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Original Article

Comparison of four methods for estimating actual radiotherapy utilisation using the 45 and Up Study cohort in New South Wales, Australia

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ABSTRACT

Aim: To compare four methods for estimating actual radiotherapy utilisation (A-RUR) reported in the literature.

Materials and methods: Participants in the 45 and Up Study in New South Wales (NSW) Australia completed a baseline questionnaire during 2006–2009 and consented to record linkage with administrative health datasets. Incident primary cancers (2006–2010) were identified through linkage with the NSW Cancer Registry. Radiotherapy receipt was identified through linkage with the Medicare Benefits Schedule and/or NSW Admitted Patient Data Collection (2006–2014). The four methods for estimating A-RUR were: 1 – crude proportion; 2 – crude proportion for patients followed for a defined period; 3 – life table without censoring of deaths; 4 – life table with censoring of deaths.

Results: There were 9817 participants with a diagnosis of cancer between recruitment and end of 2010, median follow-up 5.4 years. Crude A-RUR for the cancer cohort was 30.2%, below the "optimal" 48%. The 5 yr A-RUR was 29.7%, 29.8% and 33.4% using methods 2–4 respectively.

Conclusions: A-RUR estimates differed depending on the method used and all were below optimal. The method for estimating A-RUR for future studies should depend on the availability of the data as well as the intended audience for the results.

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Radiotherapy is a cost-effective treatment and an integral part of cancer care [1,2]. Evidence-based models [3,4] have been used to estimate the proportion of patients who have an indication for radiotherapy during their lifetime and this represents the "optimal" radiotherapy utilisation rate (RUR). The CCORE optimal utilisation model, developed in 2005 [3] and updated in 2012 [5], estimates the optimal RUR to be 48% for all cancer patients in Australia. The model has been adapted for use in other jurisdictions, including Europe [6].

Obtaining estimates of the actual radiotherapy utilisation rate (A-RUR) within a jurisdiction is important for benchmarking cancer services and planning adequate services, as gaps in radiotherapy service delivery may be identified. Limitations in estimating the actual radiotherapy utilisation rate (A-RUR) include the lack of availability of population-based data on an individual patient level. Many reports attempting to estimate A-RUR [7–12] have used a basic method of dividing an aggregate total of radiotherapy courses by an aggregate total of cancer registrations for a given calendar year. This method was used in these studies due to the lack of available individual patient data and the A-RUR estimates may lack accuracy. The 45 and Up Study, a large population-based study of healthy ageing, provided the opportunity to accurately estimate A-RUR for a cohort of cancer patients within New South Wales (NSW), Australia.

Where jurisdictions have access to individual population-based data for radiotherapy patients, there is no consensus on the best method with which to estimate A-RUR. Recent estimates from Sweden [8], Norway [13] and Belgium [14] have used different methods to estimate A-RUR. There have been 4 methods used in the literature to estimate A-RUR, however these have not been compared using the same data. Therefore, the primary aim of our study was to evaluate four methods for estimating A-RUR. Our second aim was to briefly compare the A-RUR estimates with the optimal RUR for the 45 and Up Study cancer cohort.

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Methods

The 45 and Up Study

There were 267,153 individuals aged ≥45 years enrolled in the Sax Institute's 45 and Up Study, a population-based cohort study of healthy ageing in NSW, the most populous Australian state. NSW has a population of 7.5 million and cancer incidence of 41,888 new cases in 2013 [15]. The 45 and Up Study methods have been described previously in detail [16]. Prospective participants were randomly sampled from the Department of Human Services (formerly Medicare Australia) enrolment database. The database has almost complete coverage of the Australian population as it includes all citizens and permanent residents. About 18% of those invited went onto participate, completed a 58-question postal baseline questionnaire during Jan 2006-Dec 2009 and consented to follow up and linkage to administrative health datasets. The cohort includes 11% of the NSW population aged 45 and over.

Data collection and linkage

For the purposes of this study, the linked datasets included:

(1) The 45 and Up Study baseline questionnaire – detailed health, lifestyle and socio-demographic information;
(2) Medicare Benefits Schedule (MBS; to December 2014), data on outpatient medical services and some in-hospital procedures; supplied by the Department of Human Services.
(3) NSW Cancer Registry (NSWCR; to December 2010), all notifications of primary cancer diagnosed and/or treated in NSW
(4) NSW Admitted Patient Data Collection (APDC; to June 2014), data on public and private hospital inpatient services
(5) Vital status recorded in the Register of Births, Deaths and Marriages (RBDM; to Dec 2014), all deaths that occur in NSW.

Individual records from (1) were linked to health database (2) by the Sax Institute using a unique identifier that was provided by the Department of Human Services, while individual records in databases (3) to (5) were linked by the Centre for Health Record Linkage [17].

Participants with an incident primary cancer diagnosed after completion of the baseline questionnaire were identified from the NSWCR. Patients who had multiple incident cancers diagnosed after completion of the baseline questionnaire, as well as those who had received radiotherapy for other cancers prior to recruitment, were excluded from the analysis. Patients were considered to have received radiotherapy if they had a code corresponding to external beam radiotherapy recorded after the diagnosis date in the MBS and/or APDC up to December 2014. Re-treatment radiotherapy was not evaluated in this study, nor was brachytherapy included.

Ethics approval

The conduct of the 45 and Up Study was approved by the University of New South Wales' Human Research Ethics Committee. This study was approved by the NSW Population and Health Services Research Ethics Committee (approval number 2014/08/551).

Adaptation of the CCORE model

The 2012 CCORE model was adapted to reflect the cancer case-mix observed in the 45 and Up Study cohort, as has previously been performed for other populations [18]. The inputs into the 2012 CCORE model were: optimal RURs for each cancer site as estimated from the literature and the proportions of each cancer site with respect to the total Australian cancer incidence in 2008. The model was adjusted by replacing the latter with the proportion of patients in the 45 and Up Study cohort diagnosed with cancer at each site, which in turn adjusted the overall optimal RUR. The optimal RUR inputs for each cancer site remained unchanged.

A-RUR estimates

We used four different methods to estimate A-RUR as reported in the literature to date. (Supplementary Table 1).

Method 1 was a crude estimate of the proportion of all cancer cases who received radiotherapy during the follow-up period.

Method 2 was a crude estimate of the proportion of cancer cases who received radiotherapy during a fixed time (X years) after diagnosis and was restricted to those who were diagnosed with incident cancer at or prior to X years before the end of the study follow-up period.

Method 3 used a life-table approach, which accounted for differing lengths of follow up, but did not censor those who died without receiving radiotherapy (i.e. they remained "under observation").

Method 4 also used a life-table approach but those who died without receiving radiotherapy were censored at the time of death from any cause.

The estimated A-RURs from the four methods for each year after diagnosis were compared. The estimated A-RURs at 5 years after diagnosis were compared with the optimal RUR, consistent with previous literature [14,19].

Statistical analysis

The period of observation for each patient was defined as the time from the date of cancer diagnosis to 31st December 2014 and, except for Method 4, this was not adjusted according to date of death. Data in the APDC were available until June 2014. However, MBS data were available until 31st December 2014, capturing the majority of patients receiving radiotherapy which is generally administered to outpatients rather than inpatients. Using Methods 3 and 4, patients were censored when they received radiotherapy and additionally when they died for Method 4. The 5 yr A-RUR was estimated at 5 years after diagnosis for each individual cancer site as well as for all cancers combined. SASv9.4 was used for statistical analysis.

Results

Patients diagnosed with cancer

There were 9817 participants with a diagnosis of cancer between the date they completed the baseline questionnaire and the end of 2010. The record linkage and exclusions are shown in detail in Fig. 1. The median period of observation after a cancer diagnosis was 5.4 years (range 4.0–8.9 years). The patients' characteristics and those of all cancer cases diagnosed over a similar time-period in NSW are shown Table 1 A larger proportion of the 45 and Up Study cancer cases were aged 60 or over and/or were male and/or had localised stage disease at diagnosis compared with all cancer cases diagnosed in NSW.

Optimal RUR for 45 and Up Study cohort

The proportions of all cancer cases with the five most common cancers in the 45 and Up Study cohort and NSW are shown in Table 1. In our cohort, a larger proportion of cases had prostate cancer. Adjusted for the distribution of cancer sites in our cohort,

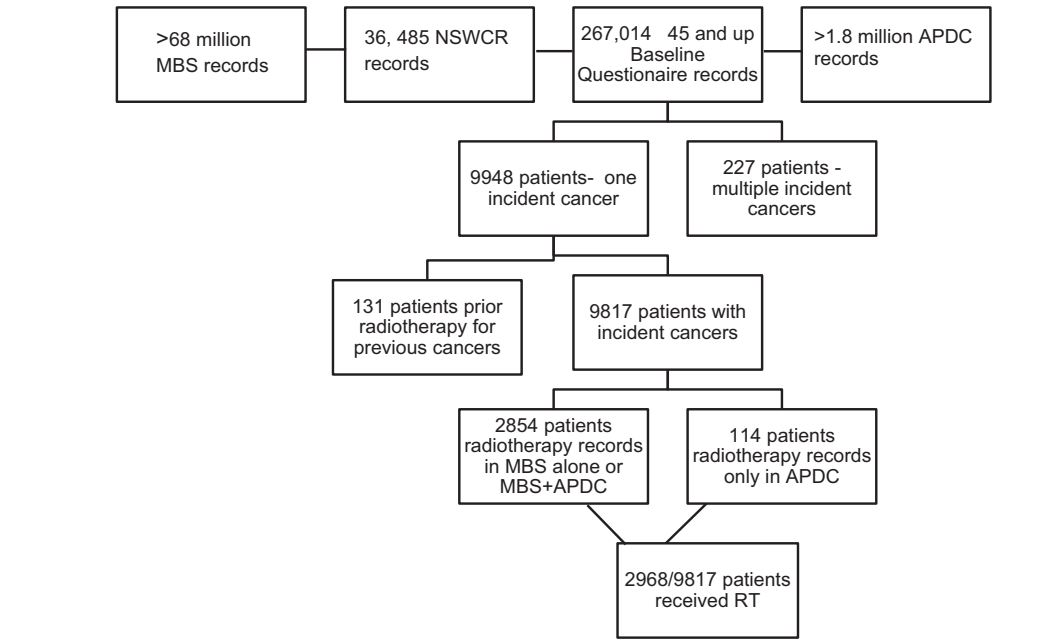


Fig. 1. Record linkage and incident cancers.

Table 1
Proportion of incident cancer cases in the 45 and Up Study (2006–2010) compared with the all cancers registered in NSW by patient characteristics.

Characteristic	45 and Up Study Cohort (2006–2010)		NSW Cancer Population, all (2008–2010)	NSW cancer population, aged ≥45 (2008–2010)
Age	*N*	%	%	%
0–44	0	0	8	0
45–59	1946	20	22	24
60–69	3052	31	27	29
70–79	2626	27	25	27
80+	2193	22	19	21
Total	9817	100	100	100
Gender				
Female	3773	38	43	42
Male	6044	62	57	58
Total	9817	100	100	100
Cancer site				
Prostate	2432	25	18	20
Breast	1189	12	12	12
Colorectal	1228	13	13	13
Melanoma	1070	11	10	9
Lung	741	8	9	10
Other cancers	3157	31	38	37
Total	9817	100	100	100
Degree of spread				
Localised	4429	45	41	41
Regional	1786	18	20	20
Distant	1247	13	16	16
Unknown	2355	24	23	23
Total	9817	100	100	100

NSW – New South Wales.

the optimal RUR was 48.5%, similar to the optimal RUR of 48.3% for the whole of Australia.

Estimates of actual RUR

There were 2986 cancer patients who received radiotherapy by the end of the observation period. Of these, 2854 (95.6%) had radiotherapy codes recorded in either the MBS alone or both the MBS and APDC databases. One hundred and fourteen cancer patients had radiotherapy codes recorded only in the APDC; 105 (92%) and 113 (99%) received radiotherapy within 3 and 4 years of diagnosis respectively. Table 2 shows the A-RUR estimates from Method 1 and by year after diagnosis from Methods 2–4. The numbers of patients included in Method 2 estimates were consistently

Table 2
Four methods used to estimate actual radiotherapy utilisation rate (A-RUR) with individual patient data.

	Method 1	Method 2	Method 3	Method 4
Definition	Crude method of estimating A-RUR	Crude method of estimating A-RUR, for a defined time-period after cancer diagnosis	Life table approach without deaths censored	Life table approach with deaths censored
Estimated A-RUR				
1 year		23.8%	24.0%	25.8%
2 year		26.1%	26.2%	28.5%
3 year		27.7%	27.8%	30.6%
4 year		29.1%	29.2%	32.4%
5 year		29.7%**	29.8%	33.4%
6 year		28.0%**	30.7%	34.5%
7 year		30.8% **	31.4%	35.7%
	A-RUR = 30.2%*			

* Only an overall A-RUR can be estimated because this method refers to the whole cohort and not to a specific time-period.
** 5yr A-RUR is estimated using $N = 6207$, 6 yr A-RUR $N = 2769$ and 7 yr A-RUR $N = 870$ as this method includes only the patients who have a follow-up period at least to the relevant time point.

lower due to the constraint that they had to be under observation for at least the relevant time period. For example, 6207 (out of 9817) patients reached 5 years of follow-up for inclusion in the 5 yr A-RUR and those who received radiotherapy but did not have at least 5 years of follow-up (due to a later cancer diagnosis) were not counted. The estimates from Method 3 were similar to those from Method 2 up until 5 years; the differences became more pronounced once the median follow-up of the cohort had been exceeded.

Fig. 2 shows the cumulative proportions of patients who received radiotherapy estimated using Methods 3 and 4. Both curves indicate that of those patients who received radiotherapy, >70% of patients received it within the first year after diagnosis. The estimated proportions receiving radiotherapy are larger from Method 4 than those from Method 3 as the Method 4 only includes patients who are still alive and under observation while in Method 3 those who have died are considered to be still under observation.

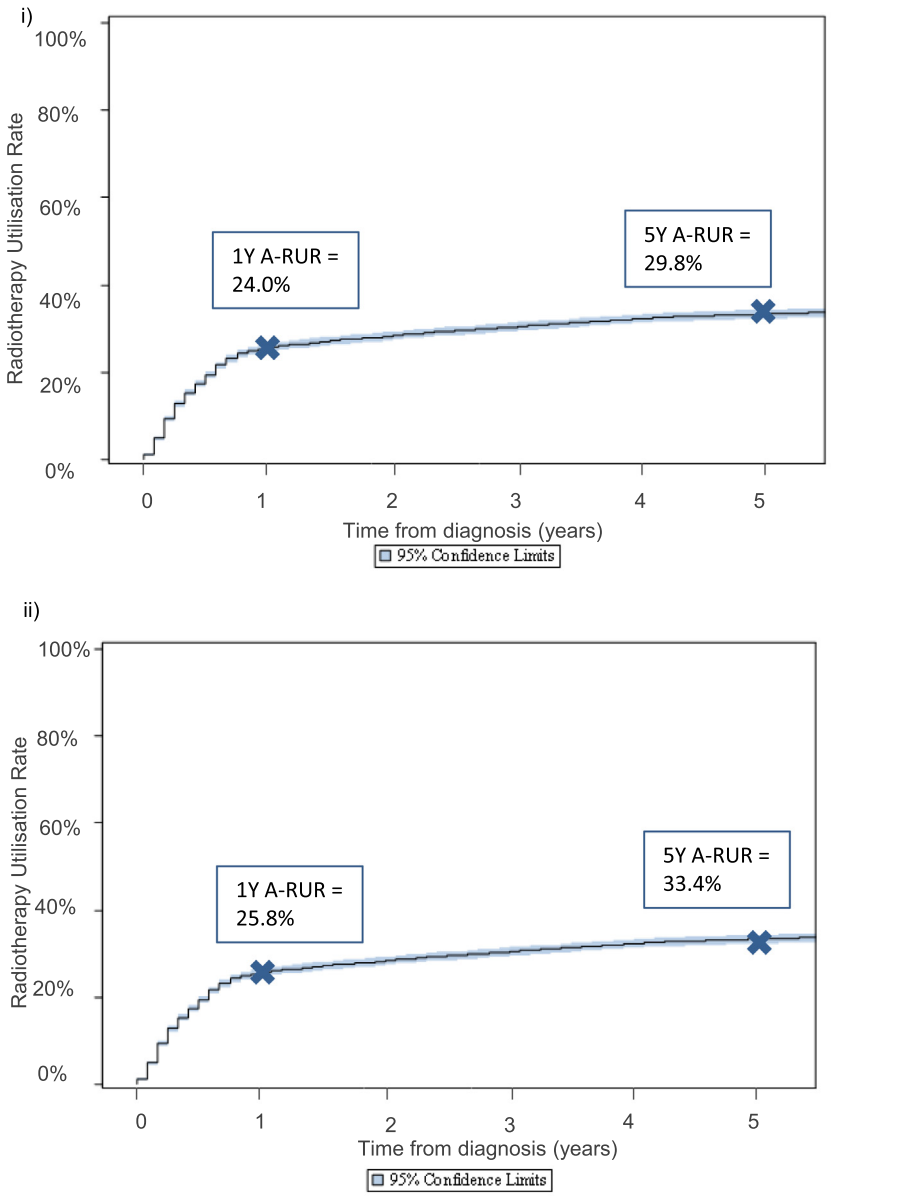
Table 3 shows the optimal RUR for each cancer site and the estimated A-RUR from Method 1 and the 5 yr A-RURs from Methods 2–4. The estimated A-RURs from all methods were lower than the optimal RURs for all cancer sites except for a few sites that have very low optimal RURs and/or low numbers of patients (leukaemia, liver, other and ovarian). The A-RUR estimates from Methods 1–3 were similar for sites with larger numbers of patients, but differed for other sites due to the differences in the numbers of patients included in the calculations. The A-RUR estimates from Method 4 were generally higher than those from Methods 2 and 3, particularly for those sub-sites with poor prognosis such as lung and pancreatic cancers.

Discussion

This is the first study to compare four methods to estimate A-RUR for the same population-based study cohort. A number of methods have been reported in the literature to date (Table 4), with no consensus regarding the most robust approach. A common approach uses a crude rate for the whole study cohort (Method 1), in which each patient potentially has a different length of follow-up. In comparison, A-RUR is estimated for a fixed timeframe in Method 2 e.g. 1 or 5 years following diagnosis. A life-table method without censoring of deaths has been proposed [20]. Our Method 3 is based on a life-table which allows for inclusion of patients with differing follow-up, provided the cohort is contemporaneous so patients have received current practice. For cohorts where the treatment received may not reflect current practice, e.g. 10–20 years of follow-up, the Multicohort Current Utilisation Table (MCUT) method has been favoured [20]. We did not use the MCUT method in our study, as the follow-up period ranged from 4-8.9 years. Method 4 is a life-table method in which patients are censored at death, to be comparable with common analyses of time-to-event data with variable lengths of follow-up.

The A-RUR for the cancer cohort using Method 1 as well as the 5-year A-RUR from Methods 2 and 3 were similar, due to the length of follow-up of the cohort being 5.4 years on average. The drop in A-RUR at year 6 using Method 2 is likely due to random variation in the cohort who had exactly 6 years of follow-up as there was no change in practice at the time. The 5-yr A-RUR from Method 4 was higher than that from the other methods by 3% (absolute). These differences were more apparent when comparing poor prognosis cancer sites, such as gallbladder, lung and pancreas. For these tumour sites, the estimates of 5 yr A-RUR from Method 4 were higher by >10% (absolute) than from Methods 2 and 3. This is due to the large number of patients who were censored when they died, thereby continually reducing the remaining numbers under observation. In contrast, there are no differences in the 5 yr A-RUR between Method 4 and Methods 2 or 3 for breast cancer, because very few patients died during the period of follow-up. The differences between Methods 2 and 3 became more evident at 6 and 7 years after diagnosis, as fewer patients reached this length of follow up.

The four methods vary in terms of their relative advantages and disadvantages, as well as their interpretations and potential applications (Supplementary Table 1). While Method 1 is the easiest to calculate, the results cannot be compared easily across jurisdictions due to the differing follow-up time for each patient. Method 2 ensures that all patients included in the A-RUR calculation have a minimum follow-up time, so can be used to compare across jurisdictions, but this may limit the number of patients included in the calculations. For example, in the Norwegian study [13], although the patient population included cancer diagnoses up to 2010, only those diagnosed up to 2005 were used to estimate 5 yr A-RUR. Method 3 has the flexibility of being applicable to cohorts in which there is a range in follow-up time. It also allows a graphical representation of the A-RUR. However, this method does not censor patients when they die [20] which diverges from the more common life-table approach used in survival analysis. Method 4 estimates the cumulative proportion who received radiotherapy over a specified time interval. Using Method 4, the 5-yr A-RUR is the proportion of patients who had received radiotherapy within 5 years after diagnosis, taking into account those who had died before 5 years or were less than 5 years post-diagnosis. Of the four methods, the results from Method 4 are most similar to the results reported for previous studies in NSW which used a cross-sectional aggregate method (total radiotherapy patients/cancer incidence for a given calendar year) [21]. The choice of method used for a future



i) Actual radiotherapy utilisation rate, method 3 - life table without deaths censored
ii) Actual radiotherapy utilisation rate, method 4 – life table with deaths censored

Fig. 2. Time to receipt of radiotherapy from Method 3 and Method 4.

study will depend on the availability of the data and the potential applications. For example, if follow-up over time and death data are available and the intent is to determine the chance of a patient receiving radiotherapy up to a given time-point, then Method 4 should be used. However, if the data-set does not include detailed information on when each patient received radiotherapy and when they died, then method 1 would need to be used.

Regardless of the method used for estimating A-RUR, our results were far below the optimal RUR of 48%. Previous studies in NSW have also reported A-RURs below optimal, such as Morgan et al. [5], who estimated an A-RUR of 35.5% in 2006, using a cross sectional aggregate method as described above. A recent study of NSW cancer patients diagnosed in 2004–2006 using individual patients' data [22] reported an A-RUR of 26%, with the follow up for each patient ranging from 6 months to 3.5 years. A number of other jurisdictions worldwide have also estimated A-RURs, as summarised in Table 4. Few have reported 5 yr A-RUR, most likely due to limitations in data availability. Some studies [23,24] have estimated A-RUR for a few cancer sites only. A Norwegian study [13] reported similar A-RURs to ours, of 29% at 5 years for diagnoses up to 2005. A recent study from Belgium ([14] found a crude A-RUR of 37% for patients diagnosed in 2007–2009 with varying follow-up of up to 5 years. This is a higher overall A-RUR than that for our population and could in part relate to the ease of access to radiotherapy services in smaller jurisdictions. The cancer sites for which a higher A-RUR was observed than in our study included colorectal and head and neck cancers. The comparisons in A-RUR between our study and other population-based studies in the literature for the top 10 cancers worldwide are shown in Supplementary Table 2. A study from Ontario [25] also reported a higher lifetime A-RUR, of 38%. In their 'Criterion benchmark population', which consisted of areas that met criteria including waiting time for radiotherapy and distance from the nearest radiotherapy centre, the lifetime A-RUR was higher, at 42%. Given that Ontario is

Table 3
Optimal and estimates of actual radiotherapy utilisation rate (RUR) for each cancer site using four methods.

Cancer site	Total number of patients used for Methods 1, 3 & 4 (Method 2)	Optimal lifetime RUR (%)	Estimated 5-year Actual RUR (%)			
			Method 1 Estimated Actual RUR	Method 2	Method 3	Method 4
Bladder	167 (96)	47	28	28	26	31
Brain	113 (74)	80	66	70	66	74
Breast	1189 (749)	87	66	66	66	66
Cervix	22 (16)	71	41	50	41	43
Colorectal	1228 (779)	23	13	11	13	15
Corpus uteri	186 (110)	38	23	19	23	23
Gallbladder	45 (27)	17	11	15	11	22
Head and neck	251 (146)	74	53	53	53	55
Kidney	179 (122)	15	13	13	13	15
Leukaemia	204 (135)	4	5	7	5	7
Liver	87 (63)	0	10	10	10	18
Lung	741 (467)	77	46	46	45	61
Lymphoma	359 (216)	71	26	23	25	29
Melanoma	1186 (734)	21	10	9	10	10
Multiple myeloma	124 (69)	45	37	39	37	43
Oesophagus	96 (65)	71	46	49	45	56
Other	448 (269)	19	25	25	24	30
Ovary	90 (52)	4	9	6	9	13
Pancreas	216 (135)	49	7	4	7	18
Prostate	2432 (1604)	58	33	33	33	34
Stomach	144 (90)	27	23	21	23	32
Thyroid	109 (70)	4	<5*	<5*	<5*	<5*
Unknown primary	177 (104)	61	20	17	20	36
Vulva	24 (15)	39	38	33	38	38
TOTAL	9817 (6207)	47	30	30	30	33

Method 1 = Crude rate Method 2 = Crude rate for patients with follow-up period of ≥5 years; Method 3 = Life table approach without deaths censored; Method 3 = Life table approach with deaths censored.
* Exact figures not given in order to protect the identity of small communities.

Table 4
Methods for calculating actual radiotherapy utilisation rates with individual patient data published in the literature.

Author	Population	Years of cancer diagnosis	Estimated Actual RUR	Method for calculating RUR
Studies of all cancers				
Lievens, 2017 [14]	Belgium	2009–2010	37.0% crude	Method 1 for crude A-RUR (Up to 5 years follow-up) Method 4 for Fig. 2 graph
Gabriel, 2015 [22]	NSW, Australia	2004–2006	26.0% crude	Method 1 for crude RUR, follow-up ranged from 6 months to 3.5 years
Mackillop, 2015 [25]	Ontario, Canada, Benchmark population	2009–2011	33.6% 1 yr, 41.5% Lifetime	1 yr A-RUR Method 2, MCUT method for projected Lifetime-RUR
Asli, 2014 [13]	Norway	1997–2010	28.7% 5 yr	Method 2 for 1 yr A-RUR and 5 yr A-RUR, MCUT method for projected Lifetime-RUR
Luke, 2003 [26]	South Australia, Australia	1990–1994	29.0% crude 25.2% 1 yr	Method 2 for 1 yr A-RUR, Method 1 for crude A-RUR (5–10 years follow up)
Studies of selected cancer sites				
Shack, 2017 [23]	Alberta, Canada	2004–2008	1 yr: breast 51.5%, cervix 48.9%, lung 37.1%, prostate 26.9%, rectum 39.3%	Method 2 for 1 yr A-RUR
Tyldesley, 2011 [19]	British Columbia, Canada	1997–2004	5 yr: Breast 55.1%, Lung 52.7%, Prostate 42.5%	Method 2

Method 1 – Crude rate, Method 2 = Crude rate for patients with follow-up period of ≥5 years; Method 3 = Life-table approach without deaths censored; Method 3 = Life-table approach with deaths censored, A-RUR = Actual radiotherapy utilisation rate, MCUT – Multicohort Current Utilisation Table.

a similarly sized jurisdiction to NSW, this suggests that factors beyond geography may be resulting in the low A-RUR found in our study, such as socio-demographic factors and patterns of referrals.

A main strength of this study is the use of routinely collected administrative datasets, which allows for capture of radiotherapy receipt regardless of outpatient provider. Another strength is the length of follow-up of 5.4 years on average. Although the APDC database had a shorter follow-up to June 2014 compared to MBS to Dec 2014, difference in follow up would be unlikely to affect our findings, given that of the small number of patients who had radiotherapy codes recorded only in APDC, 92% received radiotherapy within 3 years of diagnosis. The main limitation of our study is that it represents a cohort of patients who were included in the 45

and Up Study, but does not include all cancer patients from NSW. Our sample comprised a higher proportion of older patients, as well as most likely, health literate patients, but also under-sampled those from non-English speaking backgrounds. However, the main aim of this paper was to compare four methods for estimating A-RUR and this is unlikely to be affected by the coverage of the dataset. We adjusted the optimal RUR model to account for the small differences in the cancer case-mix in our study compared to the whole NSW cancer population. Finally, the data do not include TNM category and this limits the ability to assess the appropriateness of the radiotherapy treatment received.

This study demonstrates that the A-RUR for this cancer cohort in NSW is far below the optimal RUR and is also lower than that for other jurisdictions such as Belgium and Ontario. Given the known benefits of radiotherapy, the consequence of this large short-fall in services will be fewer cancer cures and less freedom from distressing symptoms, compared to the scenario where the optimal RUR is reached. The causes in the short-fall are likely to be related at least in part to socio-demographic and geographical factors, and these will be explored in further work by our group. Lastly, A-RUR estimates differ depending on the method used; each method has its own strengths, limitations and interpretations. Future studies of A-RUR in other jurisdictions should consider availability of the data as well as the potential interpretation and application of their results before choosing the most appropriate method for estimating A-RUR.

Conflicts of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.radonc.2018.10.039.

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