RADIATION ONCOLOGY—ORIGINAL ARTICLE

Disparities in radiation therapy utilization for cancer patients in Victoria

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Abstract

Introduction: To evaluate the proportion of cancer patients who received radiation therapy (RT) within 12 months of cancer diagnosis (RTU12) and identify factors associated with RTU12.
Methods: This is a population-based cohort of individuals with incident cancer, diagnosed between 2013 and 2017 in Victoria. Data linkages were performed between the Victorian Cancer Registry and Victorian Radiotherapy Minimum Dataset. The primary outcome was the proportion of patients who had RTU12. For the three most common cancers (i.e., prostate, breast and lung cancer), the time trend in RTU12 and factors associated with RTU12 were evaluated.
Results: The overall RTU12 in our study cohort was 26–20% radical RT and 6% palliative RT. Of the 21,735 men with prostate cancer, RTU12 was 17%, with no significant change over time (*P*-trend = 0.53). In multivariate analyses, increasing age and lower socioeconomic status were independently associated with higher RTU12 for prostate cancer. Of the 20,883 women with breast cancer, RTU12 was 64%, which increased from 62% in 2013 to 65% in 2017 (*P*-trend < 0.05). In multivariate analyses, age, socioeconomic status and area of residency were independently associated with RTU12 for breast cancer. Of the 13,093 patients with lung cancer, RTU12 was 42%, with no significant change over time (*P*-trend = 0.16). In multivariate analyses, younger age, male and lower socioeconomic status were independently associated with higher RTU12.
Conclusion: In this large population-based state-wide cohort of cancer patients, only 1 in 4 had RT within 12 months of diagnosis. There were marked sociodemographic disparities in RTU12 for prostate, breast and lung cancer patients.

Key words: health services; Radiation oncology; Radiotherapy utilization.

Introduction

Radiation therapy (RT) is an indispensable treatment modality for cancer. Epidemiologic evidence-based estimation of RT utilization (RTU) guidelines recommend that half of all cancer patients, considering patient and tumour case-mix, should receive RT at some point over the course of their disease.[1] The optimal lifetime RTU varies for different cancers depending on clinical indications, ranging from <10% for testicular cancer, to approximately 60% for prostate cancer and more than 80% for breast cancer.[1]

Several population-based studies have reported RTU in Australia[2–8] and overseas[9–11] over the past decade. There are, however, limited published data on RTU in the state of Victoria in Australia.[12] In 2010, the Victorian Radiotherapy Minimum Data Set (VRMDS) was established by the Victorian Department of Health in collaboration with all public and private RT facilities in Victoria, to collect demographic, administrative and clinical data on all patients receiving RT in the state.[13] The aim of the VRMDS is to provide relevant data on the current practice to inform the Department of Health RT service planning and to assess metrics such as RTU.

The aim of this current study is to utilize this administrative dataset to evaluate contemporary practice in RTU and identify any factors that may be associated with disparities in RTU. Given that evaluation of the lifetime RTU will require following patients for the entire course of the disease from diagnosis to end of life, and there could be long trajectory of disease for some cancers (e.g. prostate cancer and breast cancer), for this study, we focus on RTU within 12 months of cancer diagnosis (RTU12), which has been reported in earlier studies to be reasonably accurate in predicting lifetime RTU.[14]

Methods

Data source and study population

This is a population-based study in the state of Victoria. All Victorians with newly diagnosed cancer were reported to the Victorian Cancer Registry (VCR). Data linkage between the VCR and the VRMDS dataset was performed by the Centre for Victorian Data Linkages based on probabilistic matching, using a combination of personal identifier variables including first and last name, birth date, sex, statistical linkage key and Medicare number. For this study, we included all individuals with an incident cancer (ICD-10 code: C00-C96) diagnosed between January 2013 and December 2017. Individuals were excluded where their only cancer notifications were from death certificates. For individuals who had multiple cancer diagnoses within the study period, only the first diagnosis was retained. The study was approved by our institutional Human Research Ethics Committee (LNR/18/34).

Primary outcomes and co-variables

The primary outcome was RTU12, defined as the proportion of all new cancer patients in Victoria (regardless of the stage of cancer), who were documented to have received RT (with curative or palliative intent) in Victoria within 12 months of the date of cancer diagnosis. We evaluated factors associated with RTU12 for different cancers, focusing on prostate, breast and lung cancers, which were the three most common cancers. The factors that we evaluated include the year of cancer diagnosis, age at diagnosis, sex, socioeconomic status, remoteness of the area of residence and integrated cancer service (ICS) region of residence.

Socio-economic status was assigned to individuals based on the Australian Statistical Geographic Standard (ASGS) Statistical Area Level 1 of the usual residential address at diagnosis, and classified by the Socio-Economic Indexes for Areas (SEIFA) Indexes for Relative Socio-Economic Disadvantage based on the data from the Australian Bureau of Statistics[15]; this was subdivided into quintiles based on the Victorian population. The *area of residence* was classified as major cities, inner regional, or outer regional/remote areas based on the ASGS remoteness structure.[16] The *integrated cancer service (ICS)* region is based on the cancer service framework developed by the Victorian government to promote the development of cohesive integrated and multidisciplinary cancer care for all Victorians. Each ICS comprises clusters of hospitals and associated health services within a geographical area—there are three metropolitan ICS and five regional ICS. ICS region was assigned to individuals based on the usual residential address at the time of diagnosis, and not the region where treatment was provided.

Statistical analyses

Descriptive statistics were used to describe RTU12. For the three most common cancers, differences in RTU12 by sociodemographic factors were evaluated using the Pearson's chi-squared test. Logistic regression was used to evaluate the change in trend in RTU12, fitting year as continuous variables. Multivariable logistic regression was used to estimate the likelihood of RTU12, adjusting for the tumour stage for prostate cancer and breast cancer (data on tumour stage for lung cancer was not available). A two-sided *P*-value of <0.05 was considered statistically significant.

Results

RTU12

A total of 148,267 cancer patients were included in this study. The overall RTU12 was 26%: 20% for curative RT and 6% for palliative RT (Table 1). The five cancers with

Table 1. Radiation therapy utilization within 12 months of cancer diagnosis for each primary cancer type in Victoria between 2013 and 2017

Primary tumour site	Total patients, n (%)	Optimal RT utilization* (%)	Any RTU12, n (%)	Radical RTU12, n (%)	Palliative RTU12, n (%)
Bladder	3,299 (2%)	47%	606 (18%)	306 (9%)	305 (9%)
Breast	20,883 (14%)	87%	13,342 (64%)	12,790 (61%)	562 (3%)
CNS	2,264 (2%)	80%	1,313 (58%)	1,152 (51%)	164 (7%)
Colon	13,089 (9%)	4%	397 (3%)	202 (2%)	197 (2%)
Gallbladder	420 (0%)	17%	23 (5%)	8 (2%)	15 (4%)
Gynae: Cervical	930 (1%)	71%	417 (45%)	343 (37%)	76 (8%)
Gynae: Ovary	1,502 (1%)	4%	64 (4%)	48 (3%)	16 (1%)
Gynae: Uterine	3,526 (2%)	38%	856 (24%)	773 (22%)	89 (3%)
Gynae: Vagina	83 (0%)	94%	58 (70%)	41 (49%)	18 (22%)
Gynae: Vulva	436 (0%)	39%	110 (25%)	89 (20%)	22 (5%)
Head & Neck	4,879 (3%)	74%	2,625 (54%)	2,374 (49%)	265 (5%)
Leukaemia	5,109 (3%)	4%	178 (3%)	133 (3%)	45 (1%)
Liver	2,611 (2%)	0%	130 (5%)	34 (1%)	96 (4%)
Lung	13,093 (9%)	77%	5,457 (42%)	2,110 (16%)	3,416 (26%)
Lymphoma	7,800 (5%)	73%	1,602 (21%)	1,319 (17%)	291 (4%)
Melanoma	12,867 (9%)	21%	428 (3%)	172 (1%)	260 (2%)
Myeloma	2,512 (2%)	45%	408 (16%)	91 (4%)	319 (13%)
Oesophageal	1717 (1%)	78%	896 (52%)	527 (31%)	372 (22%)
Pancreas	3,949 (3%)	49%	348 (9%)	171 (4%)	177 (4%)
Prostate	21,735 (15%)	58%	3,775 (17%)	3,188 (15%)	602 (3%)
Rectum	4,776 (3%)	60%	2017 (42%)	1844 (39%)	177 (4%)
Renal	4,396 (3%)	15%	360 (8%)	91 (2%)	271 (6%)
Stomach	2,818 (2%)	27%	713 (25%)	341 (12%)	375 (13%)
Testis	1,094 (1%)	7%	20 (2%)	15 (1%)	5 (0%)
Thyroid	2,942 (2%)	4%	109 (4%)	52 (2%)	58 (2%)
Other	7,566 (5%)	19%	1888 (25%)	1,446 (19%)	455 (6%)
Unknown Primary / Ill defined	1971 (1%)	61%	389 (20%)	134 (7%)	256 (13%)
All Cancers	148,267		38,529 (26%)	29,794 (20%)	8,904 (6%)

*Optimal RT utilization based on 2012 modelling.[1]

the highest RTU12 were vagina cancer (70%), breast cancer (64%), central nervous system cancer (58%), head and neck cancer (54%) and oesophageal cancer (52%).

Prostate cancer

Of the 21,735 men with prostate cancer diagnosed within the study period, the RTU12 was 17% (Table 2). There were marked differences in RTU12 by age group with higher RTU12 in older men—28% in men aged 70–79 vs. 5% in men aged <50 years (P <0.001). RTU12 was lowest in men in the highest socioeconomic quintile (13%) and highest in men in the lowest socioeconomic quintile (22%) (P < 0.001). There were also differences in RTU12 by ICS region, ranging from 15% to 26% (P < 0.001). Men living in major cities had lower RTU12 (16%) compared to that of men living in regional or remote areas (20%) (P < 0.001).

Overall, there were no significant changes in RTU12 for prostate cancer over the 5-year study period (P-trend = 0.53). When stratified by age group, there was a decline in RTU12 in men aged 50–59 years (from 11% in 2013 to 9% in 2017, P-trend < 0.05), and an increase in RTU12 in men aged 80 years or above (from 11% in 2013 to 20% in 2017, P-trend < 0.001). There was an

increase in RTU12 in all ICS regions, except SMICS whereby there was a statistically significant decline in RTU12 from 19% in 2013 to 15% in 2017 (P-trend < 0.05).

In multivariable analyses—after adjusting for tumour stage—patients' age and socioeconomic status were independently associated with RTU12 (Table 3). Compared mean men aged <50 years, men aged 70–79 years were 8.1 times more likely to have RTU12 (95% CI = 5.4–12.2). Compared with men from lowest socioeconomic quintile, those from the highest socioeconomic quintile had 41% lower likelihood of RTU12 (95% CI = 33–47%).

Breast cancer

Of the 20,883 women with breast cancer diagnosed during the study period, the RTU12 was 64% (Table 4). The RTU12 was lowest in women aged 80 years or older (28%) and highest in women aged 50–59 years (72%) (P < 0.001). RTU12 was lower in women from lowest socioeconomic quintile (60%) compared to those from highest socioeconomic quintile (66%) (P < 0.001). RTU12 varied by ICS region, ranging from 60% to 68% (P < 0.001). Patients who lived in major cities and inner

Table 2. Radiation therapy utilization within 12 months of prostate cancer diagnosis between 2013 and 2017

Level	Total number of patients	RTU12 *n* (%)	*P*-value*	2013	2014	2015	2016	2017	*P*-trend#
Age group									
<50	549	27 (5%)	<0.001	10 (9%)	4 (4%)	4 (4%)	5 (5%)	4 (3%)	0.1
50–59	3,592	361 (10%)		83 (11%)	82 (12%)	75 (11%)	59 (8%)	62 (9%)	<0.05
60–69	8,715	1,204 (14%)		252 (15%)	232 (15%)	199 (12%)	255 (14%)	266 (13%)	0.08
70–79	6,206	1,758 (28%)		306 (28%)	301 (29%)	348 (29%)	370 (28%)	433 (28%)	0.84
≥80	2,673	425 (16%)		56 (11%)	78 (14%)	88 (16%)	100 (18%)	103 (20%)	<0.001
SEIFA quintile									
1 (Most disadvantaged)	3,855	849 (22%)	<0.001	174 (21%)	144 (21%)	148 (20%)	175 (23%)	208 (25%)	0.06
2	4,106	776 (19%)		133 (17%)	148 (20%)	141 (19%)	168 (19%)	186 (20%)	0.26
3	4,135	732 (18%)		127 (16%)	141 (19%)	147 (18%)	149 (18%)	168 (18%)	0.55
4	4,475	722 (16%)		134 (16%)	131 (17%)	147 (17%)	147 (16%)	163 (15%)	0.7
5 (Least disadvantaged)	5,010	668 (13%)		134 (15%)	126 (14%)	125 (13%)	145 (13%)	138 (13%)	0.17
Missing	154	28 (18%)		5 (19%)	7 (25%)	6 (19%)	5 (17%)	5 (12%)	
ICS of residence									
NEMICS	5,462	802 (15%)	<0.001	144 (13%)	150 (15%)	164 (16%)	171 (15%)	173 (15%)	0.43
SMICS	6,310	1,077 (17%)		234 (19%)	219 (18%)	192 (16%)	225 (17%)	207 (15%)	<0.05
WCMICS	3,444	637 (18%)		119 (20%)	109 (18%)	108 (17%)	130 (17%)	171 (21%)	0.55
BSWRICS	1,419	214 (15%)		31 (13%)	37 (15%)	42 (17%)	46 (16%)	58 (15%)	0.41
GRICS	1,244	245 (20%)		37 (16%)	50 (21%)	59 (25%)	50 (21%)	49 (17%)	0.83
HRICS	1,233	190 (15%)		36 (15%)	27 (13%)	30 (12%)	40 (16%)	57 (20%)	0.07
LMICS	1,649	360 (22%)		62 (19%)	67 (23%)	69 (22%)	72 (21%)	90 (24%)	0.22
GICS	954	249 (26%)		43 (21%)	38 (26%)	50 (28%)	55 (29%)	63 (27%)	0.17
Missing	20	1 (5%)		1 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	
Remoteness									
Major Cities	15,429	2,540 (16%)	<0.001	499 (17%)	480 (17%)	466 (16%)	534 (16%)	561 (16%)	0.53
Inner Regional	5,016	980 (20%)		173 (18%)	166 (19%)	198 (21%)	203 (20%)	240 (20%)	0.17
Outer Regional/Remote	1,270	254 (20%)		34 (14%)	51 (23%)	50 (19%)	52 (21%)	67 (22%)	0.07
Missing	20	1 (5%)		1 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	
Stage at diagnosis									
1	2,613	74 (3%)	<0.001	28 (6%)	11 (2%)	19 (4%)	12 (2%)	4 (1%)	<0.001
2	13,804	2,691 (19%)		527 (19%)	488 (20%)	511 (20%)	551 (20%)	614 (20%)	0.38
3	3,324	551 (17%)		81 (14%)	115 (18%)	91 (15%)	130 (19%)	134 (16%)	0.46
4	1,481	409 (28%)		59 (29%)	78 (28%)	83 (26%)	84 (26%)	105 (29%)	0.83
Unknown	513	50 (10%)		12 (11%)	5 (5%)	10 (10%)	12 (10%)	11 (13%)	0.39
Overall	21,735	3,775 (17%)		707 (17%)	697 (18%)	714 (17%)	789 (17%)	868 (18%)	0.53

ICS, Integrated Cancer Services; SEIFA, Socio-Economic Indexes for Areas (SEIFA).

*Chi-square test; #*P*-value for trend calculated by logistic regressions of RTU12, fitting year as continuous variables.

regional areas had higher RTU12 (64%) compared to those who lived in outer regional or remote areas (59%) (*P* < 0.05).

Over the study period, there was an increase in RTU12 in women with newly diagnosed breast cancer, from 62% in 2013 to 65% in 2017 (*P*-trend<0.05) (Table 4). When stratified by age, there was a statistically significant increase in RTU12 in women aged 70–79 years, from 58% in 2013 to 64% in 2017 (*P*-trend < 0.05). There was an increase in RTU12 in all socioeconomic quintile, but the most marked was observed in women from highest socioeconomic quintile, from 63% in 2013 to 69% in 2017 (*P*-trend < 0.05). There was also a varying degree of increase in RTU12 when stratified by ICS region. RTU12 was relatively stable over time in women who lived in major cities (*P*-trend = 0.71), but there was a marked increase in women who live in inner regional areas (from 58% in 2013 to 66% in 2017, *P*-trend < 0.05), and outer regional or remote areas (from 50% in 2013 to 66% in 2017, *P*-trend < 0.001).

In multivariable analyses, patients' age, socioeconomic status and remoteness of residency were independently associated with RTU12, after having adjusted for tumour stage (Table 3). Compared with women aged <30 years, those aged 50–59 years were more likely to have RTU12 (OR = 2.34; 95%CI = 1.58–3.47), whereas those aged >80 years were less likely to have RTU12 (OR = 0.43; 95%CI = 0.29–0.65). Women from higher socioeconomic quintiles were more likely to receive RTU12 (OR = 1.13; 95%CI = 1.02–1.25, comparing highest vs. lowest quintiles). Women living in outer regional or remote areas were less likely to have RTU12 compared with women living in major cities (OR = 0.81; 95%CI = 0.70–0.93).

Table 3. Odds of receiving radiation therapy within 12 months of cancer diagnosis, between 2013 and 2017, for prostate cancer, breast cancer and lung cancer

Variable	Level	Prostate cancer		Breast Cancer		Lung Cancer	
		n/N (%)	Adjusted OR [95% CI]*	n/N (%)	Adjusted OR [95% CI]*	n/N (%)	Adjusted OR [95% CI]*
Age at diagnosis (OR per 10-year increase)	<30	25/537 (4.7%)	Reference	58/106 (54.7%)	Reference	282/533 (52.9%)	Reference
	30–39			568/881 (64.5%)	1.48 [0.98–2.23]		
	40–49			2242/3246 (69.1%)	1.83 [1.23–2.72]		
	50–59	352/3527 (10.0%)	2.27 [1.49–3.44]	3516/4802 (73.2%)	2.34 [1.58–3.47]	796/1557 (51.1%)	0.92 [0.75–1.12]
	60–69	1179/8556 (13.8%)	3.20 [2.13–4.81]	3750/5275 (71.1%)	2.16 [1.46–3.20]	1581/3491 (45.3%)	0.72 [0.60–0.87]
	70–79	1736/6074 (28.6%)	8.14 [5.41–12.22]	2179/3434 (63.5%)	1.51 [1.01–2.24]	1784/4350 (41.0%)	0.60 [0.50–0.72]
	≥80	406/2389 (17.0%)	3.65 [2.40–5.55]	558/1619 (34.5%)	0.43 [0.29–0.65]	988/3066 (32.2%)	0.41 [0.34–0.49]
Sex	Female	–	–	–	–	2241/5658 (39.6%)	Reference
	Male	–	–	–	–	3190/7339 (43.5%)	1.22 [1.13–1.31]
Stage at diagnosis	1	74/2600 (2.8%)	Reference	5838/8886 (65.7%)	Reference	–	–
	2	2672/13715 (19.5%)	8.87 [7.00–11.23]	4944/7516 (65.8%)	1.13 [1.05–1.20]	–	–
	3	547/3301 (16.6%)	7.84 [6.10–10.08]	1724/2127 (81.1%)	2.66 [2.36–3.01]	–	–
	4	405/1467 (27.6%)	13.26 [10.20–17.22]	365/834 (43.8%)	0.49 [0.42–0.57]	–	–
SEIFA quintile	1 (Most disadvantaged)	838/3721 (22.5%)	Reference	2194/3481 (63.0%)	Reference	1612/3820 (42.2%)	Reference
	2	764/3999 (19.1%)	0.83 [0.74–0.93]	2356/3641 (64.7%)	1.05 [0.95–1.16]	1227/2973 (41.3%)	0.97 [0.88–1.07]
	3	723/4040 (17.9%)	0.80 [0.71–0.90]	2571/3798 (67.7%)	1.17 [1.05–1.29]	1071/2444 (43.8%)	1.07 [0.97–1.19]
	4	713/4394 (16.2%)	0.73 [0.65–0.82]	2750/4040 (68.1%)	1.15 [1.04–1.27]	880/2068 (42.6%)	1.03 [0.92–1.15]
	5 (Least disadvantaged)	660/4929 (13.4%)	0.59 [0.53–0.67]	3000/4403 (68.1%)	1.13 [1.02–1.25]	641/1692 (37.9%)	0.85 [0.75–0.96]
Remoteness	Major Cities	2481/14979 (16.6%)	Reference	9464/14149 (66.9%)	Reference	3742/9005 (41.6%)	Reference
	Inner Regional	969/4875 (19.9%)	1.08 [0.99–1.18]	2780/4191 (66.3%)	1.00 [0.92–1.08]	1343/3145 (42.7%)	1.02 [0.94–1.11]
	Outer Regional/ Remote	248/1229 (20.2%)	1.05 [0.90–1.23]	627/1023 (61.3%)	0.81 [0.70–0.93]	346/847 (40.9%)	0.93 [0.80–1.07]

*Adjusted for all variables in the table.

Lung cancer

Of the 13,093 patients with lung cancer, the RTU12 was 42% (Table 5). RTU12 was higher in younger patients— 53% in patients aged under 50 years vs. 32% in patients aged 80 years or above ($P < 0.001$). RTU12 was higher in men (43%) compared with women (39%) ($P < 0.001$). Patients from highest socioeconomic quintile had lower RTU12 (38%) compared with the remaining four quintiles ($P < 0.05$). RTU12 varied across ICS regions, ranging from 38% to 46% ($P < 0.05$). There was no significant difference in RTU12 when stratified by the remoteness of residency ($P = 0.42$).

Over the study period, there was no statistically significant change in RTU12 (P-trend = 0.16). When stratified by age group, there was a statistically significant increasing trend in RTU12 in patients aged over 80 years, from 28% in 2013 to 36% in 2017 (P-trend<0.001). There was an increase in RTU12 in patients from the lowest socioeconomic status, from 39% in 2013 to 46% in 2016 (P-trend<0.05). There was a varying degree of changes in RTU12 stratified by ICS regions.

In multivariate analyses, patient age, sex and socioeconomic status were independently associated with RTU12 (Table 3). Compared with patients aged <50 years, those aged 60–69 years, 70–79 years and > 80 years were 28% (95%CI = 13–40%), 40% (95%CI = 28–50%) and 59% (95%CI = 51–66%) less likely to receive RTU12 respectively. Men were 22% (95%CI = 13–31%) more likely to receive RTU12 compared with women. Compared with patients from the lowest socioeconomic quintile, those from the highest socioeconomic quintile were 15% relatively less likely to receive RTU12 (95%CI = 4–25%).

Discussion

This is to our knowledge the largest and most contemporary Australian population-based study evaluating RTU in patients with newly diagnosed cancer. Overall, 1-in-4 patients with new cancer diagnosis between 2013 and 2017 in Victoria received RT within 12 months of cancer diagnosis, similar to earlier Australian studies (Table 6).[4,5,7,8,17]

Table 4. Radiation therapy utilization within 12 months of breast cancer diagnosis between 2013 and 2017

Level	Total number of patients	RTU12 n (%)	P-value*	2013	2014	2015	2016	2017	P-trend#
Age group									
<30	126	66 (52%)	<0.001	9 (36%)	12 (57%)	13 (68%)	19 (63%)	13 (42%)	0.63
30–39	965	608 (63%)		117 (63%)	127 (69%)	118 (63%)	128 (63%)	118 (58%)	0.15
40–49	3,423	2,339 (68%)		443 (66%)	466 (69%)	433 (65%)	509 (72%)	488 (69%)	0.12
50–59	5,039	3,639 (72%)		712 (70%)	741 (75%)	709 (73%)	730 (70%)	747 (74%)	0.29
60–69	5,488	3,846 (70%)		700 (67%)	787 (71%)	817 (71%)	749 (70%)	793 (71%)	0.12
70–79	3,645	2,239 (61%)		361 (58%)	417 (60%)	487 (62%)	458 (62%)	516 (64%)	<0.05
≥80	2,197	605 (28%)		129 (29%)	105 (24%)	114 (27%)	120 (28%)	137 (29%)	0.56
SEIFA quintile									
1 (Most disadvantaged)	3,823	2,284 (60%)	<0.001	434 (59%)	443 (58%)	456 (60%)	457 (60%)	494 (62%)	0.12
2	3,943	2,429 (62%)		421 (58%)	491 (62%)	488 (63%)	512 (62%)	517 (63%)	0.06
3	4,061	2,657 (65%)		494 (64%)	554 (70%)	548 (65%)	506 (64%)	555 (64%)	0.14
4	4,290	2,820 (66%)		527 (64%)	566 (65%)	576 (66%)	581 (68%)	570 (66%)	0.17
5 (Least disadvantaged)	4,653	3,090 (66%)		588 (63%)	585 (67%)	610 (66%)	643 (67%)	664 (69%)	<0.05
Missing	113	62 (55%)		7 (44%)	16 (64%)	13 (57%)	14 (61%)	12 (46%)	
ICS of residence									
NEMICS	5,311	3,540 (67%)	<0.001	673 (65%)	700 (66%)	696 (66%)	715 (67%)	756 (69%)	0.08
SMICS	5,678	3,648 (64%)		657 (60%)	728 (68%)	749 (65%)	771 (65%)	743 (63%)	0.48
WCMICS	3,926	2,371 (60%)		465 (64%)	470 (60%)	479 (60%)	473 (60%)	484 (59%)	0.12
BSWRICS	1,492	1,017 (68%)		189 (67%)	208 (67%)	194 (69%)	199 (69%)	227 (70%)	0.3
GRICS	1,174	770 (66%)		136 (61%)	153 (70%)	156 (68%)	166 (68%)	159 (64%)	0.69
HRICS	1,133	701 (62%)		112 (54%)	161 (65%)	151 (64%)	129 (61%)	148 (65%)	0.09
LMICS	1,298	779 (60%)		131 (53%)	146 (58%)	156 (61%)	163 (62%)	183 (64%)	<0.05
GICS	862	513 (60%)		108 (53%)	89 (57%)	110 (62%)	97 (58%)	109 (68%)	<0.05
Missing	9	3 (33%)						3 (33%)	
Remoteness									
Major Cities	15,303	9,832 (64%)	<0.05	1,865 (64%)	1,950 (65%)	1,974 (64%)	2,013 (65%)	2,030 (64%)	0.65
Inner Regional	4,481	2,863 (64%)		500 (58%)	571 (66%)	598 (65%)	559 (65%)	635 (66%)	<0.05
Outer Regional/Remote	1,090	644 (59%)		106 (50%)	134 (58%)	119 (59%)	141 (62%)	144 (66%)	<0.001
Missing	9	3 (33%)						3 (33%)	
Stage at diagnosis									
1	8,931	5,865 (66%)	<0.001	1,115 (65%)	1,246 (67%)	1,206 (66%)	1,174 (65%)	1,124 (66%)	0.98
2	7,562	4,971 (66%)		860 (60%)	905 (65%)	1,033 (67%)	1,081 (68%)	1,092 (69%)	<0.001
3	2,131	1,727 (81%)		372 (80%)	395 (83%)	317 (79%)	344 (80%)	299 (81%)	0.87
4	838	366 (44%)		66 (42%)	59 (42%)	83 (44%)	68 (43%)	90 (46%)	0.51
Unknown	1,421	413 (29%)		58 (25%)	50 (21%)	52 (21%)	46 (21%)	207 (43%)	<0.001
Overall	20,883	13,342 (64%)		2,471 (62%)	2,655 (65%)	2,691 (64%)	2,713 (64%)	2,812 (65%)	<0.05

ICS, Integrated Cancer Services; SEIFA, Socio-Economic Indexes for Areas (SEIFA).
*Chi-square test; #P-value for trend calculated by logistic regressions of RTU12, fitting year as continuous variables.

There are different ways in which RTU can be, and have been, reported in the published literature.[6] The RTU12 in our cohort is lower than the 48% optimal RTU estimated using evidence-based modelling[1]—this was not unexpected given that optimal RTU is estimated over a *lifetime* of disease, rather than 12 months of cancer diagnosis (RTU12) used in our study. However, to await long-term follow-up until the date of death to report on lifetime RTU (which could be more than a decade from the date of cancer diagnosis for diseases such as prostate cancer and breast cancer) means that we may have potentially missed the opportunity to act or intervene on any unwarranted disparities in RTU identified based on the most contemporary data. Using data from the Canadian Ontario Cancer Registry between 1984 and 2015, Mackillop *et al*.

have suggested that the lifetime RTU can be reasonably accurately predicted based on RTU12 and that RTU at 20 years after cancer diagnosis was approximately 1.3 times RTU12[14]—using this measure, the estimated RTU at 20 years after cancer diagnosis in our cohort is 34%, which is still notably lower than the 48% optimal life time RTU.[1] Nonetheless, the RTU12 of 26% (and estimated RTU at 20 years of 34%[14]) in our cohort is similar to earlier Australian studies[2,3,6] and other international series.[9–11] The underutilization of RT can have far-reaching consequences, with a study from NSW, Australia using data from 2006 estimated an excess of 411 cancer deaths within 5 years of diagnosis resulting from underutilization of RT, and this translated to 4,289 years of potential life lost, and 7,192 disability-adjusted life years lost.[17]

Table 5. Radiation therapy utilization within 12-month of lung cancer diagnosis between 2013 and 2017

Level	Total number of patients	RTU12, n (%)	P-value*	2013	2014	2015	2016	2017	P-trend#
Age group									
<50	537	283 (53%)	<0.001	53 (52%)	62 (53%)	55 (50%)	48 (46%)	65 (62%)	0.4
50–59	1,569	799 (51%)		163 (55%)	152 (48%)	128 (46%)	174 (52%)	182 (54%)	0.71
60–69	3,508	1,588 (45%)		318 (46%)	344 (46%)	297 (46%)	298 (43%)	331 (45%)	0.39
70–79	4,378	1,793 (41%)		331 (40%)	380 (44%)	336 (40%)	362 (39%)	384 (42%)	0.7
≥80	3,101	994 (32%)		184 (28%)	179 (29%)	209 (35%)	211 (33%)	211 (36%)	<0.001
Sex									
Female	5,707	2,254 (39%)	<0.001	410 (38%)	472 (41%)	425 (39%)	464 (38%)	483 (41%)	0.73
Male	7,386	3,203 (43%)		639 (43%)	645 (42%)	600 (43%)	629 (42%)	690 (46%)	0.09
SEIFA quintile									
1 (Most disadvantaged)	3,820	1,612 (42%)	<0.05	299 (39%)	362 (43%)	292 (41%)	314 (41%)	345 (46%)	<0.05
2	2,973	1,227 (41%)		223 (40%)	245 (40%)	243 (42%)	261 (42%)	255 (42%)	0.36
3	2,444	1,071 (44%)		196 (42%)	213 (44%)	201 (44%)	221 (43%)	240 (46%)	0.21
4	2,068	880 (43%)		184 (43%)	166 (45%)	172 (43%)	173 (38%)	185 (45%)	0.73
5 (Least disadvantaged)	1,692	641 (38%)		145 (42%)	123 (38%)	113 (36%)	119 (36%)	141 (39%)	0.34
Missing	96	26 (27%)		2 (29%)	8 (40%)	4 (33%)	5 (21%)	7 (21%)	
ICS of residence									
NEMICS	2,802	1,097 (39%)	<0.05	237 (42%)	229 (42%)	194 (36%)	231 (39%)	206 (37%)	<0.05
SMICS	3,412	1,420 (42%)		274 (40%)	287 (42%)	289 (45%)	253 (37%)	317 (45%)	0.45
WCMICS	2,542	1,109 (44%)		207 (41%)	247 (44%)	207 (44%)	227 (45%)	221 (44%)	0.28
BSWRICS	994	427 (43%)		67 (36%)	90 (43%)	86 (46%)	79 (40%)	105 (50%)	<0.05
GRICS	933	408 (44%)		73 (46%)	74 (37%)	68 (41%)	91 (46%)	102 (49%)	0.11
HRICS	829	319 (38%)		51 (33%)	62 (37%)	51 (34%)	72 (41%)	83 (46%)	<0.05
LMICS	932	425 (46%)		95 (48%)	83 (47%)	83 (44%)	80 (43%)	84 (46%)	0.42
GICS	620	247 (40%)		45 (38%)	45 (37%)	46 (39%)	60 (42%)	51 (43%)	0.29
Missing	29	5 (17%)			0 (0%)	1 (100%)	0 (0%)	4 (19%)	
Remoteness									
Major Cities	9,066	3,761 (41%)		741 (41%)	795 (43%)	721 (42%)	721 (39%)	783 (43%)	0.8
Inner Regional	3,148	1,344 (43%)	0.42	242 (42%)	261 (42%)	237 (40%)	297 (44%)	307 (46%)	0.07
Outer Regional/Remote	850	347 (41%)		66 (41%)	61 (33%)	66 (42%)	75 (43%)	79 (46%)	0.09
Missing	29	5 (17%)			0 (0%)	1 (100%)	0 (0%)	4 (19%)	
Overall	13,093	5,457 (42%)		1,049 (41%)	1,117 (42%)	1,025 (41%)	1,093 (40%)	1,173 (44%)	0.16

ICS, Integrated Cancer Services; SEIFA, Socio-Economic Indexes for Areas (SEIFA).
*Chi-square test; #P-value for trend calculated by logistic regressions of RTU12, fitting year as continuous variables.

It is important to acknowledge that optimal RTU estimation varies depending on the methods used, which include epidemiologic evidence-based estimation, or criterion-based benchmarking.[18] The optimal RTU for evidence-based estimation may also change over time with changing cancer incidence data, indications for RT and refinement of the modelling structure.[1] One example is testicular cancer whereby the optimal RTU was 49% in 2003 and dropped to 7% in the 2012 revised modelling, given the evolving treatment paradigm for testicular cancer.[19] The only primary cancer for which we observed higher RTU12 (5%) than optimal RTU (0%) was liver cancer, and it is most likely due to changes in the indication for RT, especially stereotactic RT, for liver cancer since the last modelling in 2012.[20]

When we investigated the three most common cancers, we identified several factors associated with RTU12, including age, sex, socioeconomic status and remoteness of residency. However, the association of these factors and RTU12 varied for different cancer types. Most of the earlier studies have reported lower RTU in *older patients* for all cancers,[4,9,21,22] and we observed this in patients with *lung cancer* in our study. However, for men with *prostate cancer*, there was higher RTU12 in older men, similar to that reported in the NSW 45 and Up Study,[23] given that younger men were more likely to opt for surgery instead of RT for prostate cancer. In women with *breast cancer*, there is lower RTU12 at the extreme of age, and RTU12 was lowest in women aged >80 years. This is not surprising given that there have been several randomized studies, which have shown that omission of RT, with the use of endocrine therapy alone, is a reasonable option in older women with hormone receptor-positive early breast cancer.[24,25]

We also observed marked disparities in RT use by *socioeconomic status* for different cancers, which have previously been reported in the literature.[4,26–29] For *prostate cancer*, there is lower RTU12 in men from highest socioeconomic status. A previous Victorian study has reported men diagnosed in private health services (i.e.,

Table 6. Summary of published literature on actual radiation therapy utilization (RTU) in Australia

Study	Year of cancer diagnoses	Study population	RT utilization definition	All cancers	Prostate cancer	Breast cancer	Lung cancer
Luke C *et al*. 2003	1990–1994	South Australia Cancer Registry	RTU12	25.2%	44%	40%	37.6%
Vinod S *et al*. 2010	2001–2002	NSW Central Cancer Registry	Overall RTU*	–	–	–	40%
Batumalai V *et al*. 2018	2006	NSW Central Cancer Registry	RTU12	26%	7%	54%	42%
Merie R *et al*. 2019	2009–2011	NSW Central Cancer Registry	RTU 12	25.1%	22.5%	60.8%	40.7%
Yap ML *et al*. 2020	2006–2013	NSW 45 and up study	Overall RTU*	30.3%	33.1%	67.3%	46.5%
Current study	2013–2017	Victorian Cancer Registry	RTU12	26%	17%	64%	42%

RTU12, RTU within 12 months of cancer diagnosis.
*Any RTU, including RT beyond first 12 months of cancer diagnosis.

those with higher socioeconomic status) were more likely to have surgery instead of RT.[28] This similar pattern was reported in the NSW 45 and Up Study, whereby men with private health insurance were more likely to have surgery instead of RT for prostate cancer.[23] However, it is also important to appreciate the changing paradigm in the management of prostate cancer, such that conservative management (with active surveillance, or watchful waiting) is now the preferred management option over active treatment (including surgery or RT) for low-risk prostate cancer.[30,31] Earlier Victorian population-based study had reported disparities in conservative management for low-risk prostate cancer by socioeconomic status.[32] For *lung cancer*, the observed lower RTU12 in patients from highest socioeconomic status could be confounded by the stage of disease, which was not available for lung cancer patients in our study, and thus was not adjusted for in our multivariate analyses. It is possible that patients with higher socioeconomic status may have been diagnosed with earlier-stage disease amenable to surgery.

In contrast to prostate cancer and lung cancer, we observed lower RTU12 associated with lower socioeconomic status for *breast cancer*. The lower RTU12 following breast-conserving surgeries in women from lower socioeconomic status, or those without healthcare insurance, had been reported in earlier population-based studies in Canada[29] and the US.[26] However, we believe that findings in our study may also be confounded by the type of surgery performed for breast cancer, which is not available in our dataset. RT is generally indicated following breast-conserving surgery/lumpectomy,[33] but not necessarily indicated following mastectomy (depending on histopathological features e.g. nodal involvement).[34] An earlier systematic review of 25 studies showed that women with higher socioeconomic status were more likely to have breast-conserving surgery, while those at the extremes of age (young and old), rural residents and increasing distance from RT facilities were more likely to have mastectomy.[35] This would thus be consistent with findings of our study showing that women with lower socioeconomic status, and those who live in outer regional or remote areas were less likely to have RT.

A major strength of our study is that is we captured all incident cancer cases in Victoria with comprehensive linkage to the state-wide RT data, thereby reflecting true state-wide practice. We could not discount the possibilities of under-estimation of RTU given that some Victorian patients with newly diagnosed cancers may opt to receive RT in other states; however, this number is unlikely to impact the overall findings of this study. An inherent limitation of the use of administrative datasets, such as the VRMDS, is that they lack granularity for us to evaluate the appropriateness of RTU for each individual patient. For example, we do not have information on comorbidities and ECOG performance status, which may influence patients' general fitness of cancer treatment and hence RTU12. We also could not exclude the possibility of erroneously assigning RTU to the incorrect cancer diagnosis in individuals who had multiple cancers diagnosed within the study period, given that we only retained the first cancer diagnosis for each individual, and we are not able to elicit whether the RT course was given to the first cancer diagnoses or subsequent cancers; however, the proportion of individuals with multiple cancers and RTU12 was very low (<1%) to impact on the main findings of this study. Another factor commonly reported in the literature to be associated with disparities in RTU that is not available in our study is ethnicity.[36] Also, in the lung cancer cohort, we do not have information on the stage of cancer, and the cancer subtype (e.g., small cell lung cancer), which may influence the decision for RTU12. We also did not have access to data to allow computation of travel distance to RT facilities whereas earlier studies, both in Australia[3,37] and overseas,[21,38,39] have reported the impact of travel distance on RTU for various cancers, although the remoteness of the area of residency is an indirect measure of the convenience of access to RT facilities.

Moving forward, findings from this study using real-world population-based data highlighted the need for multipronged approaches to increase RT utilization in cancer patients where RT is clinically indicated. Advocacy initiatives such as Targeting Cancer[40] is important to increase public awareness of the role of RT in cancer care among healthcare providers, patients and their family. There is also a need to ensure patients with new cancer diagnoses are discussed in multidisciplinary meetings (MDM) or managed in multidisciplinary settings.

Systematic reviews have shown that patients discussed in MDM were more likely to receive clinically indicated multimodality treatment, including RT[41] in neo-adjuvant or adjuvant settings.[42] Some of this can be addressed through changes in healthcare funding, such as the recent revision in Medicare Benefit Schemes (MBS) Radical Prostatectomy item numbers (37210–37214), which require that men with prostate cancer in whom curative treatment is recommended be reviewed by a multidisciplinary team, and the recommendation from multidisciplinary review be documented in writing and provided to patients and referring general practitioners.[43] There is also a need to ensure easy access to RT facilities for patients who live in regional or remote areas. Earlier studies from NSW have shown that patients were 10% less likely to receive RT for each additional 100 km distance from their residence to the nearest RT facilities.[3] With an increasing number of RT facilities established in regional Victoria in recent years, we foresee that there will be an increase in clinically indicated RT utilization in these disadvantaged populations in the coming years.

In conclusion, in this large Australian population-based study, we reported RTU12 that is similar to earlier Australian studies, but lower than evidence-based estimations of optimal RTU. We observed marked sociodemographic disparities in RTU12, which varied depending on cancer types—lower RTU12 in patients with higher socioeconomic group status for prostate cancer and lung cancer, and lower RTU12 in patients with lower socioeconomic group status for breast cancer. These findings highlight the need for tailored approaches to increase awareness - among health care providers, patients and their families - of the important role of RT in cancer care. At the same time, this should draw attention to the work that needs to be done, from a health policy making and health services planning point of view, to close the gap to ensure equal and easy access to RT for all cancer patients.

Data availability statement

Research data will be shared upon request to the corresponding author.

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