

Practice patterns of radiation therapy technology in Australia: results of a national audit

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Keywords

Education, image-guided, intensity-modulated, radiotherapy, technology

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Funding Information

No funding information provided.

Received: 11 February 2015; Revised: 25 May 2015; Accepted: 10 July 2015

J Med Radiat Sci xx (2015) xxx–xxx

doi: 10.1002/jmrs.127

Abstract

Introduction: This article presents the results of a single-day census of radiation therapy (RT) treatment and technology use in Australia. The primary aim of the study was to ascertain patterns of RT practice and technology in use across Australia. These data were primarily collated to inform curriculum development of academic programs, thereby ensuring that training is matched to workforce patterns of practice. **Methods:** The study design was a census method with all 59 RT centres in Australia being invited to provide quantitative summary data relating to patient case mix and technology use on a randomly selected but common date. Anonymous and demographic-free data were analysed using descriptive statistics. **Results:** Overall data were provided across all six Australian States by 29 centres of a possible 59, yielding a response rate of 49% and representing a total of 2743 patients. Findings from this study indicate the increasing use of emerging intensity-modulated radiotherapy (IMRT), image fusion and image-guided radiation therapy (IGRT) technology in Australian RT planning and delivery phases. IMRT in particular was used for 37% of patients, indicating a high uptake of the technology in Australia when compared to other published data. The results also highlight the resource-intensive nature of benign tumour radiotherapy. **Conclusions:** In the absence of routine national data collection, the single-day census method offers a relatively convenient means of measuring and tracking RT resource utilisation. Wider use of this tool has the potential to not only track trends in technology implementation but also inform evidence-based guidelines for referral and resource planning.

Introduction

Regular audits in the literature attempt to track trends in availability of radiation therapy (RT) technology such as intensity-modulated radiotherapy (IMRT)¹ from a range of countries.^{2–4} There is a big difference, however, between the availability of resources and actual usage with the resource-hungry nature of commissioning⁵ in particular affecting implementation and usage of the available technology and equipment.⁶ Mayles' 2010 UK

study⁷ remains one of the few to investigate the link between availability and use of technology and determined that lack of personnel and funding was a common inhibitory factor rather than availability of technology. In the absence of formal national data collection procedures such as the UK RT dataset,⁸ there is a lack of data describing Australian RT patterns. This national study was built on the findings of a 2012 state-wide audit⁹ of practice in Queensland that used a fast and simple method to collect data concerning RT

indications and routine technology usage. The primary aim of the study was to ascertain patterns of RT practice and technology in use across Australia. These data would then be used to inform curriculum development of academic programs, thereby ensuring that training is matched to workforce patterns of practice. The secondary aim of the study was to compare the findings with those of the previous audit and additional published data to determine trends in practice.

Methods

The study design was a census method as previously validated.⁹ All 59 Australian RT centres in operation at the time of the study were invited to provide quantitative summary data relating to patient case mix and technology use on a randomly selected but common date (Thursday 5th December 2013). Anonymous demographic-free data were harvested using a Microsoft Excel[®] spreadsheet proforma adapted and validated from the previous study⁹ and was analysed using descriptive statistics. Modifications to the original format included separate consideration of left and right breast, radical and palliative classification and slightly amended tumour categories as informed by the previous iteration.

Clinical centres were approached by local clinical and academic RT educators who sought permission of centre managers and data collection was coordinated by State educator representatives. As with the previous study, ethical exemption was provided by the coordinating University Research Ethics Committee due to the anonymous nature of the data collection and the use of already existing datasets.

The results were combined to provide summary data relating to a number of key themes including tumour case mix and usage of IMRT, image fusion and on-treatment imaging modalities. Tumour case mix analysis indicated the relative incidence of the patients on the chosen day along with the range of techniques used. Data relating to technology use were classified into two separate measures. "Indication" data identified the tumour sites that were most likely to use the technology. "Usage" data indicated how the technology use was distributed among different sites. Results from this audit were directly compared to the previous results from the Queensland-wide study and published data to determine trends.

Results

Overall data were provided from centres in all six Australian States by 29 centres of a possible 59, yielding a response rate of 49%. A total of 2743 patients were

treated on the chosen date across these centres and Table 1 presents a summary of the national and state-wide responses. Radical treatments comprised 81.6% of the total workload and over 91% of treatments used megavoltage equipment with only 2.5% of treatments using kilovoltage therapy. A total of 198 patients (7.2%) received electron treatment either standalone or concurrent with megavoltage (Table 1).

Table 2 illustrates the 10 most common tumour sites treated radically as both an absolute number and as a percentage of all radical treatments. The Table also compares this list with results from the previous Queensland-based audit⁹ as well as Barton's 2013¹⁰ summary of the most common sites indicated for radiotherapy nationally in Australia. The most common sites receiving RT were as expected and largely as indicated in the previous study.⁹ RT of the breast, prostate and head and neck together comprised 62% of the total radical fractions as seen in Table 2. The five most common tumour sites according to the adopted categories for this study were breast, prostate, head and neck, skin and breast with nodes (including additional axillary or supraclavicular fields). These were the same as the previous study,⁹ with mostly similar incidence rates. The exception was breast which comprised almost 33% of radical treatments in this iteration but only 18.4% in the previous.

IMRT-related data are summarised in Table 3 with the left hand section showing data for fixed angle IMRT and the right hand showing data for volumetric-modulated arc therapy (VMAT), including tomotherapy. A total of 1007 (37%) of the treated patients received IMRT and 16% of these received VMAT using dynamic linear accelerator or tomotherapy technology. The "% of IMRT" column shows how IMRT is distributed among the various tumour sites with prostate accounting for over 31% of usage. The "% use per site" values indicate the percentage of each tumour site patients receiving IMRT;

Table 1. Summary of state-wide data.

State	Patients	Radical	MV	E	kV	Images	IMRT	Fusion
NSW	733	612	664	35	40	616	412	163
QLD	854	688	768	98	8	671	221	143
SA	338	286	309	17	2	314	75	52
TAS	71	54	67	5	0	70	11	16
VIC	582	473	539	30	18	556	127	119
WA	165	125	152	13	0	148	164	23
Total	2743	2238	2499	198	68	2268	1010	516

NSW, New South Wales; QLD, Queensland; SA, South Australia; TAS, Tasmania; VIC, Victoria; WA, Western Australia; MV, megavoltage radiotherapy; E, electrons; kV, kilovoltage radiotherapy; IMRT, intensity-modulated radiation therapy.

Table 2. Top 10 indications for radical radiotherapy.

Current study			Barton 2013 ¹⁰		Bridge 2010 ⁹		
Site	<i>n</i>	%	Site	%	Site	<i>n</i>	%
Breast	732	32.72	Prostate	22.15	Breast	258	26.26
Prostate	426	19.04	Breast	21.94	Prostate	209	21.28
Head and neck	233	10.42	Lung	14.28	Head and neck	71	7.23
Skin	179	8.00	Lymphoma	6.42	Lung	62	6.31
Lung	132	5.90	Rectum	5.18	Skin SCC	58	5.90
Brain	92	4.11	Head and neck	4.97	Rectum	38	3.87
Rectum	89	3.98	Melanoma	4.35	Brain	31	3.16
Uterus	36	1.61	Unknown primary	3.11	Oesophagus	21	2.14
Oesophagus	35	1.56	Brain	2.28	Cervix	19	1.93
Bladder	29	1.30	Pancreas	2.07	Lymphoma	19	1.93

it can thus be seen that over 71% of prostate patients receive IMRT. As in the previous study, the most common sites for IMRT (as a proportion of all IMRT treatments) were still prostate, breast and head and neck, although VMAT was not used for breast treatments. It was interesting to note that IMRT was more commonly delivered to the right breast (31%) than the left (23.5%), despite the increased challenge of cardiac toxicity on the left. This is at odds with published data¹¹ which reported more frequent use of IMRT for the left breast. Overall, arc therapies were used for 160 (6%) of all patient cases, with tomotherapy delivering a little under one-third of these. Most tomotherapy treatments were delivered to head and neck cancers with the oropharynx accounting for 41%. VMAT delivered the remaining arc therapy treatments, with 62% of being used for prostate, and 17% for head and neck. Intensity modulation was used in preference to other RT modalities for prostate and head and neck, with IMRT or VMAT used in 71% and 65% of these sites respectively.

Data in Table 4 relate to usage of magnetic resonance imaging (MRI) and computed tomography (CT) fusion,

where it can be seen that prostate and brain tumours made by far the most demands on the modality. Overall 9.8% of patients had their RT planned using this form of imaging. The left hand section presents the percentage of total MRI fusions for each tumour site while the right hand columns show the percentage of tumour site patients receiving MRI fusion. It can be seen that over 68% of benign tumours benefited from MRI fusion; significantly more than any other tumour site.

Table 5 illustrates the main indications for positron emission tomography (PET)-CT fusion with lung and head and neck comprising over 50% of the indications. The data from this study suggested that 9% of patients were planned with PET-CT. As indicated in Table 5, cancers of the lung, head and neck, oesophagus and rectum were the most common sites for this form of image fusion, with over 30% of lung cancer patients benefitting from the technology.

Data were also gathered to highlight usage of kilovoltage and megavoltage portal imaging as well as cone-beam CT modalities. Planar imaging modalities are the most common modalities, comprising over 80% of

Table 3. Top 10 intensity-modulated radiotherapy (IMRT) indications and usage.

All IMRT				Arc IMRT		
Site	<i>n</i>	Percentage of IMRT	Percentage use per site	Site	<i>n</i>	Percentage of IMRT
Prostate	313	31.08	71.30	Prostate	74	7.35
Breast	201	19.96	27.16	Head and neck	44	4.37
Head and neck	163	16.19	65.46	Brain	9	0.89
Brain	78	7.75	44.07	Lung	8	0.79
Bone	41	4.07	30.60	Uterus	3	0.30
Skin	41	4.07	20.00	Melanoma	3	0.30
Lung	29	2.88	15.03	Skin	2	0.20
Anus	16	1.59	59.26	Benign tumours	2	0.20
Rectum	16	1.59	15.53	Lymph nodes	2	0.20
Benign Tumours	10	0.99	52.63	Soft-tissue sarcoma	2	0.20

Table 4. Top 10 magnetic resonance imaging (MRI) fusion indications and usage.

MRI fusion indications			MRI fusion usage by site		
Site	<i>n</i>	Percentage of total MRI	Site	<i>n</i>	Percentage of each site
Prostate	107	39.92	Benign tumours	13	68.42
Brain	66	24.62	Brain	66	37.29
Head and neck	23	8.58	Whole CNS	2	33.33
Rectum	18	6.72	Trachea	1	33.33
Benign tumours	13	4.85	Endocrine tumours	1	25.00
Soft-tissue sarcoma	7	2.61	Prostate	107	24.37
Bladder	6	2.24	Soft-tissue sarcoma	7	20.59
Skin SCC	5	1.87	Bladder	6	18.18
Breast	4	1.49	Rectum	18	17.48
Anus	3	1.12	Head and neck	25	12.17

Table 5. Top 10 PET fusion indications and usage.

PET fusion indications			PET fusion usage by site		
Site	<i>n</i>	Percentage of total PET	Site	<i>n</i>	Percentage of each site
Lung	77	31.03	Mesothelioma	2	100.00
Head and neck	62	24.99	Oesophagus	24	45.28
Oesophagus	24	9.67	Ovary	2	40.00
Rectum	18	7.25	Lung	77	39.90
Brain	12	4.84	Anus	10	37.04
Anus	10	4.03	Trachea	1	33.33
Lymph nodes	8	3.22	Head and neck	62	32.29
Lymphoma	8	3.22	Middle ear	1	25.00
Cervix	5	2.02	Lymph nodes	8	23.53
Melanoma	3	1.21	Cervix	5	21.74

instances as seen in Table 6. Overall 99% of patients received imaging; some patients received multiple imaging modalities but the summary data will not permit further analysis. All ultrasound images were related to prostate localisation.

Discussion

Overall the national rate of response to the survey was 49% of centres. Although this was below that reported in previous studies,^{1,9} it does provide a reasonable indication of national practice. Some interesting themes were extracted from the data and further discussion and comparison with published findings follows.

Table 6. Relative usage of imaging modalities.

Modality	Percentage of all patients	Percentage of images
Megavoltage planar	36.2	41.61
Megavoltage CT	4.2	4.81
Kilovoltage planar	34.3	39.39
Kilovoltage CT	12	13.69
Ultrasound	0.4	0.5

Indications for RT

The 2012 study reported slightly higher rates of electron therapy (10.7%) and lower rates of kilovoltage therapy (0.5%). Interestingly, the Queensland-only data for this study reported a 0.9% kilovoltage rate, suggesting a reduction in this iteration compared to the previous Queensland-based study. In 2010, the five most commonly diagnosed cancers in Australia were prostate (19,821 cases), bowel (14,860), breast (14,308), melanoma (11,405) and lung (10,296).¹² These figures map consistently with the data from this study as prostate and breast cancer are commonly treated with RT, although it must be acknowledged that some of the most common cancers are not demonstrated. An Australian review of optimal RT utilisation rates based on evidence-based treatment guidelines was published in March 2013.¹⁰ This suggested that in Australia, RT (alone or with chemotherapy or brachytherapy) is the treatment of choice for 48.3% of notifiable cancers. Table 2 illustrates the new indicated RT utilisation rate for the 10 most common site-specific cancers and the national proportion of new cases of cancer with an indication for radiotherapy, which compares well to our data. This study's data are therefore well validated with the published findings in terms of the incidence of site-specific cancers and those treated in the highest 10 categories.

Patterns of IMRT use

There was considerable variability between States in terms of IMRT use ranging from over 99% of patients in Western Australia to 15.5% in Tasmania. These extreme figures, however, are only drawn from single-centre data so should be interpreted with caution. Most States used IMRT for between 21% and 26% of patients with New South Wales (NSW) treating over half of all patients with IMRT. It would be interesting to determine factors affecting this variation but the need for individual centre anonymity precluded this for this study. The previous iteration of this study reported a 19.6% use of IMRT.⁹

When compared to the current results for the national (37%) and Queensland data (25.9%) it is clear that IMRT use in Australia is increasing in prevalence. A comparison with published data also confirms this trend in other countries.^{3,11,13} It was noteworthy that of the 19 patients treated for benign conditions 10 received resource-intensive IMRT. It is likely that this result was influenced by benign pituitary and meningioma treatments. It is clear that IMRT usage in Australia is relatively high when compared to published data and is steadily increasing. Jacobs¹⁴ raises the interesting issue of increasing IMRT incidence linked to Medicare funding, although anecdotal evidence suggests that the cost-workload balance in Australia makes it less likely to be a factor.

This strong utilisation of arc therapy technologies for prostate and head and neck tumours is supported by the literature and associated with improved outcomes for these patients.¹⁵ While arc therapy was not delivered to any of the six paediatric cases treated, half the cases were treated with IMRT despite the decreased monitor unit and treatment times offered by VMAT. This may be due to concerns around dose baths and thereby potential increased risk of secondary malignancies and growth defects. It is also important to note that funding and reimbursement challenges within the private sector may have influenced VMAT implementation.

Patterns of image fusion use

The superior soft-tissue visualisation offered by MRI-CT fusion significantly enhances localisation of intracranial, head and neck¹⁶ and prostate tumours.¹⁷ This study's data indicated an overall increase in MRI-CT fusion use when compared to the previous study's 6.9%.⁹ The MRI data from this study again highlighted the resource-intensive nature of benign tumours with 13 of the 19 patient datasets using the technique. Over the past decade, use of PET and CT image fusion (PET-CT) has improved precision of tumour volume delineation. In particular, this allows for a reduction in margins and sparing of normal tissue with potential-dose escalation for certain tumours. The literature suggests that PET-CT image fusion is of particular use in delineating lung cancers.¹⁸ The results from this study demonstrate high uptake of PET-CT fusion for lung patients and correlates well with existing literature.¹⁹ Interestingly, when compared to data from the previous study,⁹ where PET-CT fusion was used in 11.3% of patients, it can be seen that there was an overall decrease in its use. This may be influenced by different State practices but the corresponding increase in the use of MRI-CT fusion may go some way to explaining this.

State-wide variations indicated a slightly lower uptake of MRI fusion for Queensland and Victoria and a

comparatively low uptake of PET fusion for South Australia and Western Australian despite average numbers of indicated patients being treated. To some extent, this may be influenced by cyclotron availability with facilities in place in Victoria, NSW, Western Australia and Queensland. The evidence base¹⁹ also continues to establish new roles and developing technology for PET. It will be interesting to see if future iterations of this study reveal how this evidence affects PET fusion data and whether image fusion becomes an established method of monitoring tumour regression during RT.

Image-guided radiotherapy

The data demonstrated increasing use of kV cone-beam equipment with 12% of patients nationally receiving a cone beam computed tomography (CBCT) image compared to 8.5% last time; this is consistent with the published data.²⁰

When comparing the uptake in Queensland directly between the two studies, there was a modest increase from 11.2% to 12% suggesting the findings may be skewed slightly by increased usage in other States. Although too small to be significant with this method, any increase may reflect the reticence to add to the dose burden when compared to kV planar imaging. IGRT for head and neck cancer was well established across Queensland in 2012 and this is repeated again Examination of Table 1 reveals that NSW used CBCT for 17.3% of patients; most other States were on a par at between 9% and 12%. Of the 321 CBCT images taken on the census date 36% were prostate patients, 16% head and neck and 13% lung. It will be interesting to see how increasing use of adaptive RT protocols influence use of CBCT in future iterations.

Fiducial markers were utilised in 53% of prostate patients despite recommendations for their use in the evidence base.²¹ With CBCT being indicated for patients without fiducial markers with only 36% of prostate patients receiving CBCT, it is unclear how some patients' motion was accounted for. Further study in this area would be of value.

There were some clear trends in how different modalities were used. Most planar MV images were used for verification of the breast, with bone, brain and lung treatments also ahead of the image-reliant sites such as the prostate and head and neck. The benefits of soft-tissue definition associated with kV imaging are obviously not as clear for these tumour sites. It was interesting to see that of the 19 benign tumours treated there were 16 imaging incidences reported. It is not known how many of these represented multiple imaging modalities for the same patient, but reinforces the finding of benign tumours being resource intensive.

Limitations of the study

As with the previous study, there are some limitations associated with the method. Although sufficient data existed to determine trends on a national scale, the participation rate was lower than expected. Some centres did not employ a RT educator to collate the data, while others had concerns about data sensitivity. Measures to ameliorate the latter concern were taken but future data collection may be enhanced by provision of a research assistant to those centres struggling with staffing levels. This would also allow random audit of data to check robustness of data collection.

While the design of the study allows useful information to be captured about the range and mix of patients and treatment approaches, it provides limited insight as to why individual centres adopt particular technologies or modalities. A more wide-spread data collection technique such as the National RT Dataset in the UK⁸ would help determine factors influencing local decisions about routine treatment approaches.

Recruitment issues aside, the study method also allows for possible limitations with the random date possibly not being representative. Responses could have been influenced by timing in relation to regular clinics, oncologist availability and resource availability. Such random fluctuations are expected to decrease as sample size increases and future wider participation may reveal the extent of this.

By far, the greatest limitation of the study relates to data entry error with a large number of individuals responsible for transcribing large quantities of data on top of a busy workload. Reported single-entry errors are in the region of 36 per 10,000 entries²²; this can potentially be reduced by using double data entry. Transcription errors in this study were further compounded by possible misinterpretation of guidelines. Although guidelines were developed and validated in a previous study, there was a definite discrepancy with interpretation of imaging frequency reporting. These data were discarded during the analysis phase and future iterations will need more specific guidance.

As with the previous study, the proforma utilised a simplified system of data classification for ease of interpretation, speed of entry and reporting purposes. While this is valuable for broad trend spotting, there is a loss of accuracy with tumour pathologies and stages and inability to perform correlation analysis for individual patients.

Implications of the study

The results of the study in general confirm the validity of the research method when compared with those from the

previous study. The method is a relatively convenient and powerful means of monitoring radiotherapy treatment and technology uptake trends. The overall trend demonstrated by the two studies is that of increasing use of technology in RT; in particular there is increasing use of imaging technology as part of the standard workload in line with recommendations for IGRT use from the USA²³ and the UK.²⁴ From an educational perspective these findings support increased emphasis on IGRT at both pre- and post-registration provision.

The authors are particularly interested in using the data to inform curriculum development of academic programs in Australia and to ensure training is matched to current workforce patterns of practice.²⁵ With the implementation of new technologies in radiotherapy comes the challenge to keep up to date with teaching content. What is common practice in one State may not be reflective of national trends and best practice. A regular audit such as this study provides a broader national perspective of practice and techniques. The results allow mapping of content to reflect current practice and respond to trends in new techniques for future review. Examples from this are the broad increased use of IGRT nationally and the specific increase in IMRT for prostate cases in particular; these results have led to earlier and more intensive teaching in IMRT. In considering the future formation of a national competency development framework for RT students, the results of this audit form a valuable component.

An interesting finding from this data analysis has been the apparent resource-intensive nature of benign tumour radiotherapy. For a traditionally small component of the radiotherapy workload, there is a high uptake of IMRT, fusion and IGRT; some of these technologies contribute an increased dose to these patients. It may be cogent to further examine the extent to which benign tumours utilise resources compared with malignancies.

Another point to consider is whether differences in uptake of technology between States are indicative of different policy implementation and resource availability or a by-product of the random audit method used. There has been much discussion related to the post-code lottery of cancer treatment^{26,27} with variability between and across different countries; these data could suggest that this also applies to more wide-spread differences. Certainly within Australia, newer technology is established in some States more than others with both geographical and political factors impacting on their availability.

Conclusions

Findings from this study indicate the increasing use of emerging IMRT, image fusion and IGRT technology in Australian RT planning and delivery phases. This must be

reflected in national RT curriculum development with increased provision of theoretical teaching and practical experience with these technologies. The results also highlight the resource-intensive nature of planning and treating benign tumours; frequently requiring additional radiation dose. The single-day census method offers a relatively convenient means of measuring and tracking RT resources. In the absence of more formal national data collection procedures, wider use of this tool has the potential to not only track trends in technology implementation but also inform evidence-based guidelines for referral and resource planning.^{27,28}

Acknowledgments

The authors wish to acknowledge the enthusiasm and hard work of the clinical educators who collected the data and the kind cooperation of the managers and data custodians who facilitated the data availability.

Conflict of Interest

The authors declare no conflict of interest.

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Graphical Abstract

The contents of this page will be used as part of the graphical abstract of html only. It will not be published as part of main.

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WA	165	125	152	13	0	148	164	23
Total	2743	2238	2499	198	68	2268	1010	516

NSW, New South Wales; QLD, Queensland; SA, South Australia; TAS, Tasmania; VIC, Victoria; WA, Western Australia; MV, megavoltage radiotherapy; E, electrons; kV, kilovoltage radiotherapy; IMRT, intensity-modulated radiation therapy.

This article presents the results of a national snapshot survey of radiation therapy practice in Australia. Results include prevalence of treated tumour sites and use of a range of technology.