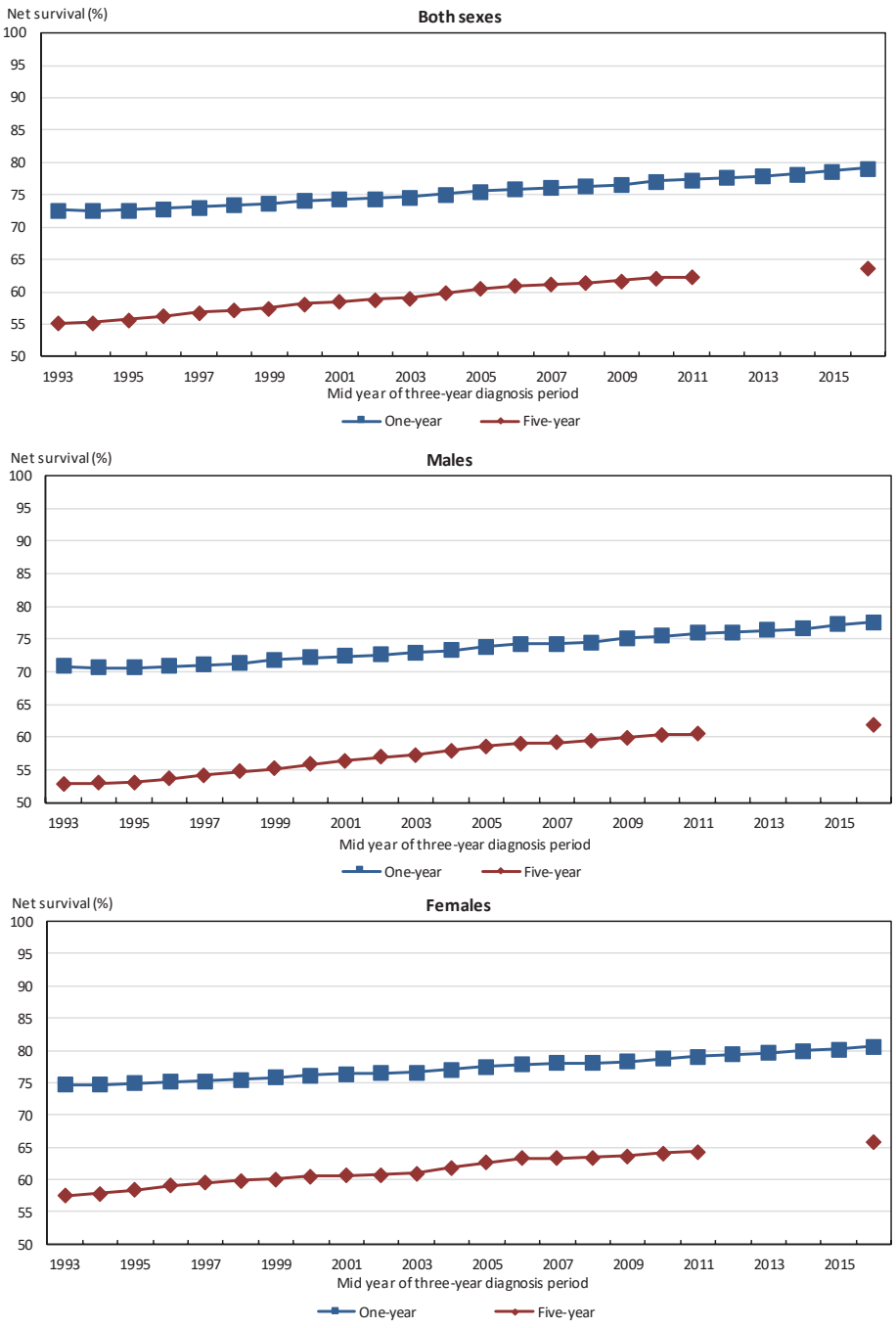
Notes: The sum total of the weights in the two columns associated with males and females combined is 1.00000. Weights were derived from the proportionate distribution of incident cases for people aged 15 to 99 years at diagnosis (20 to 99 for bone cancer), by sex and primary cancer, for diagnosis years 2010 through 2014, for Canada excluding Quebec. Cancers were classified using Surveillance, Epidemiology, and End Results (SEER) Program grouping definitions (Howlader N, Noone AM, Krapcho M, et al.).

Source: Statistics Canada, Canadian Cancer Registry International Agency for Research on Cancer multiple primary rules version tabulation file (1992-to-2015) released January 29, 2018.

Measuring component contributions to changes in net cancer survival index over time

The component contribution of a sex- and cancer-specific combination to the overall change in the CSI for both sexes combined over time was calculated as the product of the change in its sex- and cancer-specific age-standardized NS estimate and its corresponding CSI weight. The component contribution to the overall sex-specific changes in the CSI for a particular cancer results similarly from the multiplication of the change in its sex-specific age-standardized NS estimate by its corresponding sex-specific CSI weight.

Figure 1
One- and five-year net cancer survival index estimates, by sex, ages 15 to 99 years, Canada excluding Quebec, overlapping three-year time periods from the 1992-to-1994 period to the 2015-to-2017 period



Notes: The vertical error bars overlaid on the trend lines indicate 95% confidence intervals (CI). They may not be visible because the CIs are very narrow. CIs indicate the degree of variability in the estimates. Quebec is excluded because cases diagnosed in Quebec from 2011 onward had not been submitted to the Canadian Cancer Registry. Net cancer survival index (CSI) estimates for both sexes combined were calculated as a weighted average of sex- and cancer-specific age-standardized net survival estimates. Sex-specific net CSI estimates were calculated as a weighted average of cancer-specific age-standardized net survival estimates for each sex separately. CSI estimates for the 2015-to-2017 period were predicted using period analysis.
Sources: Statistics Canada, Canadian Cancer Registry death linked file (1992 to 2017); life tables.

The component percentage contribution of each sex- and cancer-specific combination to the overall change in the CSI for both sexes combined over time was then determined as the absolute value of the quotient of the component sex- and cancer-specific combination contribution to the change divided by the total change. The component cancer-specific percentage

contribution to overall sex-specific changes in the CSI over time was similarly determined using sex-specific values. Component percentage contributions must be non-negative and sum to 100%; however, if survival has decreased in the time period under consideration for a given component, its percentage contribution to the change in the CSI will be counterproductive to the goal of improved overall survival.

To aid in the interpretation of component contributions to changes in the CSI over time, sex-specific changes in the five-year age-standardized NS estimates from the 1992-to-1994 period to the 2015-to-2017 period for the more common and specific individual cancers are provided in Appendix Table A1.

Results

Weights

For both sexes combined, the cancer type and sex combination assigned the highest weight was female breast cancer, at 0.12772 (Table 1). Close behind was prostate cancer, at 0.12348, followed by male and female lung cancer, at 0.06658 and 0.06265, respectively; male and female colon cancer, at 0.04088 and 0.03899, respectively; and male bladder cancer (0.03639). These seven cancer type and sex combinations comprised virtually half of the total assigned weight, or very nearly as much as the remaining 95 combinations put together. Sex-specific weights were highest for prostate (0.24008), lung (0.12944) and colon (0.07949) cancer among males and breast (0.26298), lung (0.12900) and colon (0.08027) cancer among females.

Changes in one- and five-year net cancer survival index over time

From the 1992-to-1994 period to the 2015-to-2017 period, the five-year CSI increased by 8.6 percentage points to 63.7% (Figure 1). Over the entire time span, the one-year CSI increased by 6.4 percentage points to 79.1%. Over the most recent 10-year period between the 2005-to-2007 period and the 2015-to-2017 period, the one-year CSI increased by 3.1 percentage points, exceeding the 2.7 percentage point increase recorded for the corresponding five-year index over the same time span.

The CSI for all cancers combined was higher among females than among males for the entire study period, though the difference declined slightly over time. Among males, the five-year CSI increased by 8.9 percentage points to 61.8% and the one-year index increased by 6.8 percentage points to 77.6%. Among females, the five-year CSI increased by 8.2 percentage points to 65.8% and the one-year index increased by 5.9 percentage points to 80.6%. From the 2005-to-2007 period to the 2015-to-2017 period, the increases were by 3.4 (one-year) and 2.8 (five-year) percentage points among males, and 2.8 (one-year) and 2.5 (five-year) percentage points among females.

Contributions to change in net cancer survival index over time

Female breast cancer most influential to the increase in the five-year net cancer survival index since the 1992-to-1994 period

Of the 102 cancer type and sex combinations that contributed to the 8.6 percentage point increase in the five-year CSI since the 1992-to-1994 period, female breast cancer was found to be the most influential (Table 2). Because of a 0.12772 weight and a 7.1 percentage point increase in five-year age-standardized NS (Appendix Table A1), female breast cancer contributed 10.1% to the overall increase. The next leading combinations were prostate cancer (8.2%), female lung and bronchus (lung) cancer (7.3%), male non-Hodgkin lymphoma (6.2%), and male lung cancer (5.1%).

Lung cancer most influential to the increase in five-year net cancer survival index since the 2005-to-2007 period

The increase in the five-year CSI since the 2005-to-2007 period was most impacted by lung cancer among both females (11.1%) and males (9.4%). Among females, five-year lung cancer survival increased by 7.0 percentage points from the 2005-to-2007 period to the 2015-to-2017 period, while among males it increased by 5.6 percentage points. The third most influential contributor was prostate cancer, at 8.1%. However, unlike its positive contribution over the entire study period, the contribution of prostate cancer over the more recent time-span was counterproductive to the goal of improved overall survival, owing to a 2.6 percentage point decrease in its five-year age-standardized NS. The next leading cancer type and sex combinations were miscellaneous cancers (male 6.6%, female 5.9%) and bladder cancer among males (6.1%).

Female lung cancer also contributed the most to increases in the one-year CSI, whether over the entire study period (13.2%) or since the 2005-to-2007 period (female 15.6%). Male lung cancer was second, at 8.9% (13.7% since the 2005-to-2007 period). Male miscellaneous cancers were next, at 7.6% (10.5% since the 2005-to-2007 period), followed by female miscellaneous cancers at 7.2% (8.7% since the 2005-to-2007 period). The contributions of female breast cancer (10th, at 2.9%) and prostate cancer (15th, at 1.9%) were not nearly as impactful to increases in the one-year CSI over the study period as they were for the five-year duration.

Contributions to change in sex-specific net cancer survival index over time

Prostate cancer, at 15.5%, has had the largest impact on the 8.9 percentage point increase in the five-year CSI among males since the 1992-to-1994 period (Table 3). The next most influential cancers among males were non-Hodgkin lymphoma (11.7%), followed by lung (9.6%) and colon (9.1%) cancer. When the analysis was restricted to the most recent time span

Table 2

Leading cancer type and sex combination contributions to the percentage point change in the net cancer survival index, by time period and survival duration, Canada excluding Quebec, 1992-to-1994 period to 2015-to-2017 period

	Time span			
	1992-to-1994 period to 2015-to-2017 period		2005-to-2007 period to 2015-to-2017 period	
	Survival duration		Survival duration	
Cancer	Five-year contribution (%)	One-year contribution (%)	Five-year contribution (%)	One-year contribution (%)
Breast - Female	10.1	2.9	3.9	1.9
Prostate - Male	8.2	1.9	8.1 ‡	2.2 ‡
Lung and bronchus				
Female	7.3	13.2	11.1	15.6
Male	5.1	8.9	9.4	13.7
Non-Hodgkin lymphoma				
Male	6.2	4.7	3.9	3.0
Female	4.1	2.5	2.0	1.7
Colon				
Male	4.9	3.9	3.2	1.2
Female	4.3	3.5	2.6	1.5
Miscellaneous				
Female	4.3	7.2	5.9	8.7
Male	4.0	7.6	6.6	10.5
Rectum				
Male	3.6	2.3	2.0	1.3
Female	2.0	1.0	1.0	0.3
Kidney and renal pelvis				
Male	2.8	3.1	2.9	2.7
Female	1.3	1.3	1.0	0.9
Myeloma				
Male	2.2	1.5	2.2	1.5
Female	1.5	0.8	1.6	1.1
Bladder (including in situ)				
Male	1.6	1.4	6.1	3.7
Female	1.1	0.6	2.1	1.3
Melanoma of the skin				
Male	1.5	0.7	1.7	0.2
Female	1.2	0.4	...	...
Chronic lymphocytic leukemia - Male	1.5	0.8	1.3	0.5
Thyroid - Female	1.3	1.2	...	...
Liver - Male	1.2	3.2	...	...
Other oral cavity and pharynx - Male	1.2	0.7	...	...
Stomach - Male	1.1	1.7	1.6	2.0
Ovary - Female	1.0	1.1	...	...
Tongue - Male	1.0	0.8	...	...
Other digestive organs - Female	...	...	1.1 ‡	1.4 ‡
Other female genital organs	...	...	1.1 ‡	0.4 ‡
Esophagus - Male	...	...	1.0	1.7
Pancreas - Male	...	...	1.0	3.0

... not applicable

‡ Indicates that the contribution to the overall increase in the net cancer survival index is counterproductive because of decreases in age-standardized net survival for the particular cancer and sex combination.

Notes: Quebec is excluded because cases diagnosed in Quebec from 2011 onward had not been submitted to the Canadian Cancer Registry. Cancers were classified using Surveillance, Epidemiology, and End Results (SEER) Program grouping definitions (Howlader N, Noone AM, Krapcho M, et al.). The ranking of cancer and sex combinations is based on the five-year contribution for each time span. Cancer and sex combinations associated with five-year contributions of less than 1% are omitted. For reference, estimated percentage point increases in the net cancer survival index from the 1992-to-1994 period to the 2015-to-2017 period are 8.6 (five-year) and 6.4 (one-year); estimated increases from the 2005-to-2007 period to the 2015-to-2017 period are 2.7 (five-year) and 3.1 (one-year).

Sources: Statistics Canada, Canadian Cancer Registry death linked file (1992 to 2017); life tables.

since the 2005-to-2007 period, lung cancer was first, at 15.7%. The second most impactful, albeit in a counterproductive manner caused by a decrease in survival, was prostate cancer, at 13.5%. Miscellaneous cancers (11.0%) and bladder cancer (10.2%) were the only others to exceed 7%.

At 21.5%, breast cancer has had the largest impact on the 8.2 percentage point increase in the five-year CSI among females since the 1992-to-1994 period. Lung cancer was second among females, at 15.6%, followed by miscellaneous cancers (9.2%), colon cancer (9.2%) and non-Hodgkin lymphoma (8.7%). From the 2005-to-2007 period to the 2015-to-2017 period, the leading

contributing cancer types to the improvement in the CSI among females were lung cancer (27.5%), miscellaneous cancers (14.7%) and breast cancer (9.7%).

Discussion

Relatively steady progress has been made in five-year net cancer survival for all cancers combined in Canada since the early 1990s. The five-year CSI increased 8.6 percentage points from the 1992-to-1994 period to the 2015-to-2017 period. A slightly higher increase was observed among males than among females. The most influential cancer and sex combination in regard to the overall change was female breast cancer. However, since the 2005-to-2007 period, the change in the CSI has been most impacted by lung cancer among both females and males.

Table 3
Leading sex-specific cancer type contributors to the percentage point change in the five-year net cancer survival index, by time period, Canada excluding Quebec, 1992-to-1994 period to 2015-to-2017 period

	Time period	
Cancer by sex and type	1992-to-1994 period to 2015-to-2017 period contribution (%)	2005-to-2007 period to 2015-to-2017 period contribution (%)
Males		
Prostate	15.5	13.5 ‡
Non-Hodgkin lymphoma	11.7	6.6
Lung and bronchus	9.6	15.7
Colon	9.1	5.3
Miscellaneous	7.5	11.0
Rectum	6.8	3.3
Kidney and renal pelvis	5.2	4.9
Myeloma	4.1	3.8
Bladder (including in situ)	3.0	10.2
Melanoma of the skin	2.9	2.9
Chronic lymphocytic leukemia	2.8	2.2
Liver	2.3	1.4
Other oral cavity and pharynx	2.2	1.0
Stomach	2.1	2.8
Tongue	1.8	0.8
Pancreas	1.6	1.6
Esophagus	1.2	1.6
Small intestine	1.2	1.0
Chronic myeloid leukemia	1.0	0.1
Acute myeloid leukemia	1.0	0.6
Females		
Breast	21.5	9.7
Lung and bronchus	15.6	27.5
Miscellaneous	9.2	14.7
Colon	9.2	6.5
Non-Hodgkin lymphoma	8.7	4.9
Rectum	4.3	2.6
Myeloma	3.2	4.0
Kidney and renal pelvis	2.8	2.5
Thyroid	2.7	0.4 ‡
Melanoma of the skin	2.5	0.1 ‡
Bladder (including in situ)	2.4	5.2
Ovary	2.2	0.1 ‡
Chronic lymphocytic leukemia	2.0	0.5
Stomach	1.8	2.2
Pancreas	1.2	1.5
Chronic myeloid leukemia	1.1	0.3
Small intestine	1.0	0.1

‡ Indicates that the contribution to the overall increase in the net cancer survival index is counterproductive because of decreases in age-standardized net survival for the particular cancer and sex combination.
Notes: Quebec is excluded because cases diagnosed in Quebec from 2011 onward had not been submitted to the Canadian Cancer Registry. Cancers were classified using Surveillance, Epidemiology, and End Results (SEER) Program grouping definitions (Howlader N, Noone AM, Krapcho M, et al.). The ranking of cancers is based on their contributions to the percentage point change from the 1992-to-1994 period to the 2015-to-2017 period; cancers associated with contributions of less than 1% over this time span are omitted. For reference, percentage point increases in the net cancer survival index among males are 8.9 (since the 1992-to-1994 period) and 2.8 (since the 2005-to-2007 period); percentage point increases among females are 8.2 (since the 1992-to-1994 period) and 2.5 (since the 2005-to-2007 period).
Sources: Statistics Canada, Canadian Cancer Registry death linked file (1992 to 2017); life tables.

Particular features of the CSI have been described in detail elsewhere.[9-11] In short, the index summarizes the overall cancer survival in a population in one number and can be used to monitor progress over time. In conjunction with other metrics, the index may assist public health professionals and policy makers in evaluating the effectiveness of cancer control plans. Changes in the CSI over time better reflect the changes in survival because of diagnosis and treatment factors. This is because such changes are unaffected by temporal changes in the age, sex and cancer type distribution of cancer cases. Because of the incorporation of NS, they are also unaffected by any changes in the underlying risk of death in the population from other causes.

The contribution of a cancer and sex combination to a change in the CSI over time is a function of the fixed weight assigned to the component and changes in the age-standardized NS of the component over the given time span. Changes in survival among cancer and sex combinations that occur more frequently in the population under consideration are emphasized to a greater extent than changes in those that are rarer. In Canada, this means that breast cancer among females and prostate cancer are given the most emphasis. Changes in the CSI also reflect changes in survival among many individual cancer and sex combination components. In general, the largest increases in age-standardized NS were observed among blood cancers like chronic myeloid leukemia.[4]

The largest contributors to the increase in the five-year CSI were female breast cancer and prostate cancer. Gains in breast cancer survival have been attributed to the success of population-based screening programs, which have resulted in the earlier diagnosis of cases.[12] However, while gains in age-standardized NS were achieved for both of these cancers over the study period, their contributions to the CSI were more attributable to their assigned weights. To a lesser extent, the same was true for lung cancer among males, which was the fifth leading contributor to the index. By contrast, the contribution of non-Hodgkin lymphoma among males was more attributable to a relatively large increase in age-standardized NS, as opposed to the effect of its weight. The latter, while 11th among more than 100 cancer and sex combinations, was about one-fifth that of female breast and of prostate cancer. The contribution of lung cancer among females to the CSI exceeded its assigned weight as well. It also surpassed the contribution of lung cancer among males as a direct result of faster-paced increases in survival among females. With the exception of non-Hodgkin lymphoma, the effect that large increases in survival among blood cancers have had on the index have been attenuated by their corresponding relatively small weights.

Since the 2005-to-2007 period, the leading contributors to the increase in the five-year CSI have been female and then male lung cancer. While the weights assigned to these cancer type and sex combinations were the third and fourth highest of all such combinations, their proportionate contributions to the index were still considerably higher than the weights. This indicates that substantive improvements in survival were instrumental to their contributions. Advances in treatment, including the increasing use of targeted therapy drugs, may be behind at least some of the more recent survival gains for lung cancer.[36] Given the high frequency of lung cancer among all diagnoses of cancer, and its relatively inferior current prognosis, continued improvements in NS for this disease appear to offer the best opportunity for future improvements in the CSI. One potential pathway for this may be through the introduction of recommended lung cancer screening programs.[37]

The third leading contributor to the CSI from the 2005-to-2007 period to the 2015-to-2017 period was prostate cancer. However, unlike its impact over the entire study period, the contribution of prostate cancer since the 2005-to-2007 period has been counterproductive because of a recent decrease in survival. Efforts to reduce the overdiagnosis (i.e., the detection of disease that would not progress to cause symptoms or death[38]) of this cancer likely played an indirect role in the survival reduction. Following changes to prostate cancer screening guidelines,[39-41] age-standardized prostate cancer incidence rates in Canada (excluding Quebec) decreased by 25% from 2011 to 2017, and have declined by 33% since 2007.[42] The decrease disproportionately affected cases that were less likely to result in death. Specifically, the proportion of stage I and II prostate cancer cases decreased by 5 percentage points from 2011 to 2017.[43]

The five-year CSI among females was 4 to 5 percentage points higher than among males throughout the study period. By comparison, Quaresma et al. reported an advantage among females twice as large among those diagnosed with cancer in England and Wales.[10] The Canadian difference can be predominantly attributed to survival being a little higher among females than males for several individual cancers. While this was also a factor in England and Wales, the majority of the difference there was attributed to the fact that the cancers that are most common in women (e.g., breast) generally have higher survival than the cancers that are most common in men (e.g., lung). In Canada, however, the most common cancers among females generally have similar weights and survival to the most common cancers among males.

Strengths and limitations

The current study has a number of strengths, including the use of incidence data from the CCR, one of the highest-quality national population-based cancer registries in the world.[44] Another major strength is the additional consideration of cancer type and sex as potential confounders in measuring changes in cancer survival over time for all cancers combined. Doing so ensured more valid comparisons of cancer survival, as did the use of such a large number of individual cancers in the derivation of the CSI. Additionally, the use of recent Canadian-specific weights in the adjustment process in this study enhanced the interpretability of CSI estimates in the Canadian context.

The CSI has several limitations. As a summary measure, it does not provide any information regarding survival for individual cancers. It also does not reflect any given individual's prognosis and is therefore not useful in a clinical sense. In addition, it does not provide insight into the reasons behind changes in survival estimates over time. Changes in the CSI over time need to be interpreted in the context of public health interventions undertaken during the time period considered. A limitation of this study was the absence of complete incidence data from the province of Quebec. The CCR has not received data from this jurisdiction since the 2010 data year, and data that were submitted up to 2010 were based primarily on hospital data (i.e., hospitalizations or day surgeries). Thus, the results herein pertain to Canada, excluding Quebec.

Conclusion

This study represents the first comprehensive evaluation of progress in cancer survival for all cancer types combined in Canada. As measured by the CSI, steady improvement in overall NS has been made in Canada since at least the early 1990s. Continued monitoring of this index is recommended as a means to help measure ongoing progress in the diagnosis and management of cancer in Canada, including the effects of the COVID-19 pandemic. Future work will involve deriving provincial-level CSI estimates for the purposes of examining both interprovincial differences in the CSI and province-specific trends in the CSI over time.

Appendix Table A.1

Predicted five-year age-standardized net survival (ASNS) for 2015 to 2017, and changes in ASNS over time, by selected cancer type and by sex, ages 15 to 99 at diagnosis, Canada, excluding Quebec, 1992-to-1994 period to 2015-to-2017 period

	Sex					
	Males			Females		
Cancer	ASNS (%)	1992-to-1994 period to 2015-to-2017 period Change (% points)	2005-to-2007 period to 2015-to-2017 period Change (% points)	ASNS (%)	1992-to-1994 period to 2015-to-2017 period Change (% points)	2005-to-2007 period to 2015-to-2017 period Change (% points)
Tongue	63	18.9	4.0	64	7.8	-1.1
Esophagus	16	7.0	4.7	18	5.9	2.4
Stomach	27	8.8	5.7	32	11.9	5.6
Small intestine	60	19.8	8.5	56	18.8	-0.7
Colon	66	10.8	3.1	66	10.0	2.7
Rectum	66	13.2	3.2	69	12.1	2.7
Anus	60	1.6	-0.9	66	-4.5	-4.8
Liver	22	13.1	3.8	24	13.3	4.0
Pancreas	10	6.0	3.0	10	4.2	2.0
Larynx	65	3.0	2.2	59	2.1	-2.8
Lung and bronchus	19	7.0	5.6	26	10.6	7.0
Soft tissue (including heart)	61	-2.6	-1.1	61	0.8	-3.0
Melanoma of the skin	87	6.8	3.3	92	6.0	-0.1
Breast	77	1.1	-3.4	89	7.1	1.2
Cervix uteri	...	...	...	73	3.5	1.4
Ovary	...	...	...	44	6.4	-0.1
Corpus uteri and uterus not otherwise specified	...	...	...	56	-5.1	-7.5
Prostate	91	6.0	-2.6	...	...	...
Testis	97	1.7	0.0	...	...	...
Bladder (including in situ)	77	4.0	6.6	75	8.8	7.2
Kidney and renal pelvis	72	13.2	6.1	74	11.0	3.7
Brain	19	2.4	-0.4	21	1.9	-2.7
Thyroid	96	5.1	1.6	98	4.6	-0.3
Hodgkin lymphoma	84	5.6	1.7	87	3.2	2.0
Non-Hodgkin lymphoma	67	23.1	6.4	72	18.6	4.0
Myeloma	50	24.4	11.0	51	21.8	10.3
Chronic lymphocytic leukemia	84	16.8	6.5	89	17.4	1.7
Acute myeloid leukemia	23	12.3	3.7	24	10.2	4.6
Chronic myeloid leukemia	57	22.0	1.5	64	31.0	3.5
Mesothelioma	7	1.5	2.3	16	-0.8	5.6
Miscellaneous	42	18.8	13.5	45	22.8	13.7

... not applicable

Notes: Quebec is excluded because cases diagnosed in Quebec from 2011 onward had not been submitted to the Canadian Cancer Registry. The province of Ontario did not submit in situ bladder cancer cases to the Canadian Cancer Registry prior to the 2010 data year. Cancer cases were defined based on the International Classification of Diseases for Oncology, Third Edition (Fritz A, Percy C, Jack A, et al.), and classified using Surveillance, Epidemiology, and End Results (SEER) Program grouping definitions (Howlader N, Noone AM, Krapcho M, et al.). Estimates were age-standardized using the Canadian cancer survival standard weights (Ellison LF, 2018).

Sources: Canadian Cancer Registry death linked file (1992 to 2017); life tables.

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