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What will be the radiotherapy machine capacity required for optimal delivery of radiotherapy in Scotland in 2015? ☆

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ABSTRACT

Aims: Lack of radiotherapy capacity has been cited as a reason for poor cancer outcomes reported in the United Kingdom. This modelling study was conducted to ensure sufficient capacity in the future and to aid health service planning.
Methods: The predicted changes in the incidence of each cancer type to 2015 were calculated using the age–period–cohort technique. To develop the model the indications for radiotherapy now and in 2015 were established, as were the fractionation schedules for each clinical scenario. The optimal radiotherapy utilisation rates and required radiotherapy capacity were estimated for 2005 and for 2015.
Results: Cancer incidence is expected to rise by 18.9% by 2015. In Scotland, the estimated optimal radiotherapy utilisation rate during initial management is 44.2–47.9%. The model suggested that currently for optimal delivery, the capacity for 195,300–256,300 fractions is required. Due to predicted changes in the patient population, it is anticipated that requirements will increase to between 276,400 and 354,200 fractions per annum by 2015. Based on the current working practices, this is a 20–54% increase in current capacity, or from 5 to 6–7.6 machines per million head of population.
Conclusions: In order to meet the current and projected demand, a marked increase in the provision of radiotherapy machine capacity will be required in Scotland by 2015.

1. Introduction

Unless there is a major unheralded discovery in cancer therapeutics, radiotherapy will remain a core component of cancer treatment. Therefore, to ensure that patients have optimal and equitable access to radiotherapy, there must be sufficient radiotherapy treatment machine (LinAc) capacity.

In the United Kingdom, some cancer patients have inferior survival compared with those of other European countries.[1] Potential explanations for this have included the lack of radiotherapy equipment and inadequate numbers of trained staff. Indeed, a 1998 survey revealed that the UK had 3.4 radiotherapy machines per million head of population in the UK, compared with 4.6 per million in Germany.[2] The estimate of the required number of LinAcs per million people has

☆ For further information readers should also consult the Scottish Executive Healthcare Department website – (www.scotland.gov.uk/Publications/2006).

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been shown to vary substantially by country. The average for 25 European countries was 5.9 per million people.[3]

In response to this, in the early part of this decade, there was a renewed drive to increase the provision of radiotherapy equipment in the UK. By December 2005 the number of LinAcs had increased to 4.2 per million population in England and Wales and will be 5 per million population in Scotland by the end of 2007.

Sufficient machine capacity is important to ensure that all patients receive optimal treatment and also to avoid waiting times. Despite the service reorganisation and the recent investment in radiotherapy equipment, waiting times have not shown sustained improvement.[2,4] Reasons for this are complex, but include the increased incidence of cancer, greater proportions of patients requiring radiotherapy, longer treatment courses and more complex radiotherapy plans, all of which affect machine capacity requirements.

The following study was undertaken by the Radiotherapy Activity Planning Group of the Scottish Executive Health Department to aid health-care planning by predicting the LinAc capacity required for Scotland for the period 2011–2015. It represents one of the first initiatives in Scotland to plan radiotherapy services over the long-term to ensure that there will be sufficient radiotherapy capacity to meet projected future demand.

2. Methods and materials

The aims of this project were to

(1) Calculate the actual radiotherapy provision in 2003.
(2) Estimate the optimal radiotherapy utilisation rate in 2005, based on evidence-based guidelines.
(3) Estimate the potential change in the incidence of cancer in Scotland over the next decade.
(4) Estimate the potential radiotherapy capacity required by 2015.

2.1. Actual radiotherapy utilisation 2003

To examine the actual radiotherapy utilisation, the five Scottish cancer centres were asked to supply data on all treatments delivered in 2003, including details of the primary tumour site, indication for radiotherapy and fractionation schedule used.

2.2. Optimal radiotherapy utilisation in 2005

To accurately quantify the optimal radiotherapy utilisation for Scotland, a Scottish model was developed. Several systematic reviews have been conducted to establish the clinical indications for radiotherapy.[5–8] The Australian model, which was completed in 2003 by the Collaboration for Cancer Research and Evaluation, provides a recent, comprehensive and wide ranging review based on tumour type. This model was used as the basis for the Scottish model.

2.2.1. Indications for radiotherapy

For the Scottish model, an indication for radiotherapy was defined as ‘a clinical situation when a patient diagnosed with cancer first requires radiotherapy’. As subsequent treatments are usually palliative with short fractionation schedules, these were not included in the model.

The indications for radiotherapy in the Scottish Intercollegiate Guidelines (SIGN) evidence based reviews for the management of cancer[9] were compared with the recommendations in the Australian model. In some instances the recommended treatments differed, but in order to make the models relevant to Scotland the SIGN indications were used.

2.2.2. Epidemiological data

In order to construct the Scottish model local data were used, if possible from Scottish national audits, but if not available from regional audits.[10–14] When no specific Scottish data could be identified, the figures were not altered from the Australian model.

The proportion of patients in Scotland with each indication for radiotherapy was entered into a commercial software programme called TreeAge®. An example of the flow chart produced by the software for breast cancer is given in Fig. 1. Each branch of the tree signifies an attribute that affects a management decision (e.g. post-operative radiotherapy following a lumpectomy for early breast cancer). Above each branch is a description of the specific attribute that has led to that decision. Each number below the branch signifies the proportions of the attribute based on epidemiological data. Each terminal branch represents either ‘requirement for radiotherapy’ or ‘no requirement for radiotherapy’ as the clinical management decision.

The data were then combined to calculate the optimal radiotherapy utilisation for each tumour type and all cancers combined.

In order to calculate the current machine capacity requirement, the Scottish Site Specialist Clinical Oncologists were asked their current fractionation scheme for each clinical scenario. A range of responses were obtained, which reflects different management approaches. An example for breast cancer is shown in Table 1.

2.3. Potential change in cancer incidence over the next decade

The data and methodology for the cancer incidence projections for Scotland have been published in detail elsewhere.[15] In summary, data from the Scottish Cancer Registry and General Registrar of Scotland annual population estimates were used to examine historical cancer incidence trends in the period 1961–2000 (excluding non-melanoma skin cancer). Generalised linear models (the so-called age–period–cohort models)[16] were fitted to the historical data for the major diagnostic groups, and the parameter estimates were applied to population projections for Scotland[17] to predict the number of incident cases in 2015. Different parameterisations of the period and cohort effects were considered and it was assumed that age effects would remain constant in the future.

The 19 most common malignancies were considered separately (90% of all malignancies) and the remainder combined into a category labelled ‘other and unspecified’.

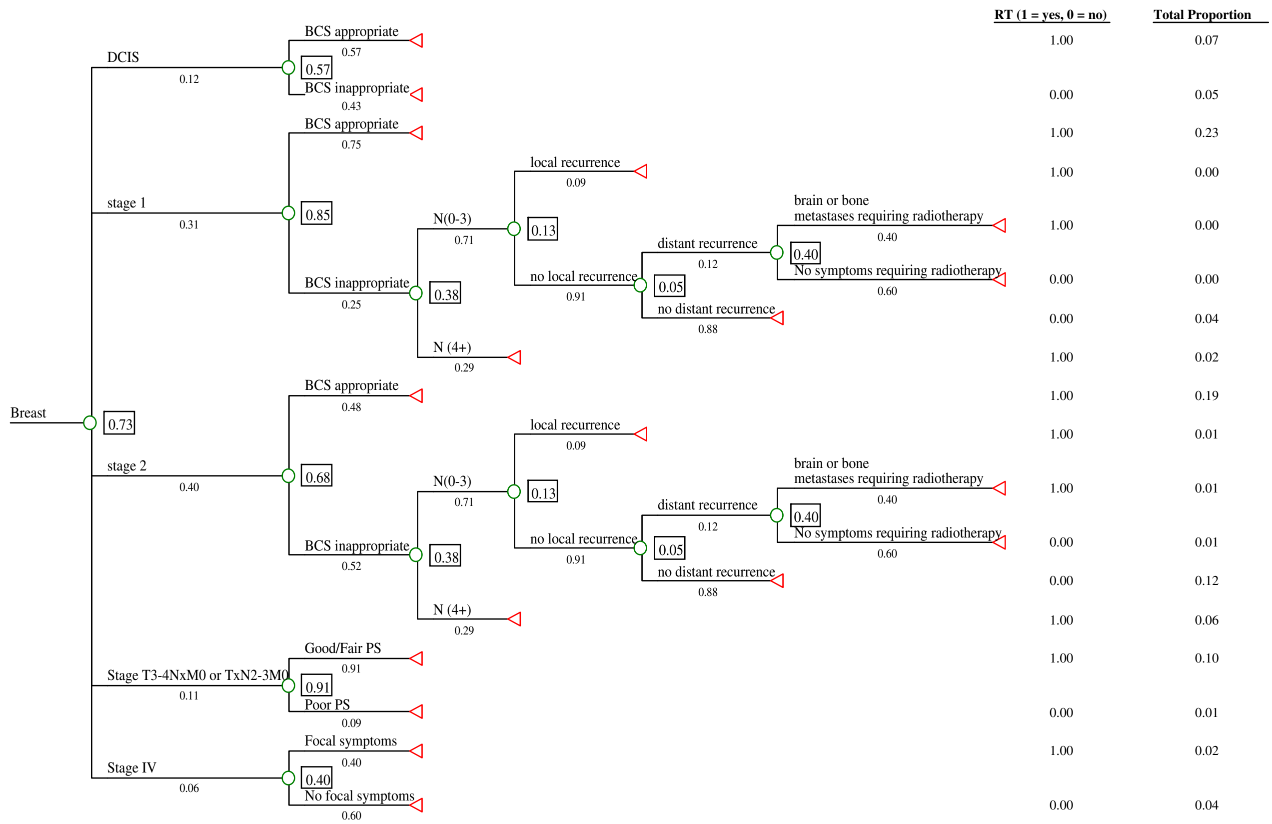

Fig. 1 – Treeage® diagram showing optimal radiotherapy utilisation for breast cancer. Each branch represents a clinical scenario and the numbers represent the proportion of patients with that radiotherapy indication.

Table 1 – Model for the number of fractions required to treat breast cancer

Indication	Number 1996–2000	Current fractionation	Fractions required in 2004	Predicted numbers in 2015 (+23%)	Fractionation in 2015	Fractions required in 2015
DCIS and WLE	243	20–25	4860–6075	300	20–25	6000–7500
Stage 1 and WLE	826	20–27	16,520–22,302	1019	5–25[a]	5095–25,475
Stage I and mastectomy and ⩾4 nodes	80	20	1600	99	20	1980
Stage II and WLE	682	20–27	13,640–18,414	842	15–25	12,630–21,050
Stage II and mastectomy and ⩾4 nodes	214	20	4280	264	20	5280
Stage T3-4NxM0 or TxN2-3M0 Good PFS	356	20	7120	439	20	8780
Stage IV focal symptoms	85	5	425	105	5	525
Total	2486 (70.0%)		48,445–60,216	3068		40,290–70590

DCIS = *in situ* carcinoma, WLE = wide local excision.
a Intra-operative radiotherapy, which is at the early stages of clinical evaluation, may potentially replace external beam radiotherapy for these patients.

2.4. *Potential radiotherapy requirements by 2015*

The factors that will affect the LinAc capacity required in 2015 are: (i) the indications for radiotherapy, (ii) the fractionation schedule and (iii) incidence of each cancer type. Predicting future indications and fraction schedules for radiotherapy is difficult. Future regimens will probably be dependant on the results from current clinical trials which will be published around 2010–2015. Consequently, the Site-Specialist Clinical Oncologists were asked to predict from their knowledge of on-going clinical trials, what changes may occur. Over recent years there has been a trend to more prolonged fractionation regimes for curative treatments. For example, in the treatment of head and neck cancer, trials demonstrating improved outcome from concurrent chemo-radiation have led to an increase in fractions per course from 20 to 34.

These predicted fractionation schedules were then combined with the estimated number of patients with each cancer type, to calculate the number of radiotherapy fractions required in the future.

3. Results

3.1. *Actual radiotherapy utilisation in 2003*

Data from the five Scottish radiotherapy departments demonstrated that in 2003, the 19 LinAcs were used to deliver a total of 175,954 fractions of radiotherapy (Table 2). This equates to an average of 9260 fractions per LinAc per annum, or 40 fractions per day. The total LinAc time available was approximately 138 hours per week.[18] The average hours worked per day was 7.3 with the two large centres in Glasgow and Edinburgh treating 5.0 and 5.7 patients per hour, respectively.

Detailed audit data were available on 163,442 of the fractions delivered to 11,932 patients. This approximates to 46% of newly diagnosed cases in Scotland in 2003. However, this figure over-estimates the percentage of newly diagnosed patients receiving radiotherapy, as it includes some patients who will have received treatment more than once during 2003 and others who had been diagnosed in previous years.

3.2. *Optimal radiotherapy utilisation in 2005*

The optimal radiotherapy utilisation rate for Scotland, during the initial management, was calculated to be between 44.2% and 47.9% of patients. The optimal radiotherapy use ranged from 4% of patients with leukaemia to 79% for patients with head and neck cancers (see Table 3). Therefore, for the current

Table 2 – Fractions of radiotherapy delivered in 2003

Scottish Cancer Centre	Number of LinAcs (2003)	Total fractions (actual)	Hours worked per week[a]	Days worked per year	Average number of fractions per hour
Aberdeen	2	21,507	13.6	236	6.7
Dundee	2	15,402	15	236	4.4
Edinburgh	5	41,506	31	236	5.7
Glasgow	9	88,263	71.5	244	5
Inverness	1	9276	7	236	5.6
All Scotland	19	175,954			

a RCR document table 19.

Table 3 – Radiotherapy indications and estimated patient numbers for Scotland in 2011–2015

Cancer type	% Predicted change from 2005 to 2015	Predicted average annual incidence 2011–2015	Optimal XRT indication during initial phase (%)	Estimated number of XRT patients 2011–2015
Head and neck	24.9	1249	78.6	982
Oesophagus	44.1	1126	53.9	607
Colon	29.0	2939	1.0	29
Rectum	29.0	1528	27.8–88.7[a]	425–1355
Lung	−9.6	4224	62.8	2653
Melanoma	51.8	1005	15.7	158
Breast	23.4	4380	70.0	3066
Cervix	−32.7	234	56.1	131
Corpus Uteri	23.0	542	46.3	251
Prostate	35.0	2716	61.4	1668
Testis	26.8	245	46.0	113
Bladder,	22.0	1839	28.2	520
CNS	15.4	413	60.7–81.9[b]	257–338
Hodgkin’s disease	6.8	134	71.4	96
Non-Hodgkin’s lymphoma	50.4	1250	54.4	680
Stomach	−18.5	786	13.4	105
Pancreas	20.2	761	41.9	319
Ovary	26.4	803	4.0	32
Leukaemia	32.0	791	4.0	32
Kidney	50.8	822	24.0	197
Myeloma	16.9	360	33.1	119
Other and unspecified	16.9	3290	44.2–47.9	1436–1558
Total		31,437	44.2–47.9	13,895–15,027

a Variation due to possible use of pre-operative RT in all or only selected patients.
b Variation depends if all patients have undergone an operation are fit for radiotherapy or only a proportion.

incidence of around 26,000 cases per annum, between 11,492 and 12,454 patients require radiotherapy as part of their initial therapy.

3.3. Potential change in cancer incidence over the next decade

By using the methodology described,[14,15] it is predicted that there will be around 31,500 new cancer cases diagnosed in Scotland per annum in 2011–2015. This represents about 6000 cases more than the latest published Scottish statistics for 2003. The overall predicted increase in cancer incidence from 1996–2000 to 2011–2015 is 18.9%.

The incidence of all cancers is expected to rise, with the exception of stomach, lung and cervix, which are predicted to decline. Marked increases are expected for some cancers, most notably oesophagus, prostate, colorectal, non-Hodgkin's lymphoma (NHL) and melanoma (see Table 3).

3.4. Potential radiotherapy requirements

3.4.1. Current optimal radiotherapy capacity

When the recommended fractionation schedules were applied to each treatment scenario (see Table 1 for breast cancer model), the model suggested that for optimal treatment a total of between 195,283 and 256,321 fractions should be delivered per annum (see Table 4). An additional 4% capacity was added for re-treatments and 0.5% for benign diseases based on the 2003 audit data. The Royal College of Radiologists have recently published fractionation schedules by tumour type,[19] which are comparable with the fractionation regimens used in this model.

However, radiotherapy is a fast evolving speciality, so additional machine time is required for development work. In addition, it is recommended that capacity should exceed average demand to ensure that fluctuations do not lead to the development of waiting times.[20] Therefore, an additional 10% capacity was added to the estimates above. Consequently, optimal current capacity is between 216,981 and 284,801 fractions per annum.

3.4.2. Optimal radiotherapy capacity in 2015

In the opinion of the Site-Specialist Clinical Oncologists, there were very few current uses for radiotherapy that would no longer be indicated in 2010–2015. The major clinical development that might reduce the use of LinAc based radiotherapy is intra-operative radiotherapy for early stage breast cancer, but the clinical trials into this technique are at a very early

Table 4 – Fractionation requirements for optimal treatment now and in 2011–2015

	Current fractionation for radical treatments	Current total fractions required[a]	Future fractionation for radical treatments	Future total fractions required
Head and neck	34	26724	35	34370
Oesophagus	20–25	7400–9505	20–25	10670–13705
Colon	20–25[b]	35–4850	25[b]	43–6245
Rectum	25	6620–7720	25	8991–9931
Lung	20–36	27247–39261	24–39	34698–41382
Melanoma	20[b]	2035	25[b]	3850
Breast	20–27[b]	48445–60,216	5–25[b]	40290–70,590
Cervix	20–25	3810–4740	25	3185
Corpus Uteri	20–25	3830–4740	25[b]	5810–5825
Prostate	20–41	14516–29195	32–41	30930–39426
Testis	15[b]	1350	0–15[b]	0–1830
Bladder,	20–25	7183–9135	25–30	10950–12970
CNS	28–32	5272–6818	28–32	6090–8010
Hodgkin's disease	15–20	1350–1800	15	1440
Non-Hodgkin's lymphoma	15–20	6780–9040	10–20	9090–12555
Stomach	25[b]	195–4260	25	160–2805
Pancreas	25	6150	25	7390
Ovary	–	125	–	160
Leukaemia	10	240	10	320
Kidney	–	212–1310	–	1060
Myeloma	–	500	–	595
Other and Unspecified[c]	22	16,855–18198	36	29962–30396
Deferred treatment[d]	–	7475	–	9522
Benign conditions[e]	15	934	15	1190
Total		195,283–256,321		248,766–318,752

a Includes radical, post-operative and palliative fractions.
b Post-operative radiotherapy for incomplete resection.
c Represent 10.5% of cancers, assuming 44.2–47.9% use of chemotherapy with distribution of 52% of courses having radical intent, 20% local palliative, 28% metastatic with fractions of 22, 7 and 4 respectively, currently and to take into account general trend to more prolonged fractionation, 30, 10 and 6 fractions in 2011–2015.
d Taken as 4% of total fractions using data from NHS Radiotherapy Episodes Statistics.
e Taken as 0.5% of total fractions as seen in the 2003 Scottish audit.

stage. Consequently, the optimal radiotherapy utilisation rate was not altered for 2011–2015.

It was predicted that many treatment schedules will involve increased numbers of fractions, either due to the increased use of chemo-radiation or hyper-fractionated schedules. However, there may be some notable exceptions, for example, in breast cancer; a trial is currently comparing a five fraction and a twenty-five fraction schedule. If the shorter regimen is proven to be equally efficacious, then a significant amount of machine capacity would be made available (around 20,000 fractions per annum).

Taking into consideration the projected number of patients requiring radiotherapy and the predicted treatment schedules, the clinical demand for radiotherapy in Scotland in 2011–2015 was calculated to be between 248,766 and 318,752 fractions (see Table 4). If an additional 10% is added for research and development and to avoid waiting times, then the capacity to deliver between 276,400 and 354,169 fractions per annum will be required by 2010–2015.

4. Scottish service model

4.1. *Current*

In 2003, the Scottish LinAcs worked an average of 7.3 clinical hours a day, treating up to 5.7 patients per hour.[17] Therefore, based on the current standard Scottish working practices, each LinAc can deliver 9200 fractions per annum (5 fractions per hour, 40 h a week with 8 public holidays, 16 service days and 3% down time). By the end of 2007, there will be 25 LinAcs in Scotland with the potential to deliver 230,000 fractions per annum. This is above the lower estimate of 216,981 fractions in the model, but 24% below the upper estimate of 284,801.

4.1.1. *Future*

In order to meet the predicted requirement in 2015 of between 276,400 and 354,169 fractions per annum, there will have to be a 20–54% increase in the capacity above that which is available in 2007.

4.1.2. *Ways of meeting this demand*

If each LinAc is able to deliver 9200 fractions per annum, then between 30 and 38 machines will be required. This equates to 6.0–7.6 LinAcs per million head of population.

However, if working practices are changed and each machine were to work 10 h per day with only three public holidays, then each machine could deliver 11,700 fractions per annum, and therefore only 23–30 machines would be required (4.6–6.0 LinAcs per million). However, it should be noted that whatever working practices are adopted, a proportionate increase in staff numbers will be required to accommodate the increased numbers of fractions that will need to be delivered.

5. Discussion

A number of models exist which can be used to project LinAc requirements for a population.[3] The first of these is a simple approach based on the Royal College of Radiologists recommendations that there should be 5.5 LinAcs per million population by 2011.[21] The projected population of Scotland in 2015 is 4.98 million; therefore, if no new machines are installed, there will be 5.02 LinAcs per million population. In order to achieve 5.5 LinAcs per million, 27.4 LinAcs would be required.

This model is useful for assessing the equity of access to radiotherapy facilities. However, the simplicity of the model gives rise to questions about the robustness of it as a long-term planning aid as differences in cancer incidence, the rate of radiotherapy use, the treatment indicated and the productivity of LinAcs are not taken into account. Indeed, adopting 'LinAcs per million population' as the basis for long-term service planning in Scotland could work inversely since the declining Scottish population will, over time, result in the number of LinAcs per million population effectively increasing without the addition of any more equipment. However, the decline in population is due to fewer younger people and ageing population is one of the main reasons behind the predicted rise in cancer incidence. Therefore 'LinAc per million head of population will under-estimate the number of machines required.

5.1. *Optimal utilisation*

It is widely accepted that radiotherapy will remain an essential component of cancer treatment for many years. Previous radiotherapy planning assumptions were based on the premise that indications for radiotherapy would diminish as the use of other treatment modalities increased, but this has not happened. In reality, the activity has increased at a rate of about 5% per annum.

In Scotland, radiotherapy utilisation rates vary across the country,[22] but are lower than the optimal indications deduced by this study. In 2003, 175,000 fractions were delivered, whereas our model predicted that 195–256,000 fractions should have been delivered in 2005.

The correlation between lower treatment utilisation and poorer cancer survival rates has been highlighted by the EUROCARE studies[1] and in Scotland the variation between current and optimal utilisation appears significant.[22] While the reasons for lower radiotherapy utilisation rates are not clear-cut, some relationship between available equipment capacity, staff resources, service organisation, medical nihilism, patient choice and geography may provide viable explanations. As a baseline, service planning should aim to lessen the potential negative effect of at least equipment capacity and staff resources. Not only will such planning ensure that all patients who could derive benefit from radiotherapy receive it, but will also potentially improve outcomes by reducing waiting times, which are known to have a detrimental effect on outcome for several cancer sites.[23]

The calculated Scottish optimal radiotherapy utilisation rate of between 44.2% and 47.9% during initial management is similar to that predicted in other countries. The Australian model predicted between 51.7% and 53.1% of patients should receive radiotherapy,[6,7] but this figure includes treatment at relapse whereas the Scottish model includes only initial treatment. The reported rates of population-based radiotherapy utilisation around the world vary from 24% to 43%.[24,25] In general, countries with a higher LinAc provision use more radiotherapy.[3,26] Therefore it is important, in order to ensure every patient receives optimal treatment, that there is sufficient capacity.

5.1.1. *Weaknesses of the models*

(1) Scotland has a relatively stable population with little immigration and emigration; therefore, predicting future cancer incidence is more reliable than for many countries where the flux of individuals with different cancer risks makes this type of modelling more difficult. However, even within Scotland's relatively stable population, there are theoretical reasons why the predictions may be fallible and changes may occur in the future, which cannot be identified in the current statistical analyses. These include changes in the exposure of the population to risk factors either in the new time periods or in birth cohorts who were too young to be included in the analyses. Empirical testing of historical data projected to the present day showed that although the overall estimate was very close to the observed number of cancers (1.2% difference), for some of the individual cancer sites the estimates varied by as much as 20% compared to the observed numbers. These were mainly due to changes that could not have been predicted, for example, the large rise in recorded cases of prostate cancer diagnoses due to use of the PSA test on diagnosing asymptomatic cases.

(2) Though a number of national audits for the major cancer sites have been conducted in Scotland, the data on the distribution of stage and performance status within these audits were of variable quality. Therefore, it was not possible to use pan-Scottish figures within the models for all cancer sites. If this information was not available, Scottish regional[14] or Australian data[6,7] had to be used. If epidemiological data from another population is used the model will be weakened. For this reason is it planned to repeat this modelling process every 3–4 years, as improved prospective audit data becomes available from the Scottish Cancer Networks. It is also necessary to repeat the modelling process to identify the impact of new initiatives, such as colorectal screening, which might reduce the number of locally advanced rectal cancers requiring chemo-radiation.

(3) Although the proportion of patients who should receive radiotherapy is a major determinant of the required capacity, so is the fractionation schedule; any significant prolongation of treatment schedules will undermine any calculations. Although the variation in fractionation schedules used in the UK is reducing,[27] there are still wide discrepancies. It is hoped that the site specialist guidelines published recently by the Royal College of Radiologists[19] will reduce this variation.

(4) Clinical trials which are currently recruiting may have a large impact on the future use of external beam radiotherapy. This effect will be most marked for breast cancer, which currently utilises around 40% of machine capacity. At present the most commonly used fractionation schedules in Scotland deliver between 20 and 27 fractions, but there are ongoing studies of 13–15 fractions (START Trial), 5 fractions (FAST Trial) and intra-operative radiotherapy, when no external beam treatment is given.

However with all these caveats, a sizeable increase in LinAc capacity will be required and how to achieve this is a major challenge. Simply installing more machines in the current Cancer Centres is not a practical solution because of the lack of available space, the distribution of the population across Scotland and the availability of staff and support services. A more complex solution will be required. Changes to working practices of the LinAcs and Cancer Centre referral patterns need to be considered. Any new machines should be located to best match caseload and minimise travelling times, but also to ensure staff recruitment and retention. Whatever solution is chosen, workforce planning is imperative to ensure that sufficient therapeutic radiographers, physicists and radiation oncologists are trained to meet this demand.

6. Conclusions

Using this type of modelling optimal treatment capacity now and in the future can be estimated. Although, we have used this technique for radiotherapy it is equally applicable to other cancer treatments, such as surgery or chemotherapy, and indeed the treatment of many other diseases.

The model developed in this study suggests that an increase of between 20% and 54% over the current LinAcs capacity will be required in Scotland by 2011–2015. The upper estimate suggests a requirement of 354,000 fractions per annum and this has been selected for planning purposes to ensure that there is an allowance for unscheduled machine downtime, research and development needs, and that patient waiting times are not built into the system. Further work on how to meet this projected demand is ongoing.

Conflicts of interest statement

There are no conflicts of interest declared by the authors.

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