Clinical Oncology 31 (2019) e95–e101

Contents lists available at ScienceDirect

Clinical Oncology

journal homepage: www.clinicaloncologyonline.net

Original Article

Comparison of Methods for Measuring Radiotherapy Utilisation

W.J. Mackillop [*] [†], W. Kong [*]

[*] *Division of Cancer Care and Epidemiology, Queen's Cancer Research Institute, Kingston, Ontario, Canada*
[†] *Department of Oncology, Queen's University, Kingston, Ontario, Canada*

Received 11 May 2018; received in revised form 1 March 2019; accepted 7 March 2019

Abstract

Aims: Evidence-based estimates of appropriate rates of radiotherapy utilisation are usually stated as the proportion of cancer patients who should receive radiotherapy at least once in their lifetime. However, the prolonged follow-up required to measure the lifetime radiotherapy rate limits its value in monitoring access to radiotherapy in routine practice. The objectives of this study were to evaluate shorter-term methods for measuring radiotherapy utilisation and to determine how well they predict the lifetime radiotherapy rate.
Materials and methods: The Ontario Cancer Registry provided records of all cases of cancer diagnosed in Ontario between 1984 and 2015. Records of all radiotherapy delivered by Ontario cancer centres were linked to individual cases in the Ontario Cancer Registry. Patients were followed forward for 20 years to determine the relationship between short-term and long-term rates of use of radiotherapy. Radiotherapy utilisation was also estimated by comparing total radiotherapy workload with cancer incidence; these measures were compared with observed long-term radiotherapy rates.
Results: The rate of use of radiotherapy within 1 year of diagnosis (RT_{1y}) was strongly predictive of the rate of use of radiotherapy after 20 years (RT_{20y}); for each annual cohort of cases between 1984 and 1995, RT_{20y} was approximately equal to $1.3 \times RT_{1y}$. The number of cases treated for the first time with radiotherapy in a specified period, divided by the number of new cases diagnosed in the same period, was about equal to the proportion of cases treated with radiotherapy within 20 years of diagnosis (RT_{20y}).
Conclusions: The lifetime rate of use of radiotherapy may be predicted quite accurately from the rate observed within 1 year of diagnosis, or from the ratio of new cases treated to cancer incidence in a specified period. Either of these measures may therefore be used to audit radiotherapy utilisation against the existing evidence-based targets.

Key words: Cancer; health care accessibility; performance indicator; radiotherapy; utilisation rate

Introduction

Achieving optimal outcomes in oncology requires that effective treatments should be accessible to all those who need them [1]. Radiotherapy is known to be effective in many different clinical situations and optimal access to radiotherapy is therefore a prerequisite for optimal outcomes [1,2]. Quality assurance in radiation oncology should therefore extend beyond assuring the technical quality of radiotherapy, to assuring that radiotherapy is accessible to all those who need it [2]. The first step towards optimising access is to identify performance indicators that can be used to set targets for optimal access to radiotherapy and to monitor actual access against those targets [2–5]. It is important to distinguish between indicators of potential access, which measure the level of resources required to provide a service, from indicators of realised access, which measure the actual use of the service [6]. Potential access to radiotherapy can be measured by the number of treatment machines, or by numbers of key radiotherapy personnel, per million people in the population. These simple indicators of the structure of radiotherapy systems have been very useful in describing international variations in treatment capacity, and in identifying nations where inadequate availability of resources limits access to radiotherapy [7,8]. However, optimal structures are necessary, but not sufficient, for optimal processes [9]; the availability of the equipment and personnel required to provide radiotherapy

Author for correspondence: W.J. Mackillop, Division of Cancer Care and Epidemiology, Queen's Cancer Research Institute, 10 Stuart Street, Level 2, Kingston, ON K7L 3N6, Canada. Tel: +1-613-533-6895; Fax: +1-613-533-6794.

E-mail address: william.mackillop@krcc.on.ca (W.J. Mackillop).

https://doi.org/10.1016/j.clon.2019.03.046
0936-6555/

does not guarantee that radiotherapy will be delivered to all those who need it, because these indicators of potential access are insensitive to other factors that may affect access to radiotherapy, including its spatial accessibility, its affordability and the awareness of its potential benefits in the medical community [2,10]. It is therefore also essential to monitor realised access to radiotherapy, i.e. the proportion of patients who actually receive radiotherapy [2].

Performance indicators should be precise but practical, they should be measured consistently and they should conform to international standards, if these exist [3]. Evidence-based methods have been developed to set standards for optimal radiotherapy utilisation. The quantity that has been most frequently used in setting those standards is the lifetime rate of use of radiotherapy, i.e. the proportion of patients who will require radiotherapy at least once in their lifetime [11,12]. Two different approaches have been used to describe the proportion of patients treated with radiotherapy, but neither can be used to measure this indicator directly. The longitudinal approach, initially developed in the Netherlands [13] and since used extensively in Canada [14], directly measures the proportion of cases who receive radiotherapy, by following the cohort of interest forward over time to determine whether or not each patient ever receives radiotherapy. This approach is straightforward where it is possible to link comprehensive electronic radiotherapy records to individual cases in a population-based cancer registry. To be useful, however, indicators of performance must be reportable within a relatively short time frame, and it takes many years of follow-up to measure the lifetime rate of use of radiotherapy directly. The first objective of this study, therefore, was to determine whether the lifetime rate of use of radiotherapy can be predicted based on the results of more practical, shorter-term longitudinal measures of radiotherapy utilisation. The cross-sectional approach estimates the proportion of patients who will ever be treated with radiotherapy in their lifetime. This is carried out by comparing the total number of new patients treated with radiotherapy with the total number of new cases diagnosed, in the same population, during the same period. This method, which was developed in the UK [15], can used more widely because it requires only aggregate records of radiotherapy workload and cancer incidence, without the need to link radiotherapy records to individual patients [15,16]. However, this method, as far as we are aware, has never been validated. The second objective of this study was to test the assumptions underlying this approach and to compare cross-sectional estimates of radiotherapy utilisation with direct measurements of the lifetime rate of use of radiotherapy, after at least 20 years of follow-up.

Materials and methods

Context: the Canadian Province of Ontario

All radiotherapy in Ontario is provided by a network of radiation oncology centres, co-ordinated by Cancer Care Ontario. In accordance with the Canada Health Act [17], the entire cost of radiotherapy for residents of Ontario is covered by the provincial government.

The Ontario Radiotherapy Database

The Ontario Cancer Registry (OCR) [18] provided records of all invasive cancers diagnosed in the province between 1984 and 2015. Non-melanoma skin cancers were excluded. Records of all radiotherapy delivered by Ontario cancer centres were linked to individual cases in the OCR. Records of radiotherapy delivered to Ontarians in the US between 1999 and 2001, under a contract with the Ontario Government, were also linked to the OCR.

Definitions

A case is defined as a specific patient, with a specific primary cancer. A new radiotherapy case is a patient who receives radiotherapy for the first time for a specified primary cancer. A retreated radiotherapy case is a patient who receives radiotherapy for a specified cancer, after having received previous radiotherapy for the same cancer. A radiotherapy case is defined as an individual who receives radiotherapy for a specific cancer within a defined period, and includes both new radiotherapy cases and retreated cases. A course of radiotherapy is defined as including all fractions delivered sequentially to one anatomic region, or to contiguous anatomic regions, without an interruption of more than 7 days.

Establishing the Relationship Between Short-Term and Long-Term Longitudinal Measures of Radiotherapy

Cohorts of incident cases were followed for at least 20 years in the radiotherapy database to determine the proportion who received radiotherapy [14]. We calculated the relationship between the rates of use of radiotherapy observed 1 year after diagnosis (RT_{1y}) and the rate observed after 20 years (RT_{20y}). Bootstrapping was used to establish 95% confidence limits on the ratio RT_{20y}/RT_{1y}.

Validating the Cross-Sectional Approach

In equating the ratio of new radiotherapy cases/incidence with the lifetime rate of use of radiotherapy, it is implicitly assumed that the number of patients who were diagnosed in previous years, but treated for the first time in the year of interest, is equal to the number of cases diagnosed in the year of interest, who will receive radiotherapy for the first time in future years [15]. We tested this assumption for each calendar year for which we were able to follow patients both forwards and backwards for at least a decade. The cross-sectional method was then used to estimate lifetime rates of radiotherapy utilisation as described by Williams and Drinkwater [15], and those estimates were compared with RT_{20y} measured by the longitudinal method.

Analysis

All analyses were carried out in SAS.

Results

Longitudinal Measures of Radiotherapy Utilisation

As illustrated in Figure 1, the proportion of cases treated with radiotherapy increases with time after diagnosis. In a historical cohort of 475 129 cases diagnosed between 1984 and 1995, for which 20-year follow-up was available, the proportion of incident cases who ever received radiotherapy increased from 15.9% at 3 months (RT_{3m}) to 21.0% at 6 months (RT_{6m}), 24.3% at 1 year (RT_{1y}) to 29.0% at 5 years (RT_{5y}), 30.5% at 10 years (RT_{10y}) and 31.6% at 20 years (RT_{20y}). In the remainder of this study, RT_{20y} is used as a proxy for the proportion of cases that will receive radiotherapy at any time, because the curve almost reaches a plateau by 20 years.

Supplementary Figure S1 shows that the impact of follow-up time on the observed radiotherapy rates is disease-specific; the proportion of cases treated with radiotherapy for lung cancer and head and neck cancer almost reached a plateau by 2 years, whereas the radiotherapy rates for breast and prostate cancer continued to increase slowly for many years.

Figure 2 shows that the proportion of incident cases who received radiotherapy with curative intent (CRT) increased rapidly to 16.2% at 1 year and then increased more slowly to 17.8% at 5 years, 18.4% at 10 years and 18.9% at 20 years, Thus, within 1 year of diagnosis, about 86% of the cases in which radiotherapy will ever be used with curative intent have already been treated. Figure 2 also shows that the proportion of cases who received palliative radiotherapy (PRT) increased more gradually, from 5.4% at 3 months to 6.6% at 6 months, 7.9% at 1 year, 10.9% at 5 years, 11.9% at 10 years and 12.4% at 20 years. Thus, only 64% of the cases who will ever receive radiotherapy with palliative intent are treated for the first time within 1 year of diagnosis. Supplementary Figure S2a shows that the time to first CRT is disease-specific. The CRT rates for head and neck and lung cancer reach an early plateau at about 6 months. The CRT rate for breast cancer does not plateau until about 1 year and the CRT rate for prostate cancer continues to increase over many years. Supplementary Figure S2b shows that the relationship between follow-up time and the observed rate of use of PRT is also disease-specific. The PRT rates for lung cancer and head and neck cancer reach an early plateau, whereas the rates for breast and prostate cancer increase slowly over many years.

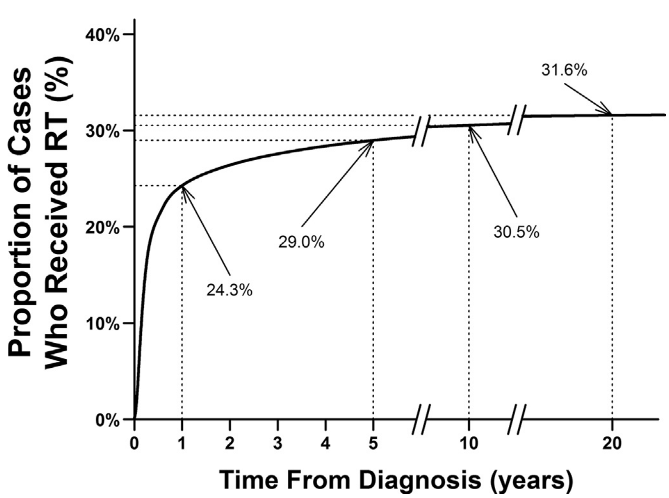

Fig 1. Cumulative probability of receiving radiotherapy at least once as a function of time from diagnosis.

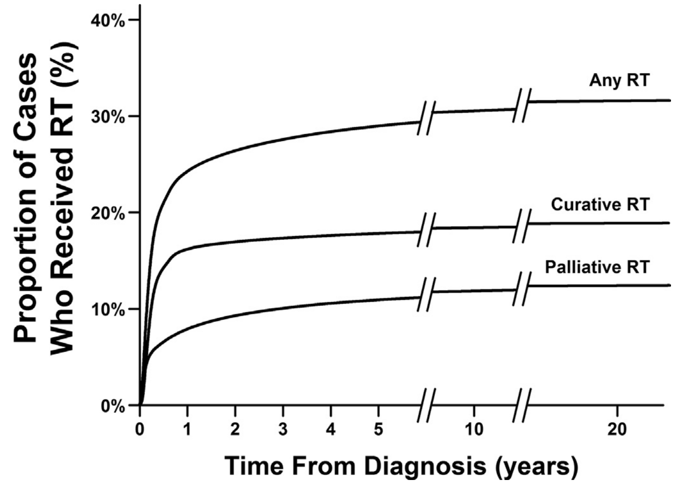

Fig 2. Cumulative probability of receiving curative or palliative radiotherapy at least once as a function of time from diagnosis. Note that the proportion of patients who receive radiotherapy with any intent is less than the sum of the proportion who receive curative radiotherapy and the proportion who receive palliative radiotherapy, because some patients initially treated with curative radiotherapy are treated later with palliative radiotherapy.

Predicting the Lifetime Rate of Use of Radiotherapy Based on the Rate of Use of Radiotherapy at 1 Year

We compared the rate of use of radiotherapy measured at 1 year (RT_{1y}) with the rate of use of radiotherapy measured after 20 years (RT_{20y}) to determine how well the more practical, short-term measure predicts the use of radiotherapy at any time in the course of the illness. Table 1 shows that, for all cases combined, the ratio RT_{20y}/RT_{1y} remained quite consistent over the study period, with RT_{20y} about equal to $1.3 \times RT_{1y}$. Table 1 also shows, however, that the ratio of RT_{20y}/RT_{1y} varies with primary cancer site, ranging from 1.84 for prostate cancer to 1.05 for head and neck cancer.

Testing the Assumptions Underlying the Cross-Sectional Approach

The cross-sectional approach assumes that the number of patients who were diagnosed in previous years, but treated for the first time in the year of interest, is about equal to the number of cases diagnosed in the year of interest, but treated for the first time in future years. Table 2 shows the

Table 1
Rate of use of radiotherapy observed 1 year after diagnosis (RT_{1y}) compared with the rate observed after 20 years (RT_{20y})

Year	All cancer sites			Head and neck cancer			Lung cancer			Prostate cancer		
	RT_{1y}	RT_{20y}	$RT_{20y/1y}$ (95% CI)*	RT_{1y}	RT_{20y}	$RT_{20y/1y}$ (95% CI)*	RT_{1y}	RT_{20y}	$RT_{20y/1y}$ (95% CI)*	RT_{1y}	RT_{20y}	$RT_{20y/1y}$ (95% CI)*
1984	23.4%	30.8%	1.31 (1.28, 1.35)	60.8%	64.1%	1.05 (1.00, 1.12)	43.2%	47.9%	1.11 (1.06, 1.16)	16.7%	28.4%	1.70 (1.54, 1.89)
1985	23.8%	31.0%	1.30 (1.27, 1.34)	57.4%	62.4%	1.09 (1.03, 1.15)	42.5%	47.4%	1.12 (1.07, 1.17)	14.7%	27.0%	1.84 (1.66, 2.05)
1986	23.8%	31.1%	1.31 (1.27, 1.34)	58.4%	62.2%	1.06 (1.00, 1.13)	42.1%	47.2%	1.12 (1.08, 1.17)	14.7%	27.0%	1.83 (1.65, 2.04)
1987	22.8%	30.2%	1.32 (1.29, 1.36)	56.6%	61.1%	1.08 (1.02, 1.15)	40.4%	45.7%	1.13 (1.09, 1.18)	16.8%	29.9%	1.78 (1.62, 1.95)
1988	22.8%	30.1%	1.32 (1.29, 1.35)	55.7%	60.4%	1.08 (1.02, 1.15)	39.0%	44.2%	1.13 (1.09, 1.18)	18.0%	30.9%	1.72 (1.58, 1.88)
1989	22.4%	29.7%	1.33 (1.30, 1.36)	53.9%	58.6%	1.09 (1.02, 1.16)	35.8%	41.4%	1.15 (1.10, 1.21)	19.4%	31.8%	1.64 (1.51, 1.79)
1990	22.7%	30.2%	1.33 (1.30, 1.36)	51.8%	58.1%	1.12 (1.05, 1.20)	35.6%	41.7%	1.17 (1.12, 1.23)	18.7%	31.5%	1.68 (1.55, 1.82)
1991	24.3%	31.4%	1.29 (1.27, 1.32)	54.7%	59.3%	1.08 (1.02, 1.15)	36.3%	42.6%	1.17 (1.12, 1.22)	21.9%	33.8%	1.54 (1.45, 1.65)
1992	25.7%	33.1%	1.29 (1.26, 1.32)	55.3%	60.6%	1.09 (1.03, 1.16)	37.4%	43.4%	1.16 (1.11, 1.21)	23.1%	35.9%	1.55 (1.47, 1.65)
1993	25.9%	33.2%	1.28 (1.26, 1.31)	56.8%	62.2%	1.10 (1.03, 1.16)	37.6%	43.2%	1.15 (1.10, 1.20)	24.5%	38.4%	1.57 (1.49, 1.65)
1994	25.9%	33.1%	1.28 (1.25, 1.30)	57.4%	62.4%	1.09 (1.03, 1.15)	37.3%	43.2%	1.16 (1.11, 1.21)	24.0%	38.6%	1.61 (1.53, 1.70)
1995	26.5%	33.7%	1.27 (1.25, 1.30)	57.4%	62.2%	1.08 (1.02, 1.15)	38.6%	44.3%	1.15 (1.10, 1.19)	22.2%	36.6%	1.65 (1.56, 1.76)

CI, confidence interval.
* $RT_{20y/1y}$ is the radiotherapy rate observed at 20 years (RT_{20y}) divided by the rate observed at 1 year (RT_{1y}).

year in which radiotherapy was first administered in the 56 402 new cases diagnosed in 2003; this was determined by following the incident cases forward for 10 years to determine when and if they received radiotherapy. Table 3 shows the year of diagnosis of 19 177 cases treated for the first time in 2003; this was determined by following the treated cases backwards in time to determine when they were diagnosed. A comparison of Tables 2 and 3 reveals that the number of cases diagnosed in 2002 and treated for the first time with radiotherapy in 2003 ($n = 6132$) is approximately equal to the number of cases diagnosed in 2003 but not treated until 2004 ($n = 5956$), Similarly, the number of cases diagnosed in 2001, who were treated in 2003 ($n = 806$) is approximately equal to the number of cases diagnosed in 2003 but not treated until 2005 ($n = 849$). Tables 2 and 3 show that this pattern continued as patients diagnosed in 2003 were followed forwards for 10 years and patients first treated in 2003 were followed backwards for 10 years. As a result, the total number of cases who received radiotherapy for the first time in 2003 and were diagnosed at any time in the preceding 10 years ($n = 19\,177$) is approximately equal to the total number of cases that were diagnosed in 2003 and who received radiotherapy for the first time at any point in the next 10 years ($n = 18\,799$). Supplementary Table S1 shows very similar findings for every year for which we had 10 years of follow-up and 10 years of follow-back. Thus, the total number of cases who receive radiotherapy for the first time in a given calendar year, regardless of their year of diagnosis, is a reasonable proxy for the total number of cases diagnosed in that calendar year who will receive radiotherapy at some point in the future.

Comparison of Cross-Sectional Estimates of the Lifetime Rate of Radiotherapy Utilisation with the Observed Rate after 20 Years of Follow-up

Table 4 shows the incidence of cancer in Ontario by calendar year between 1984 and 1995, together with three measures of radiotherapy workload: the total number of courses of radiotherapy delivered in the calendar year; the total number of cases treated at least once with radiotherapy in that calendar year (including those who had already received radiotherapy in previous years); and the number of cases treated for the first time with radiotherapy

Table 2
The relationship between calendar year of diagnosis and the calendar year in which the patient first received radiotherapy: the year of first treatment for 56 402 cases diagnosed in 2003

Treatment year	No. cases first treated	Cumulative no. cases first treated	% incident cases first treated	Cumulative % cases first treated
2003	9980	9980	17.7%	17.7%
2004	5956	15 936	10.6%	28.3%
2005	849	16 785	1.5%	29.8%
2006	560	17 345	1.0%	30.8%
2007	405	17 750	0.7%	31.5%
2008	318	18 068	0.6%	32.0%
2009	234	18 302	0.4%	32.4%
2010	210	18 512	0.4%	32.8%
2011	169	18 681	0.3%	33.1%
2012	118	18 799	0.2%	33.3%

Table 3
The relationship between calendar year of diagnosis and the calendar year in which the patient first received radiotherapy: the year of diagnosis of 19 177 cases treated for the first time in 2003

Year of diagnosis	No. cases first treated in 2003	Cumulative no.	% first treated cases	Cumulative %
2003	9980	9980	17.7%	17.7%
2002	6132	16 112	10.9%	28.6%
2001	806	16 918	1.4%	30.0%
2000	471	17 389	0.8%	30.8%
1999	337	17 726	0.6%	31.4%
1998	272	17 998	0.5%	31.9%
1997	174	18 172	0.3%	32.2%
1996	146	18 318	0.3%	32.5%
1995	113	18 431	0.2%	32.7%
1994	110	18 541	0.2%	32.9%
Any Year	–	19 177	–	34.0%

in that calendar year (new radiotherapy cases). Table 4 also shows each of these three aggregate measures of radiotherapy workload in relation to cancer incidence: courses of radiotherapy/incident case; radiotherapy cases per incident case; and new radiotherapy cases per incident case. The actual rate of use of radiotherapy, measured after 20 years of follow-up (RT_{20y}) is shown in the final column of Table 4. The number of new radiotherapy cases per incident case closely approximated the proportion of incident cases that went on to receive radiotherapy within 20 years of diagnosis (RT_{20y}). Note, however, the total number of all radiotherapy cases per incident case (including retreated cases) consistently overestimates RT_{20y}, to the extent that RT_{20y} is approximately equal to 0.84 $\times$ (all radiotherapy cases)/incident case. The number of courses of radiotherapy per incident case more greatly overestimates RT_{20y}, to the extent that RT_{20y} is approximately equal to 0.68 $\times$ (courses of radiotherapy)/incident case.

Discussion

Performance indicators are required to set standards for optimal utilisation of health services and to monitor utilisation of those services in relation to standards. Standards for the appropriate rate of use of radiotherapy are usually stated as the proportion of cases who should receive radiotherapy at least once in their lifetime [11,12]. However, the long-term follow-up required to audit compliance with these standards directly cannot provide the timely information about radiotherapy utilisation that is needed to manage a radiotherapy programme. The main finding of this study is that the lifetime rate of utilisation of radiotherapy can be predicted quite accurately, either from shorter-term longitudinal measures of radiotherapy utilisation or from the relationship between cross-sectional measures of radiotherapy workload and cancer incidence. This makes it possible to compare short-term measures of

Table 4
Comparison of cross-sectional and longitudinal measures of the use of radiotherapy

Year	No. incident cases	All courses of radiotherapy		All radiotherapy cases*		New radiotherapy cases		RT_{20y}
		No.	No./incidence	No.	No./incidence	No.	No./incidence	
1984	33 005	14 835	0.45	11 505	0.35	9984	0.30	0.31
1985	34 236	15 892	0.46	12 454	0.36	10 666	0.31	0.31
1986	34 597	16 177	0.47	12 529	0.36	10 564	0.31	0.31
1987	36 437	16 442	0.45	12 794	0.35	10 780	0.30	0.30
1988	38 044	16 683	0.44	13 231	0.35	11 040	0.29	0.30
1989	38 300	16 296	0.43	13 053	0.34	10 962	0.29	0.30
1990	40 213	16 577	0.41	13 390	0.33	11 287	0.28	0.30
1991	42 378	18 601	0.44	15 148	0.36	12 732	0.30	0.31
1992	43 394	19 723	0.45	16 302	0.38	13 788	0.32	0.33
1993	44 406	20 443	0.46	16 919	0.38	14 309	0.32	0.33
1994	45 124	20 793	0.46	17 369	0.38	14 621	0.32	0.33
1995	44 995	20 967	0.47	17 529	0.39	14 747	0.33	0.34
1984–1995	475 129	213 429	0.45	172 223	0.36	145 480	0.31	0.32

RT_{20y}, radiotherapy rate observed at 20 years.
* includes cases who received radiotherapy for the first time in the specified calendar year and cases who received radiotherapy in that calendar year after previous radiotherapy in an earlier year.

actual radiotherapy utilisation with standards that have been set for optimal lifetime rates [11,12].

The rate of use of radiotherapy within a year of diagnosis (RT_{1y}) was strongly predictive of the lifetime rate of use of radiotherapy. For all cases combined, our best estimate of the lifetime rate of use of radiotherapy, RT_{20y}, was about equal to $1.3 \times RT_{1y}$. This relationship can be used as a rule of thumb for predicting the lifetime rate of radiotherapy from the rate observed 1 year after diagnosis. Thus, where records of radiotherapy can be linked to individual cases in a population-based registry, radiotherapy utilisation can be measured in terms of RT_{1y}, converted to RT_{20y}, and compared with published standards, within a timeframe that is still relevant to the management of the radiotherapy programme. It may be tempting to try to further shorten the period of observation, by reporting the rate of use of radiotherapy within 6 months of diagnosis, or even less, but, as shown in Figure 1, these earlier timepoints lie in the steep part of the up-going, time-to-first-radiotherapy curves for some major diseases and the observed rates may therefore be sensitive to waiting times for treatment and/or to the timing of radiotherapy in relation to other treatments. We acknowledge that the relationship between RT_{1y} and RT_{20y} was disease-specific and that the relationship between RT_{1y} and RT_{20y} may be somewhat different in populations with a different mix of primary cancers.

The alternative, cross-sectional approach for estimating the lifetime radiotherapy rate by comparing aggregate measures of radiotherapy workload and cancer incidence also proved to be surprisingly accurate. This method is based on the implicit assumption that the number of patients diagnosed in previous years, but treated for the first time in the year of interest, is about equal to the number of cases diagnosed, but not treated in the year of interest, who will go on to receive radiotherapy for the first time in future years. We have shown here that this assumption is indeed correct. Furthermore, we have shown that the quotient of new radiotherapy cases/incident cases in a given calendar year closely approximates the rate of use of radiotherapy observed after 20 years of follow-up. This is important, because the cross-sectional approach can be used without linking radiotherapy records to individual cases, which may be impossible in some jurisdictions, either for technical reasons or because of concerns about privacy.

We have previously described and validated an alternative approach for projecting the lifetime rate of utilisation of radiotherapy in a cohort of incident cases based on past and current practice [19], but this requires historical records of radiotherapy linked to a cancer registry and is therefore less widely applicable than the cross-sectional approach evaluated here.

Furthermore, as shown by Williams and Drinkwater [15], the simple cross-sectional method can be applied using a sample of radiotherapy workload collected over a short period of time, without the need for continuous data collection. We confirmed, however, that it is critical to use the right measure of radiotherapy workload. All cases treated for the first time with radiotherapy in the period of interest should be included, regardless of their date of diagnosis, but cases who have received previous radiotherapy must be excluded [15]. The inclusion of retreated cases together with new cases in the numerator or the use of courses instead of cases leads to significant overestimation of the lifetime radiotherapy utilisation rate. Although this approach avoids the need to link radiotherapy records to individual cases, it is important that the radiotherapy workload data and the cancer incidence data should relate to exactly the same population. This requirement may be relatively easy to meet at the national level, but may be impossible at a regional level, unless the referral boundaries of radiotherapy centres are strictly defined and non-overlapping. This approach does not, therefore, lend itself to describing small area variations in radiotherapy utilisation or to identifying socioeconomic and health system-related factors associated with inadequate access to radiotherapy. By contrast, the longitudinal approach, which requires radiotherapy records linked to individual cases, permits the use of regression analysis to explore factors associated with the probability of receiving radiotherapy, at the level of the individual patient [20–22]. This is, therefore, the method of choice for identifying the causes of inadequate and/or inequitable access to radiotherapy [2].

Conflict of interest

The authors declare no conflicts of interest.

Acknowledgments

The authors thank Cancer Care Ontario for providing access to the electronic records used in this study. The work was supported in part by a team grant from the Canadian Institutes of Health Research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clon.2019.03.046.

References

[1] Aday LA, Andersen RM. Equity of access to medical care: a conceptual and empirical overview. *Med Care* 1981;19(12):4–27.

[2] Mackillop WJ, Hanna T, Brundage MD. Health services research in radiation oncology: toward achieving the achievable for patients with cancer. In: Gunderson LL, Tepper JE, editors. *Clinical radiation oncology*, 4th ed. Philadelphia, PA: Elsevier; 2015.

[3] Bird SM, Cox D, Farewell VT, Goldstein H, Holt T, Smith PC. Performance indicators: good, bad, and ugly [The report of a Working Party on Performance Monitoring in the Public Services]. *J R Stat Soc A* 2005;168:1–27.

[4] Smith PC, Mossialos E, Papanicolas I, Leatherman S. *Performance measurement for health system improvement:*

experiences, challenges and prospects. Cambridge: Cambridge University Press; 2010.

[5] Papanicolas I, Kringos D, Klazinga NS, Smith PC. Health system performance. *Health Policy* 2013;112:1–3.

[6] Andersen R, Aday LA. Access to medical care in the U.S.: realized and potential. *Med Care* 1978;16(7):533–546.

[7] Abdel-Wahab A, Bourque J-M, Pynda Y, Iżewska J, Van der Merwe D, Zubizarreta E, *et al*. Status of radiotherapy resources in Africa: an International Atomic Energy Agency analysis. *Lancet Oncol* 2013;14(4):e168–e175.

[8] Rosenblatt E, Izewska J, Anacak Y, Pynda Y, Scalliet P, Boniol M, *et al*. Radiotherapy capacity in European countries: an analysis of the Directory of Radiotherapy Centres (DIRAC) database. *Lancet Oncol* 2013;14(2):e79–e86.

[9] Donabedian A. Evaluating the quality of medical care. *Milbank Meml Fund Q* 1966;44:166–206.

[10] Penchansky R, Thomas JW. The concept of access: definition and relationship to consumer satisfaction. *Med Care* 1981;19:127–140.

[11] Tyldesley S, Boyd C, Schulze K, Walker H, Mackillop WJ. Estimating the need for radiotherapy for lung cancer: an evidence-based, epidemiological approach. *Int J Radiat Oncol Biol Phys* 2001;49:973–985.

[12] Delaney GP, Barton MB. Evidence-based estimates of the demand for radiotherapy. *Clin Oncol* 2015;27(2):70–76.

[13] de Jong B, Crommelinb M, Louis van der Heijden L, Coebergh J-W. Patterns of radiotherapy for cancer patients Netherlands, 1975–1989. *Radiother Oncol* 1994;3:13–22.

[14] Mackillop WJ, Groome PA, Zhou Y, Zhang-Salomons J, Holowaty EJ, Cummings B, *et al*. Does a centralized radiotherapy system provide adequate access to care? *J Clin Oncol* 1997;15:1261–1271.

[15] Williams MV, Drinkwater KJ. Radiotherapy in England in 2007: modelled demand and audited activity. *Clin Oncol* 2009;21(8):575–590.

[16] Rosenblatt E, Barton M, Mackillop W, Fidarova E, Yarney J, Lim G, *et al*. Optimal radiotherapy utilisation rate in developing countries: an IAEA study. *Radiother Oncol* 2015;116:35–37.

[17] Canada Health Act. Available at: http://www.canadian-healthcare.org (accessed on March 1, 2019).

[18] Clarke EA, Marrett LD. *Cancer registration in Ontario: a computer approach*. Lyon: IARC; 1991.

[19] Zhang-Salomons J, Mackillop WJ. Estimating the lifetime utilization rate of radiotherapy in cancer patients: the Multicohort Current Utilization Table (MCUT) method. *Comp Meth Progr Biomed J* 2008;92:99–108.

[20] Tyldesley S, Zhang-Salomons J, Groome P, Zhou S, Schulze K, Paszat L, *et al*. Association between age and the utilization of radiotherapy in Ontario. *Int J Radiat Oncol Biol Phys* 2000;47:469–480.

[21] Mackillop WJ, Kong W, Brundage M, Hanna T, Zhang-Salomons J, McLaughlin P-Y, *et al*. A comparison of evidence-based estimates and empirical benchmarks of the appropriate rate of use of radiation therapy in Ontario. *Int J Radiat Oncol Biol Phys* 2015;91(5):1099–1107.

[22] McLaughlin PY, Kong W, de Metz C, Hanna T, Brundage M, Warde P, *et al*. Do radiation oncology outreach clinics increase the use of radiation therapy? *Radiother Oncol* 2018;127(1):143–149.