Disparities in radiation therapy utilization for cancer patients in Victoria

Wee Loon Ong,1,2,3,4,5 Norah Finn,6,7 Luc Te Marvelde,6,7 Colin Hornby,7 Roger L Milne,8,9,10 Gerard G Hanna,3,11 Graham Pitson,12 Hany Elsaleh,1,13 Jeremy L Millar1,13 and Farshad Foroudi2

1 Alfred Health Radiation Oncology Services, Melbourne, Victoria, Australia
2 Department of Radiation Oncology, Olivia Newton-John Cancer Wellness and Research Centre, Austin Health, Heidelberg, Victoria, Australia
3 Department of Radiation Oncology, Peter MacCallum Cancer Centre, Melbourne, Victoria, Australia
4 Department of Epidemiology and Preventive Medicine, Monash University, Melbourne, Victoria, Australia
5 School of Clinical Medicine, University of Cambridge, Cambridge, Victoria, UK
6 Victorian Cancer Registry, Cancer Council Victoria, Melbourne, Victoria, Australia
7 Department of Health, State Government of Victoria, Melbourne, Victoria, Australia
8 Cancer Epidemiology Division, Cancer Council Victoria, Melbourne, Victoria, Australia
9 Center for Epidemiology and Biostatistics, School of Population and Global Health, The University of Melbourne, Melbourne, Victoria, Australia
10 Precision Medicine, School of Clinical Sciences, Monash Health, Monash University, Melbourne, Victoria, Australia
11 Sir Peter MacCallum Department of Oncology, University of Melbourne, Parkville, Victoria, Australia
12 Department of Cancer Services, Barwon Health, Geelong, Victoria, Australia
13 Central Clinical School, Monash University, Melbourne, Victoria, Australia

WL Ong BMedSc, MBBS, MPhil, FRANZCR; NF Finn MSc; LtM Te Marvelde PhD; CH Hornby MAppSci, FASMIRT, RL Milne PhD; GG Hanna MBBCh, PhD, MRCPI(UK), FCR, FRANZCR; GP Pitson MBBS, FRANZCR; HE Elsaleh MBBS, PhD, FRANZCR; JLM Millar MBChB, FRANZCR; FF Foroudi MBBS, MPA, DMedSc, FRANZCR.

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. 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.

Several population-based studies have reported RTU in Australia and overseas over the past decade. There are, however, limited published data on RTU in the state of Victoria in Australia. 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. 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.

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; 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. 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
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 lowest 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
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 66% 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 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%) | 169 (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%) | | | | | |
| 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 (13%) | 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 (23%) | 19 (43%) | 12 (23%) | 4 (13%) | <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 (18%) | 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.
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 | <30 | 25/537 (4.7%) | Reference | 58/106 (5.4%) | Reference | 282/533 (52.9%) | Reference |
| (OR per 10 year increase) | 30–39 | 352/7357 (10%) | 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] |
| | 40–49 | 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 (40.0%) | 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 | – – | – – | – – | – – | – – | – – |
| | Male | – – | – – | – – | – – | – – | – – |
| 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 (Most disadvantaged) | 1 | 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).
There are different ways in which RTU can be, and have been, reported in the published literature. The RTU12 in our cohort is lower than the 48% optimal RTU estimated using evidence-based modelling—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—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 lifetime RTU. Nonetheless, the RTU12 of 26% (and estimated RTU at 20 years of 34%) in our cohort is similar to earlier Australian studies and other international series.

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.

| Level | Total number of patients | RTU12 n (%) | 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 (33%) | 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%) | 792 (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 (63%) | 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 (64%) | 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 |
| GRCICS | 1,174 | 770 (66%) | 136 (61%) | 153 (70%) | 156 (68%) | 166 (68%) | 159 (64%) | 0.69 |
| HRICS | 1,153 | 701 (62%) | 112 (50%) | 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%) | 3 (33%) | |
| Remoteness | | | | | | | | |
| Major Cities | 15,303 | 9,382 (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 (60%) | 598 (59%) | 559 (65%) | 635 (65%) | <0.05 |
| Outer Regional/Remote | 1,090 | 644 (59%) | 106 (50%) | 134 (58%) | 119 (59%) | 141 (62%) | 144 (65%) | <0.001 |
| Missing | 9 | 3 (33%) | 3 (33%) | 3 (33%) | |
| Stage at diagnosis | | | | | | | | |
| 1 | 8,931 | 5,865 (60%) | <0.001 | 1,115 (65%) | 1,246 (67%) | 1,206 (66%) | 1,174 (65%) | 1,124 (65%) | 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.

Table 4. Radiation therapy utilization within 12 months of breast cancer diagnosis between 2013 and 2017.
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.\textsuperscript{18} The optimal RTU for evidence-based estimation may also change over time with changing cancer incidence data, indications for RT, especially stereotactic RT, for 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.\textsuperscript{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,\textsuperscript{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,\textsuperscript{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.\textsuperscript{24,25}

We also observed marked disparities in RT use in different cancers, which have pre-\textsuperscript{4,9,21,22}viously been reported in the literature.\textsuperscript{4,26} 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.,
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 Canada29 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 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 Australia3,37 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 Cancer40 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.

### 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.
Systematic reviews have shown that patients discussed in MDM were more likely to receive clinically indicated multimodality treatment, including RT in neo-adjuvant or adjuvant settings. 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. 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.

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.

Acknowledgement

We acknowledge the assistance of the Victorian Department of Health Centre for Victorian Data Linkage (CVDL) for performing data linkage for the study. Open access publishing facilitated by Monash University, as part of the Wiley - Monash University agreement via the Council of Australian University Librarians.

Funding

No financial support/ funding for this study.

Data availability statement

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

References

1. Barton MB, Jacob S, Shafiq J et al. Estimating the demand for radiotherapy from the evidence: a review of changes from 2003 to 2012. Radiother Oncol 2014; 112: 140–4.
2. Barton MB, Delaney GP. A decade of investment in radiotherapy in New South Wales: why does the gap between optimal and actual persist? J Med Imaging Radiat Oncol 2011; 55: 433–41.
3. Gabriel G, Barton M, Delaney GP. The effect of travel distance on radiotherapy utilization in NSW and ACT. Radiother Oncol 2015; 117: 386–9.
4. Yap ML, O’Connell DL, Goldsby D, Weber M, Barton M. Factors associated with radiotherapy utilisation in New South Wales, Australia: results from the 45 and up study. Clin Oncol 2020; 32: 282–91.
5. Vinod SK, Simonella L, Goldsby D, Delaney GP, Armstrong B, O’Connell DL. Underutilization of radiotherapy for lung cancer in New South Wales, Australia. Cancer 2010; 116: 686–94.
6. Yap ML, O’Connell DL, Goldsby D, Weber M, Barton M. Comparison of four methods for estimating actual radiotherapy utilisation using the 45 and up study cohort in New South Wales, Australia. Radiother Oncol 2019; 131: 14–20.
7. Merie R, Gabriel G, Shafiq J, Vinod S, Barton M, Delaney GP. Radiotherapy underutilisation and its impact on local control and survival in New South Wales, Australia. Radiother Oncol 2019; 141: 41–7.
8. Luke C, Chapman P, Priest K, Roder D. Use of radiotherapy in the primary treatment of cancer in South Australia. Australas Radiol 2003; 47: 161–7.
9. Lievens Y, De Schutter H, Stellamans K, Rosskamp M, Van Eycken L, Belgian College for Physicians in radiation O. Radiotherapy access in Belgium: how far are we from evidence-based utilisation? Eur J Cancer 2017; 64: 102–13.
10. Royce TJ, Qureshi MM, Truong MT. Radiotherapy utilization and fractionation patterns during the first course of cancer treatment in the United States from 2004 to 2014. J Am Coll Radiol 2018; 15: 1558–64.
11. Rosenblatt E, Fidarova E, Zubizarreta EH et al. Radiotherapy utilization in developing countries: An IAEA study. Radiother Oncol 2018; 128: 400–5.
12. Henry MJ, Jones P, Morrissy K et al. Radiotherapy in the Barwon South Western region: a rural perspective. J Med Imaging Radiat Oncol 2014; 58: 612–7.
13. Victorian Government Department of Health. Victorian Radiotherapy Minimum Data Set (VRMDS). Available from URL: https://www.health.vic.gov.au/health-strategies/data-about-radiotherapy-services
14. Mackillop WJ, Kong W. Comparison of methods for measuring radiotherapy utilisation. Clin Oncol 2019; 31: e95–e101.
15. Australian Bureau of Statistics. Socio-Economic Indexes for Areas. Available from URL: http://www.abs.gov.au/websitedbs/censushome.nsf/home/seifa.
16. Australian Bureau of Statistics. The Australian Statistical Geography Standard (ASGS) Remoteness Structure. Available from URL: http://www.abs.gov.au/websitedbs/D3310114.nsf/home/remoteness+structure

17. Batumalai V, Shafig J, Gabriel G, Hanna TP, Delaney GP, Barton M. Impact of radiotherapy underutilisation measured by survival shortfall, years of potential life lost and disability-adjusted life years lost in New South Wales, Australia. Radiother Oncol 2018; 129: 191–5.

18. Mackillop WJ, Kong W, Brundage M 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: 1099–107.

19. Hanna NH, Einhorn LH. Testicular cancer discoveries and updates. N Engl J Med 2014; 371: 2005–16.

20. Lubel JS, Roberts SK, Strasser SI et al. Australian recommendations for the management of hepatocellular carcinoma: a consensus statement. Med J Aust 2020; 214: 475–83.

21. Tyldesley S, Zhang-Salomons J, Groome PA et al. Association between age and the utilization of radiotherapy in Ontario. Int J Radiat Oncol Biol Phys 2000; 47: 469–80.

22. Mackenzie P, Vajdic C, Delaney G et al. Factors affecting radiotherapy utilisation in geriatric oncology patients in NSW, Australia. Tech Innov Patient Support Radio Oncol 2020; 16: 17–23.

23. Yap ML, O’Connell DL, Goldsby DE, Weber MF, Smith DP, Barton MB. Patterns of care for men with prostate cancer: The 45 and up study. Med J Aust 2021; 214: 271–8.

24. Hughes KS, Schnaper LA, Bellon JR et al. Lumpectomy plus tamoxifen with or without irradiation in women aged 70 years or older with early breast cancer: Long-term follow-up of CALGB 9334. J Clin Oncol 2013; 31: 2382–7.

25. Kunkler IH, Williams LJ, Jack WJ, Cameron DA, Dixon JM, Investigators PI. Breast-conserving surgery with or without irradiation in women aged 65 years or older with early breast cancer (PRIME II): a randomised controlled trial. Lancet Oncol 2015; 16: 266–73.

26. Dragan AE, Huang B, Tucker TC, Spanos WJ. Disparities in the application of adjuvant radiotherapy after breast-conserving surgery for early stage breast cancer: Impact on overall survival. Cancer 2011; 117: 2590–8.

27. Williams MV, Drinkwater KJ. Geographical variation in radiotherapy services across the UK in 2007 and the effect of deprivation. Clin Oncol 2009; 21: 431–40.

28. Te Marvelde L, Milne RL, Hornby CJ, Chapman AB, Giles GG, Haines IE. Differences in treatment choices for localised prostate cancer diagnosed in private and public health services. Med J Aust 2020; 213: 411–7.

29. Kumachev A, Trudeau ME, Chan KK. Associations among socioeconomic status, patterns of care and outcomes in breast cancer patients in a universal health care system: Ontario’s experience. Cancer 2016; 122: 893–8.

30. Hamdy FC, Donovan JL, Lane JA et al. 10-year outcomes after monitoring, surgery, or radiotherapy for localized prostate cancer. N Engl J Med 2016; 375: 1415–24.

31. Klotz L, Vesprini D, Sethukavalan P et al. Long-term follow-up of a large active surveillance cohort of patients with prostate cancer. J Clin Oncol 2015; 33: 272–7.

32. Ong WL, Evans SM, Evans M et al. Trends in conservative management for low-risk Prostate Cancer in a population-based cohort of Australian men diagnosed between 2009 and 2016. Eur Urol Oncol 2021; 4: 319–22.

33. EBCTCG, Darby S, McGale P et al. Effect of radiotherapy after breast-conserving surgery on 10-year recurrence and 15-year breast cancer death: Meta-analysis of individual patient data for 10,801 women in 17 randomised trials. Lancet 2011; 378: 1707–16.

34. EBCTCG, McGale P, Taylor C et al. Effect of radiotherapy after mastectomy and axillary surgery on 10-year recurrence and 20-year breast cancer mortality: Meta-analysis of individual patient data for 8135 women in 22 randomised trials. Lancet 2014; 383: 2127–35.

35. Gu J, Groot G, Boden C, Busch A, Holtslander L, Lim H. Review of factors influencing Women’s choice of mastectomy versus breast conserving therapy in early stage breast cancer: A systematic review. Clin Breast Cancer 2018; 18: e539–54.

36. Smith GL, Shih YC, Xu Y et al. Racial disparities in the use of radiotherapy after breast-conserving surgery: a national Medicare study. Cancer 2010; 116: 734–41.

37. Khor R, Bressel M, Tai KH et al. Patterns of treatment with radiotherapy in a large academic Centre. J Med Imaging Radiat Oncol 2013; 57: 610–6.

38. Punglia RS, Weeks JC, Neville BA, Earle CC. Effect of distance to radiation treatment facility on use of radiation therapy after mastectomy in elderly women. Int J Radiat Oncol Biol Phys 2006; 66: 56–63.

39. Tang C, Lei X, Smith GL et al. Influence of geography on prostate cancer treatment. Int J Radiat Oncol Biol Phys 2020; 109: 1286–95.

40. Radiation Oncology Targeting Cancer 2017. Available from URL: https://www.targetingcancer.com.au/

41. Heinke MY, Vinod SK. A review on the impact of lung cancer multidisciplinary care on patient outcomes. Transl Lung Cancer Res 2020; 9: 1639–53.

42. Pillay B, Wootten AC, Crowe H et al. The impact of multidisciplinary team meetings on patient assessment, management and outcomes in oncology settings: a systematic review of the literature. Cancer Treat Rev 2016; 42: 56–72.

43. Australian Government Department of Health. Medical Benefit Schedule changes factsheet: New items for radical prostatectomy factsheet, 2020 [updated 9 October 2020. Available from URL: http://www.mbsonline.gov.au/internet/mbsonline/publishing.nsf/Content/1C7B3AED38006462CA2585E80009D95C/$File/Factsheet-Radical-Prostatectomy.pdf