Journal of Geriatric Oncology 14 (2023) 101387

Contents lists available at ScienceDirect

Journal of Geriatric Oncology

journal homepage: www.elsevier.com/locate/jgo

Systematic Review

Radiotherapy utilisation rates for patients with cancer as a function of age: A systematic review

Penny Mackenzie [a,b,c,*], Claire Vajdic [d], Geoff Delaney [b,c], Tracy Comans [e], Lucinda Morris [g], Meera Agar [f], Gabriel Gabriel [a,b,c], Michael Barton [b,c]

[a] St Andrew's Hospital, Icon Cancer Centre, Toowoomba, Australia
[b] Collaboration for Cancer Outcomes, Research and Evaluation (CCORE), Ingham Institute for Applied Medical Research, Liverpool Hospital, Sydney, Australia
[c] The University of New South Wales, Sydney, Australia
[d] The Kirby Institute, The University of New South Wales, Sydney, Australia
[e] Centre for Health Services Research, The University of Queensland, Australia
[f] Centre for Improving Palliative, Aged and Chronic Care through Clinical Research and Translation (IMPACTT), The University of Technology, Sydney, Australia
[g] St George Hospital, Sydney, Australia

ARTICLE INFO

Keywords:
Geriatric oncology
Radiotherapy
cancer

ABSTRACT

Introduction: There is an increasing incidence of cancer in older people, but limited data on radiotherapy uptake, and in particular, radiotherapy utilisation (RTU) rates. The RTU rate for older adults with cancer may be lower than recommended due to lower tolerance for radiotherapy as well as additional comorbidities, reduced life expectancy and travel for treatment. Radiotherapy use must be aligned with best available, age-specific evidence to ensure older adults with cancer receive optimal benefit without harms.

Materials and methods: A systematic review was conducted to synthesise the published data on the actual RTU rate for patients with cancer as a function of age.

MEDLINE and EMBASE were systematically searched to identify relevant population-based and hospital-based cohort studies on radiotherapy utilisation for all age groups, published in English, from 1 January 1990 to 1 July 2020. We focused on the following common cancers in older adults for which radiotherapy is recommended: breast, prostate, lung, rectal cancer, glioblastoma multiforme (GBM), and cervical cancer. Age-specific radiotherapy utilisation data were extracted and analysed as a narrative synthesis.

Results: From 2606 studies screened, 75 cohort and population-based studies were identified with age-specific radiotherapy utilisation data. The total number of patients in the 75 studies was 4,792,138. The RTU rate decreased with increasing age for all tumour sites analysed, except for patients receiving curative radiotherapy as definitive treatment for prostate or cervical cancer. This reduction with increasing age was demonstrated in both palliative and curative settings.

Discussion: There is a global reduction in radiotherapy utilisation with increasing age for most tumour sites. The reduction in delivery of radiotherapy warrants further examination and evidence-based guidelines specific to this population.

1. Introduction

There is an increasing incidence of cancer in older adults. Using GLOBOCAN estimates, Pilleron et al. have predicted that in 2050, there will be 6.9 million new cancers diagnosed in patients aged 80 years and above [1]. This is in comparison to 2.3 million new cancers diagnosed in the same age group in 2018. [1]. Radiotherapy is an important treatment modality for this cohort of patients.

Data on radiotherapy utilisation in the geriatric oncology setting is limited. Previous research by our group analysed population-based cancer registry and radiotherapy data and demonstrated a marked reduction in radiotherapy utilisation in patients aged 80+ years. Only 14% of patients in this cohort received radiotherapy within twelve months of their cancer diagnosis compared to 28% of patients <80 years of age [2].

Older adults with cancer are often excluded from randomised

* Corresponding author at: St Andrew's Hospital, Toowoomba, Australia.
E-mail address: mackenzie.penny@gmail.com (P. Mackenzie).

https://doi.org/10.1016/j.jgo.2022.10.002
Received 15 June 2022; Received in revised form 16 September 2022; Accepted 5 October 2022
Available online 20 October 2022

controlled trials that are then used to make decisions about them [3,4]. They are likely to have more comorbidities and more limited life expectancy, thus making the recommendation for radiotherapy more clinically complex [5]. There are limited age-specific evidence-based guidelines on radiotherapy for older adults with cancer [5–8]. In addition, for cancer sites where surgery is an alternative treatment modality, older adults with cancer may be preferentially treated with radiotherapy because of concerns regarding their tolerance of surgery (e.g., prostate cancer, cervical cancer, and early lung cancer). This study aimed to synthesise published data on the radiotherapy utilisation rate for cancer patients as a function of age.

2. Material and methods

2.1. Eligibility criteria

This systematic review was registered with PROSPERO (University of York; CRD42020184030) and conducted according to the PRISMA guidelines (Fig. 1). Eligibility criteria were population- or hospital-based cancer cohort studies, radiotherapy utilisation data by age group, full text available, English language and publication 1 January 1990–1 July 2020. All age groups were included. Ethics approval was obtained from the NSW cancer Institute Human Research Ethics Committee.

2.2. Information sources and search strategy

MEDLINE and EMBASE were searched in addition to reference lists of included studies. The full search strategy may be viewed in the Supplement.

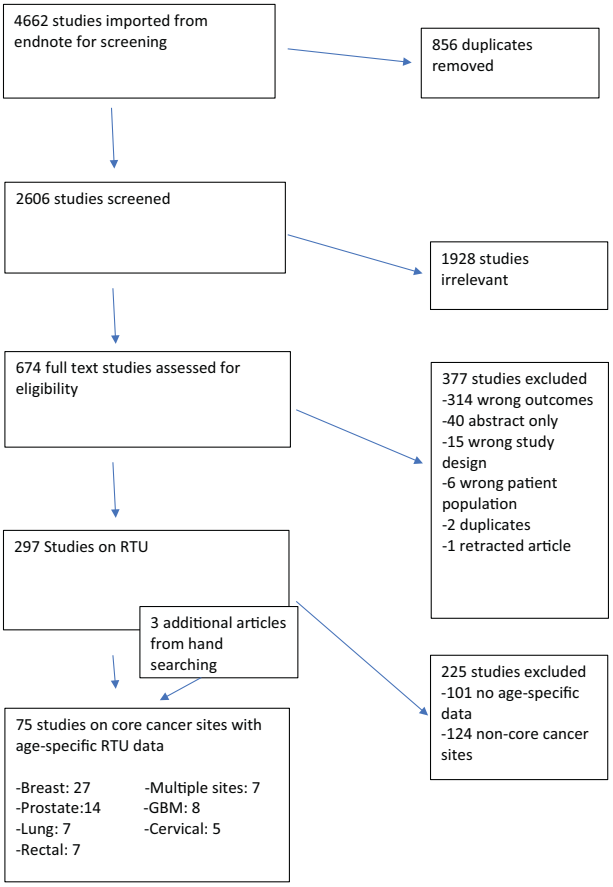

Fig. 1. PRISMA and Search strategy.

2.3. Study selection and data collection

Articles were exported to Endnote X9.3.3 (Clarivate Analytics), duplicates were removed, and then were exported to Covidence software (2021). Screening, full text eligibility and article selection was performed by two independent reviewers (PM, LM). Conflicts were resolved by discussion with a third reviewer (MA) as required. Data extracted included tumour site, age-specific radiotherapy utilisation (RTU) rate, calendar year(s), data source(s), country, number of patients, and study design.

The modified Newcastle Ottawa Scoring system was used to assess the quality of the studies and determine risk of bias [9,10].

Due to differing age categories across studies, a narrative synthesis was performed. We present findings for the most common malignancies (breast, rectal, lung, prostate, multiple sites, glioblastoma multiforme, and cervical cancer). Definitive radiotherapy is curative intent radiotherapy used as sole modality treatment (i.e., without surgery). Adjuvant radiotherapy is defined as radiotherapy after surgery.

3. Results

Seventy-five full text articles were included that reported age-specific RTU rate data *(see Table 1, supplementary appendix)*.

3.1. Study characteristics

Study sample size varied, with population-based studies generally larger than hospital-based studies. The range for the population-based studies was 562 to 398,074 patients and the range for the hospital-based studies was 235 to 9863. Many different countries were represented including the USA, Canada, Australia, New Zealand, Scotland, Italy, the Netherlands, Switzerland, Sweden, and Norway. Radiotherapy utilisation was variably defined, and follow-up periods were tumour site dependent. Different age categories were used when reporting age-specific RTUs. Therefore, a pragmatic decision was made to synthesise the data for <60 years, 60–69 years, 70–79 years, and 80+ years, where possible.

The distribution of articles by tumour site was breast ($n = 27$), prostate ($n = 14$), lung ($n = 7$), rectal ($n = 7$), multiple tumour sites ($n = 7$), Glioblastoma Multiforme ($n = 8$) and cervical cancer ($n = 5$). Select representative studies are described below.

All studies received a Modified Newcastle Ottawa quality score of ≥ 6 and thus were included in the analysis *(see Table 2, Data Quality Table, supplementary appendix)*.

3.2. Statistics

Due to study heterogeneity, a meta-analysis was not possible.

3.2.1. Breast cancer

The RTU rate decreased with increasing age across all studies and in all jurisdictions (*supplementary appendix and* Fig. 2*a-f)*. The largest study including patients of all ages was published by Showalter et al. [11] This US study analysed Surveillance, Epidemiology, and End Results program (SEER) data from 194,860 patients with stage I breast cancer from 1998 to 2007. The RTU rate for all age groups in this study was 79.5% [11]. The RTU rate was >75% for all age groups except those aged 80+ years, where it was 52% ($p < 0.01$) [11].

3.2.2. Lung cancer

Compared to patients with breast cancer, there are fewer data on radiotherapy utilisation for older adults with lung cancer. The identified studies demonstrated a reduction in RTU rate with increasing age *(Fig. 2b)*. However, for patients with stage I non-small cell lung cancer (NSCLC), the RTU rate increased with increasing age, possibly reflecting the use of radiotherapy as a substitute for surgery.

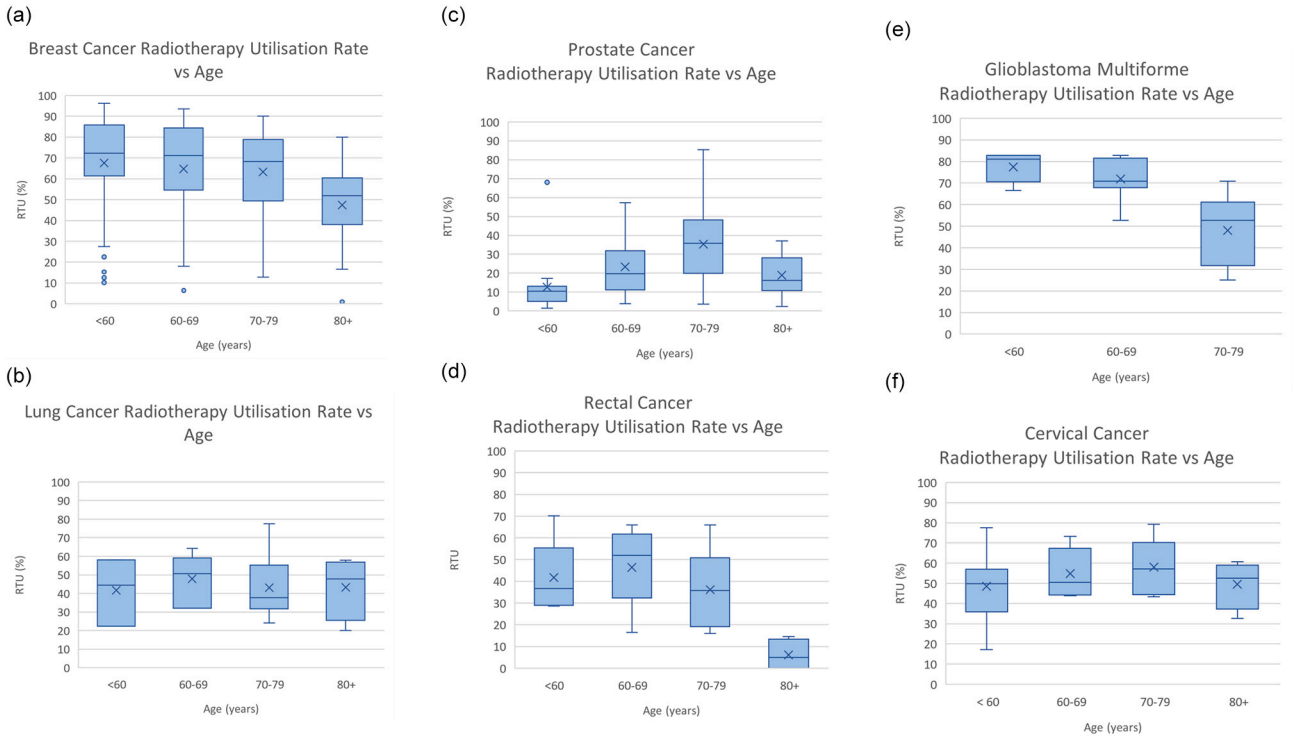

Fig. 2. Radiotherapy Utilisation vs Age.

In a New Zealand population-based cohort study of NSCLC of all stages, Stevens et al. demonstrated a reduction in RTU rate from 58% in patients aged <60 years to 20% in patients aged 80+ years [12].

In a Dutch study of the introduction of stereotactic radiotherapy in patients aged 75+ years with stage I NSCLC, Palma et al. reported an increase in RTU rate over three different time periods (1999–2001, 2002–2004, 2005–2007) [13]. The RTU rate increased from 26% to 32% to 42% across the three different eras [13]. There was also a 12% reduction in 'no treatment' (i.e., no radiotherapy or surgery) from 38% to 26% over these time periods [13].

3.2.3. *Prostate cancer*

The relationship between RTU rate and age was different in the curative versus the adjuvant setting for men with prostate cancer. Curative radiotherapy is often used as an alternative to surgery in older and frailer patients with prostate cancer, and we observed the curative RTU rate to increase with increasing age. *Fig. 2c* demonstrates the overall RTU (definitive and adjuvant) for patients with prostate cancer. This shows an increase in RTU rate with increasing age until age 75–79 years.

Chen et al., in their 2004–2013 SEER database study of 398,074 patients with localised prostate cancer, demonstrated an increase in curative radiotherapy with increasing age until age 80. The RTU increased from 35.8% (70–74 years) to 41.0% (75–79 years) and then decreased to 26.9% (80+ years) [14].

In the adjuvant setting, the RTU rate decreased with increasing age in all studies. Kalbasi et al. assessed 130,681 patients from the 2004–2011 US National Cancer Database with non-metastatic prostate cancer following surgery. The RTU rate was 8.9% for patients aged 65–79 years and 5.5% in patients aged 79+ years [15].

3.2.4. *Rectal cancer*

The RTU rate for patients with rectal cancer decreased with increasing age for all studies *(Fig. 2d)*. The largest study of rectal cancer patients was by Olsson et al. [16] This population-based cohort study analysed 16,713 patients registered in the Swedish Rectal Cancer Registry from 1995 to 2005. The RTU rate decreased from 63.8% (≤ 65 years) to 49.6% (66–79 years)to 14.6% for the oldest age group (80+ years) [16].

3.2.5. *Glioblastoma multiforme*

The RTU rate decreased with increasing age in all studies *(Fig. 2e)*. Gulati et al., in their Norwegian Cancer Registry study, analysed 2890 patients from 1998 to 2008 [17]. The RTU rate for patients aged 75 + years was 31.4%, and 52.8% for patients aged 66–74 years [17]. Higher RTU rates were observed in the US SEER database study by Scott et al. of 2836 patients from 1993 to 2005 [18]. The RTU rate for patients aged 70+ years was 64.1% and 81.1% for patients aged 50–70 years [18].

3.2.6. *Cervical cancer*

In the definitive setting, the RTU rate increased with increasing age *(Fig. 2f)*. The largest cervical cancer study included in this systematic review was a 1988–2005 US SEER database study by Sharma et al. of 28,902 patients with all disease stages [19]. The RTU for patients undergoing definitive radiotherapy was 51.3% for patients aged 70–79 years and 60.7% for patients aged 80+ years [19]. Tyldesley et al., in their Ontario Cancer Registry study, also demonstrated an RTU rate of 63.1% for ages 65–74 years and 46.5% for patients aged 75+ years [20].

In comparison, for patients in the adjuvant setting, Trifiletti et al. reported a reduction in RTU with increasing age in their review of 5947 patients from the 2002–2012 US National Cancer Database [21]. The RTU rate was 50.5% for patients aged 50–59 years and 42.6% for patients aged 69+ years [21].

3.2.7. *Palliative radiotherapy*

Palliative radiotherapy utilisation rates were reported in some articles [22–29]. The RTU rate decreased with increasing age for palliative treatments in all reported studies. Murphy et al. demonstrated a reduction in palliative radiotherapy for patients with stage IV breast, lung, prostate, and colorectal cancer [29]. The RTU rate decreased from 52% in patients aged 60–69 years to 22% in patients aged 85+ years.

4. Discussion

This systematic review has demonstrated reductions in the RTU rate for common tumour sites and an increase in the RTU rate for other tumour sites. The RTU rate was not stable with increasing age. The following tumour sites were associated with a reduction in the RTU rate with increasing age: breast, lung, rectum, and glioblastoma. The proportion of prostate and cervical cancer cases receiving radiotherapy in the adjuvant setting decreased with age. The RTU rate decreased with increasing age for patients receiving palliative treatment (as defined by radiotherapy for management of symptoms in patients with metastatic disease or radiotherapy in patients that are not suitable candidates for curative radiotherapy). Alternatively, patients undergoing definitive radiotherapy for treatment of prostate and cervical cancer (in substitute for surgery) were associated with an increase in RTU rate with increasing age.

Therefore, the proportion of cases receiving radiotherapy in the curative setting increased with increasing age where radiotherapy is used as a substitute for surgery (prostate cancer and cervical cancer). The increase in the RTU rate is likely to be due to the reduction in fitness or suitability for surgery, or non-acceptance by the patient of a surgery recommendation.

The previous optimal RTU benchmarks developed by the Collaboration for Cancer Outcomes, Research and Evaluation (CCORE) have estimated the optimal RTU for breast cancer (83%), lung (76%), prostate (60%), rectal (61%), GBM (100%), and cervical cancer (58%) [30–36] when all age groups are combined. Fig. 2*a-f* display the RTU rates identified in this review for the different tumour sites. For patients aged 80+ years, only the cervical cancer RTU rate achieves the optimal RTU rate as previously benchmarked. Therefore, there is a concern for other studied cancer sites that the actual RTU rate is less than the optimal RTU rate.

The reduction in radiotherapy utilisation with increasing age may be due to many different factors. These factors may include physician and patient biases, comorbidities, suitability and fitness for treatment, and limited social supports [37]. It is however stated on the International Geriatric Oncology Guidelines (SIOG) that cancer treatment decisions should not be based on age alone [38–40].

In the current era with modern technology and improvements in the precision and accuracy of radiotherapy, the side effect profile of treatment is much lower than historically [41]. There is also a reduction in the length of the treatment course required for many tumour sites. For example, for older adults with early-stage lung cancer, there is increasing evidence to support the use of stereotactic radiotherapy [42]. Stereotactic lung radiotherapy requires fewer sessional attendances and treatment may be completed within two weeks. Palma et al. showed an increasing proportion of older adults receiving cancer treatment for early-stage disease following the introduction of stereotactic treatment [13]. There is also an improvement in local control and less toxicity when compared to a conventional course of radiotherapy delivered over six weeks [43]. In an institutional study by Haasbeek et al. of 193 patients aged 75+ undergoing stereotactic radiotherapy treatment for stage I NSCLC, only one patient did not complete the course of treatment [44].

For patients undergoing curative intent radiotherapy as definitive treatment (that is, without surgery), the RTU rate increases with age near to the benchmark recommendation. Our review demonstrates this is well documented for patients with prostate cancer, cervical cancer, and, more recently, is being seen in early-stage lung cancer following the introduction of stereotactic lung radiotherapy. The exception to this is a reduction in RTU rate with age for patients undergoing radiotherapy for a GBM, where there is evidence of less benefit in the 60+ age group [45].

In the definitive setting, radiotherapy is an alternative treatment option to surgery for the older cohort of patients. Outcomes are thought to be equivalent for patients undergoing radiotherapy or surgery for prostate cancer [46]. For patients with cervical cancer, there are randomised data to support treatment equivalence [47]. The radiotherapy utilisation rate is therefore higher in the curative intent setting for lung, prostate, and cervical cancer, as demonstrated in Fig. 2*b, d, and f*.

For patients with a brain tumour (GBM) there is evidence for a shorter course of radiotherapy delivered over three weeks [7]. The reduction in RTU rate with increasing age in this cohort of patients is partly explained by the reduction in clinical benefit with age as seen in the initial malignant glioma recursive partitioning studies [45]. More recent studies, including a SEER database study of 2836 patients aged 70+ years and a randomised study from France of 86 patients aged 70+ years, have demonstrated an overall survival benefit with radiotherapy [18,48].

Our review has established that radiotherapy utilisation rate decreases with increasing age when radiotherapy is used in the adjuvant setting. This reduction in adjuvant treatment may be due to multiple factors. One such factor may be referral bias. Ong et al., in their retrospective cohort study of 158 patients with stage II/III rectal cancer or stage III colon cancer at the Ottawa Hospital, found that only 67% of patients aged 75+ years were referred for a radiation and/or medical oncology consultation versus 95% in patients aged <75 years [49]. Dawe et al., in their retrospective Ontario study of 61,646 patients, reported that the proportion of radiation oncology referrals for patients with NSCLC decreased with increasing age for all stages except for patients with stage I disease [50]. Only 52% of patients aged 70+ years were referred for a radiation oncology consultation versus 70% of patients aged <70 years.

Patients may elect not to proceed with radiotherapy due to concerns with the length of treatment required (usually several weeks). There are, however, randomised data to support shorter treatment schedules in multiple tumour sites including, for breast and rectal cancer treatment [51–53]. For these tumour sites, the RTU rate decreases from age 70+ years *(*Fig. 2*a and d)*. The reduction in the length of treatment may allow more patients to proceed with radiotherapy, as the number of sessional attendances required is no longer a barrier to radiotherapy.

4.1. Implications for practice and research

From this research, there is evidence that for older adults, there is a shortfall between optimal and actual radiotherapy utilisation across all tumour sites except for cervical cancer [54]. Therefore, there is a need to develop age-specific optimal benchmarks. The benefit of radiotherapy for local control and survival across multiple tumour sites has been well established [30–32,34,55–57], indicating that omission of radiotherapy may be detrimental to patient care. However, data on the benefits of radiotherapy specific to the older cohorts are generally lacking. There is a need for further research in this area to determine the age- specific clinical decision making and, furthermore, whether these age-specific utilisation rates are clinically appropriate.

4.2. Strengths and limitations

The strength of this study is that this is the largest study to review radiotherapy practice by age and tumour site. A meta-analysis was not possible due to the use of different age categories by the original studies. Study limitations include a lack of data on the reasons why there was a reduction in RTU with increasing age. Little evidence exists to determine whether this is clinician or patient decision-making related or a combination of the two. The way radiotherapy may or may not be discussed with patients is not consistently recorded. It is possible that some decisions to omit radiotherapy are entirely appropriate when considering patient's comorbidities and recurrence risk.

5. Conclusion

Overall, the RTU decreases with increasing age for patients with

breast cancer, colorectal cancer, lung cancer, and GBM and increases for patients with cervical cancer and prostate cancer. Further work is required to ensure appropriate utilisation of radiotherapy, to assess the gap between actual and optimal radiotherapy utilisation rates, and to determine whether the reduction represents underutilisation of radiotherapy or appropriate reduction treatment for older adults who may not be suitable candidates for radiotherapy based on comorbidities, tolerance of treatment, and estimated life expectancy. Radiotherapy recommendations should not be based on age alone.

Authors and contribution

PM was the chief researcher and responsible for conceptualisation, study design and methodology, data curation and analysis and interpretation and manuscript writing.

PM, LM, and MA reviewed the articles.

PM and GG have verified the underlying data.

MB, CV, GD, TC, GG, MA and LM reviewed the study design data analysis, and interpretation and manuscript.

All authors confirm that they had access to all the data in the study and accept responsibility to submit for publication.

Declaration of Competing Interest

There were no conflicts of interest for any of the authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jgo.2022.10.002.

References

[1] Pilleron S, Soto-Perez-de-Celis E, Vignat J, Ferlay J, Bray F, Sarfarti D. Estimated global cancer incidence in the oldest adults in 2018 and projections to 2050. Int J Cancer 2020;148:601–8.

[2] Mackenzie P, Vajdic C, Delaney G, Gabriel G, Agar M, Comans T, et al. Factors affecting radiotherapy utilisation in geriatric oncology patients in NSW, Australia. Tech Innov Patient Support Radiat Oncol 2020;16:17–23.

[3] Scher KS, Hurria A. Under-representation of older adults in cancer registration trials: known problem, little progress. J Clin Oncol 2012;30(17):2036–8.

[4] Bertagnolli MM, Singh H. Treatment of older adults with cancer—addressing gaps in evidence. N Engl J Med 2021;385(12):1062–5.

[5] Kunkler I, Audisio R, Belkacemi Y, Betz M, Gore E, Hoffe S, et al. Review of current best practice and priorities for research in radiation oncology for elderly patients with cancer: the International Society of Geriatric Oncology (SIOG) task force. Ann Oncol 2014;25(11):2134–46.

[6] Hughes KS, Schnaper LA, Bellon JR, Cirrincione CT, Berry DA, McCormick B, et al. Lumpectomy plus tamoxifen with or without irradiation in women age 70 years or older with early breast cancer: long-term follow-up of CALGB 9343. J Clin Oncol 2013;31(19):2382–7.

[7] Perry JR, Laperriere N, O'Callaghan CJ, Brandes AA, Menten J, Phillips C, et al. Short-course radiation plus temozolomide in elderly patients with glioblastoma. N Engl J Med 2017;376(11):1027–37.

[8] Kunkler IH, Williams LJ, Jack WJ, Cameron DA, Dixon JM. 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(3):266–73.

[9] Zeng X, Zhang Y, Kwong JS, Zhang C, Li S, Sun F, et al. The methodological quality assessment tools for preclinical and clinical studies, systematic review and meta-analysis, and clinical practice guideline: a systematic review. J Evid Based Med 2015;8(1):2–10.

[10] Wells G, Shea B, O'Connell D, et al. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Available from: http://www.ohri.ca/programs/clinicalepidemiology/oxford.asp.

[11] Showalter SL, Grover S, Sharma S, Lin L, Czerniecki BJ. Factors influencing surgical and adjuvant therapy in stage I breast cancer: a SEER 18 database analysis. Ann Surg Oncol 2013;20(4):1287–94.

[12] Stevens G, Stevens W, Purchuri S, Kolbe J, Cox B. Radiotherapy utilisation in lung cancer in New Zealand: disparities with optimal rates explained. N Z Med J (Online) 2009;122(1306).

[13] Palma D, Visser O, Lagerwaard FJ, Belderbos J, Slotman BJ, Senan S. Impact of introducing stereotactic lung radiotherapy for elderly patients with stage I non-small-cell lung cancer: a population-based time-trend analysis. J Clin Oncol 2010;28(35):5153–9.

[14] Chen J, Oromendia C, Halpern JA, Ballman KV. National trends in management of localized prostate cancer: a population based analysis 2004-2013. Prostate 2018;78(7):512–20.

[15] Kalbasi A, Swisher-McClure S, Mitra N, Sunderland R, Smaldone MC, Uzzo RG, et al. Low rates of adjuvant radiation in patients with nonmetastatic prostate cancer with high-risk pathologic features. Cancer. 2014;120(19):3089–96.

[16] Olsson L, Granström F, Glimelius B. Socioeconomic inequalities in the use of radiotherapy for rectal cancer: a nationwide study. Eur J Cancer 2011;47(3):347–53.

[17] Gulati S, Jakola AS, Johannesen TB, Solheim O. Survival and treatment patterns of glioblastoma in the elderly: a population-based study. World Neurosurg 2012;78(5):518–26.

[18] Scott J, Tsai Y-Y, Chinnaiyan P, Yu H-HM. Effectiveness of radiotherapy for elderly patients with glioblastoma. Int J Radiat Oncol Biol Phys 2011;81(1):206–10.

[19] Sharma C, Deutsch I, Horowitz DP, Hershman DL, Lewin SN, Lu YS, et al. Patterns of care and treatment outcomes for elderly women with cervical cancer. Cancer. 2012;118(14):3618–26.

[20] Tyldesley S, Zhang-Salomons J, Groome PA, Zhou S, Schulze K, Paszat LF, et al. Association between age and the utilization of radiotherapy in Ontario. Int J Radiat Oncol Biol Phys 2000;47(2):469–80.

[21] Trifiletti DM, Swisher-McClure S, Showalter TN, Cantrell LA, Grover S. Utilization of postoperative chemoradiotherapy among women in the United States with high-risk cervical Cancer. Am J Clin Oncol 2018;41(5):452–7.

[22] Kumar R, Jain K, Beeke C, Price TJ, Townsend AR, Padbury R, et al. A population-based study of metastatic colorectal cancer in individuals aged≥ 80 years: findings from the South Australian Clinical Registry for Metastatic Colorectal Cancer. Cancer. 2013;119(4):722–8.

[23] Cho CJ, Sunderland K, Pickles T, Bachand F, Chi KN, Tyldesley S. A population-based study of palliative radiation therapy for bone metastases in patients dying of prostate cancer. Pract Radiat Oncol 2019;9(3). e274-e82.

[24] Nieder C, Haukland E, Mannsåker B, Norum J. Impact of intense systemic therapy and improved survival on the use of palliative radiotherapy in patients with bone metastases from prostate cancer. Oncol Lett 2016;12(4):2930–5.

[25] Parikh RR, Byun J, Goyal S, Kim IY. Local therapy improves overall survival in patients with newly diagnosed metastatic prostate cancer. Prostate 2017;77(6):559–72.

[26] Åsli LM, Myklebust TÅ, Kvaløy SO, Jetne V, Møller B, Levernes SG, et al. Factors influencing access to palliative radiotherapy: a Norwegian population-based study. Acta Oncol 2018;57(9):1250–8.

[27] Corral J, Solà J, Galceran J, Marcos-Gragera R, Carulla M, Izquierdo Á, et al. A population perspective on the use of external beam radiotherapy in Catalonia. Spain Clin Transl Oncol 2020;22:2222–9.

[28] Grendarova P, Sinnarajah A, Trotter T, Card C, Wu JS. Variations in intensity of end-of-life cancer therapy by cancer type at a Canadian tertiary cancer centre between 2003 and 2010. Support Care Cancer 2015;23(10):3059–67.

[29] Murphy JD, Nelson LM, Chang DT, Mell LK, Le Q-T. Patterns of care in palliative radiotherapy: a population-based study. J Oncol Pract 2013;9(5). e220-e7.

[30] Delaney G, Barton M, Jacob S. Estimation of an optimal radiotherapy utilization rate for gastrointestinal carcinoma: a review of the evidence. Cancer. 2004;101(4):657–70.

[31] Delaney G, Jacob S, Barton M. Estimating the optimal external-beam radiotherapy utilization rate for genitourinary malignancies. Cancer. 2005;103(3):462–73.

[32] Delaney G, Barton M, Jacob S. Estimation of an optimal radiotherapy utilization rate for breast carcinoma. Cancer. 2003;98(9):1977–86.

[33] Tyldesley S, Delaney G, Foroudi F, Barbera L, Kerba M, Mackillop W. Estimating the need for radiotherapy for patients with prostate, breast, and lung cancers: verification of model estimates of need with radiotherapy utilization data from British Columbia. Int J Radiat Oncol Biol Phys 2011;79(5):1507–15.

[34] Delaney G, Barton M, Jacob S, Jalaludin B. A model for decision making for the use of radiotherapy in lung cancer. Lancet Oncol 2003;4(2):120–8.

[35] Delaney G, Jacob S, Barton M. Estimating the optimal radiotherapy utilization for carcinoma of the central nervous system, thyroid carcinoma, and carcinoma of unknown primary origin from evidence-based clinical guidelines. Cancer: Interdisc Int J Am Cancer Soc 2006;106(2):453–65.

[36] Delaney G, Jacob S, Barton M. Estimation of an optimal radiotherapy utilization rate for gynecologic carcinoma: Part I–Malignancies of the cervix, ovary, vagina, and vulva. Cancer. 2004;101(4):671–81.

[37] McKenna RJ. Clinical aspects of cancer in the elderly. Treatment decisions, treatment choices, and follow-up. Cancer. 1994;74(S7):2107–17.

[38] Biganzoli L, Battisti NML, Wildiers H, McCartney A, Colloca G, Kunkler IH, et al. Updated recommendations regarding the management of older patients with breast cancer: a joint paper from the European Society of Breast Cancer Specialists (EUSOMA) and the International Society of Geriatric Oncology (SIOG). Lancet Oncol 2021;22:e327–40.

[39] Boyle HJ, Alibhai S, Decoster L, Efstathiou E, Fizazi K, Mottet N, et al. Updated recommendations of the International Society of Geriatric Oncology on prostate cancer management in older patients. Eur J Cancer 2019;116:116–36.

[40] Montroni I, Ugolini G, Saur NM, Spinelli A, Rostoft S, Millan M, et al. Personalized management of elderly patients with rectal cancer: expert recommendations of the European Society of Surgical Oncology, European Society of Coloproctology, International Society of Geriatric Oncology, and American College of Surgeons Commission on Cancer. Eur J Surg Oncol 2018;44(11):1685–702.

[41] Citrin DE. Recent developments in radiotherapy. N Engl J Med 2017;377(11):1065–75.

[42] Chang JY, Mehran RJ, Feng L, Verma V, Liao Z, Welsh JW, et al. Stereotactic ablative radiotherapy for operable stage I non-small-cell lung cancer (revised

STARS): long-term results of a single-arm, prospective trial with prespecified comparison to surgery. Lancet Oncol 2021;22(10):1448–57.
[43] Ball D, Mai GT, Vinod S, Babington S, Ruben J, Kron T, et al. Stereotactic ablative radiotherapy versus standard radiotherapy in stage 1 non-small-cell lung cancer (TROG 09.02 CHISEL): a phase 3, open-label, randomised controlled trial. Lancet Oncol 2019;20(4):494–503.
[44] Haasbeek C, Palma D, Visser O, Lagerwaard F, Slotman B, Senan S. Early-stage lung cancer in elderly patients: a population-based study of changes in treatment patterns and survival in the Netherlands. Ann Oncol 2012;23(10):2743–7.
[45] Curran Jr WJ, Scott CB, Horton J, Nelson JS, Weinstein AS, Fischbach AJ, et al. Recursive partitioning analysis of prognostic factors in three radiation therapy oncology group malignant glioma trials. JNCI: J Natl Cancer Inst 1993;85(9):704–10.
[46] Beesley LJ, Morgan TM, Spratt DE, Singhal U, Feng FY, Furgal AC, et al. Individual and population comparisons of surgery and radiotherapy outcomes in prostate Cancer using Bayesian multistate models. JAMA Netw Open 2019;2(2):e187765.
[47] Landoni F, Maneo A, Colombo A, Placa F, Milani R, Perego P, et al. Randomised study of radical surgery versus radiotherapy for stage Ib-IIa cervical cancer. Lancet 1997;350(9077):535–40.
[48] Keime-Guibert F, Chinot O, Taillandier L, Cartalat-Carel S, Frenay M, Kantor G, et al. Radiotherapy for glioblastoma in the elderly. N Engl J Med 2007;356(15):1527–35.
[49] Ong S, Watters JM, Grunfeld E, O'Rourke K. Predictors of referral for adjuvant therapy for colorectal cancer. Can J Surg 2005;48(3):225.
[50] Dawe DE, Pond GR, Ellis PM. Assessment of referral and chemotherapy treatment patterns for elderly patients with non–small-cell lung cancer. Clin Lung Cancer 2016;17(6). 563–72. e2.
[51] Haviland JS, Owen JR, Dewar JA, Agrawal RK, Barrett J, Barrett-Lee PJ, et al. The UK Standardisation of Breast Radiotherapy (START) trials of radiotherapy hypofractionation for treatment of early breast cancer: 10-year follow-up results of two randomised controlled trials. Lancet Oncol 2013;14(11):1086–94.
[52] Whelan TJ, Pignol JP, Levine MN, Julian JA, MacKenzie R, Parpia S, et al. Long-term results of hypofractionated radiation therapy for breast cancer. N Engl J Med 2010;362(6):513–20.
[53] Ngan SY, Burmeister B, Fisher RJ, Solomon M, Goldstein D, Joseph D, et al. Randomized trial of short-course radiotherapy versus long-course chemoradiation comparing rates of local recurrence in patients with T3 rectal cancer: trans-Tasman Radiation Oncology Group trial 01.04. J Clin Oncol 2012;30(31):3827–33.
[54] 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(4):433–41.
[55] Shafiq J, Delaney G, Barton MB. An evidence-based estimation of local control and survival benefit of radiotherapy for breast cancer. Radiother Oncol 2007;84(1):11–7.
[56] Jacob S, Wong K, Delaney G, Adams P, Barton M. Estimation of an optimal utilisation rate for palliative radiotherapy in newly diagnosed cancer patients. Clin Oncol 2010;22(1):56–64.
[57] Shafiq J, Hanna TP, Vinod SK, Delaney GP, Barton MB. A population-based model of local control and survival benefit of radiotherapy for lung cancer. Clin Oncol (R Coll Radiol) 2016;28(10):627–38.