

Original Article

Radiotherapy Dose Fractionation, Access and Waiting Times in the Countries of the UK in 2005

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ABSTRACT:

Aims: The Royal College of Radiologists has published a review of the evidence base for radiotherapy dose fractionation. We modelled the implications of changes in practice on radiotherapy demand and compared it with current activity, access and waiting times across the countries of the UK.

Materials and methods: We collected data on diagnosis, dose fractionation and waiting times on all patients in the UK starting a course of radiotherapy in the week commencing 26 September 2005. Excluding skin cancer, 2610 patients were prescribed 34 194 fractions.

Results: Radiotherapy access rates were 38% in England, 43% in Scotland and 37% in Wales. These are all lower than the 52% of cancer patients recommended by modelling. To increase access to the recommended level, a 33% increase in activity is required across the UK. For each of 13 cancer diagnoses, we modelled optimum fractionation and compared it with current practice. To deliver the dose fractionation with the best evidence base, a further increase in activity of 37% is required. To take account of both access and optimal fractionation, the two factors should be multiplied ($1.33 \times 1.37 = 1.82$) giving an overall increase of 82% for the UK. This would require 53 741 fractions per million population annually. The exact value depends on the cancer incidence in each country, but should be compared with current activity of 28 040 in England, 39 584 in Scotland and 31 228 in Wales. Limited capacity is reflected in waiting times. The percentage of patients exceeding the maximum recommended wait of 28 days for radical or adjuvant postoperative radiotherapy was 55% in England, 44% in Scotland and 74% in Wales.

Conclusions: To secure adequate access to treatment and optimal dose fractionation, substantial increases in radiotherapy activity of 92% in England, 61% in Scotland and 97% in Wales are required. Achieving this will require a planned programme of investment in staff, training and equipment. Williams, M. V. *et al.* (2007). *Clinical Oncology* ■■■, ■—■

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Key words: Access rates, fractionation, modelling, radiotherapy, waiting times

Introduction

Radiotherapy is a relatively cheap and effective treatment that consumes a low proportion of the total cancer budget, amounting to 5% in Sweden [1]. Nevertheless, radiotherapy services are perceived to be both capital and revenue intensive. Their development has a long planning horizon because even after a purchasing decision has been made it will be at least 2–3 years before installation is complete and an additional machine starts treating patients. The planning horizon for the training of radiographers and other staff is even longer.

Radiotherapy services in the UK are inadequate and the failure of capacity to match demand has been shown by substantial waiting lists. An audit undertaken by the Royal College of Radiologists (RCR) in 2005 showed that across the UK, 53% of patients treated radically and 57% having adjuvant radiotherapy waited longer than the maximum recommendation of 28 days [2].

World-wide, different methods have been used to predict radiotherapy demand. These are summarised in Table 1. In many cases, the results have been used to predict the number of linear accelerators required per million population. The figure is usually derived in a top-down manner by determining the incidence of cancer, estimating the access rate (the percentage of patients receiving radiotherapy as part of their treatment for cancer), and machine productivity [3,4]. The RCR has produced a number of reports over the years and the recommended capacity has shown a progressive increase [5–7]. Other national specialist societies have also produced recommendations for their populations: these show substantial variation, which in part relates to economic status [8,9].

More recently, bottom-up modelling has been used. This was initiated by McKillop and colleagues in Canada [10] and has been further developed by Delaney and Barton in Australia [11,12]. The method requires incidence data on individual cancers, with details of stage and performance status to

Table 1 – Summary of radiotherapy provision models

	RCR [5]	RCR [6]	RCR [7]	DoH [4]	Thomas [3]	Van Daal & Bos [16]	Slotman & Leer [15]	Delaney <i>et al.</i> [12]	Scottish Executive [14]	Bentzen <i>et al.</i> [9]
	1998	2000	2003	2000	2003	1997	2003	2004	2005	2005
Demand										
Cancer incidence/million		4410		4250	5000	4000	4730		Modelled	Crude incidence data
Access		45%		36%	50%	47%	47%	52%	50%	52%
Course/patient	1.4	1.5			1.5	1.25		1.25		1.25
Exposure/course	27.5	35								
Fraction/course		11.6*			15.4		~16		Individualised	Individualised
Specialist work				Factor added	Excluded		Included T1–T4		Included	Included
Fraction per case					11.25					
Demand summary										
Exposure/million		104 186								
Fraction/million					56 250	39 072–57 793†	58 000		56 300–69 500	
Course/million		2976			3653		3621			
Productivity										
Fraction/hour				4.0	4.5				4.5	
Hours/day					8				8	
Day/year					224				236	
Utilisation					90%				90%	
Linac summary										
Exposure/year/machine		19 000								
Fraction/year/machine		6333*			7258	7523–8600	~8000		7646	
Course/year/machine		542			471		500	450		450
Linac/million	4.0	5.5	5.5–6.0	4	7.7	4.5–7.7	7.2		7.4–9.1	6.5

*Converted to fractions using a ratio of 3.0 (see [9]). †Both estimates were too low (see [15]).

trriage patients to an appropriate treatment category. Evidence-based recommendations are then used to define the proportion of patients requiring radiotherapy. This method has been extended in Scotland to define radiotherapy workload in terms of fractions [13,14]: a panel of clinical oncologists was used to determine evidence-based optimal treatment. This then allowed calculation of the number of fractions required by the Scottish population [13,14].

Another approach to modelling the demand for radiotherapy is to use bands incorporating both fractionation and complexity [15]. This work built on previous population-based modelling that described a 'standard and a quality scenario', both of which underestimated the requirement for radiotherapy [16].

The ESTRO-QUARTS publication by Bentzen *et al.* [9] used an approach based on crude cancer incidence and radiotherapy courses rather than fractions. It defined the equipment requirements in terms of linacs per million population. For the UK, 6.5 linacs per million were recommended. With the machines installed in 2003, the country had only 53% of the capacity it required to treat patients [9]. This was on a par with the Czech Republic and Hungary. By contrast, Belgium, France and Sweden had over 90% of the radiotherapy machinery predicted to be required by their populations.

Table 1 compares these studies and takes into account the different currencies used in terms of exposures, fractions and courses. The demand for radiotherapy expressed as fractions per million population per year is estimated to be between 39 000 and 69 000 fractions per year. Reasonable planning assumptions centre around 58 000 fractions per million population per year.

The present work was undertaken to estimate the number of fractions currently delivered to the UK population and the activity that would be required to deliver an evidence-based radiotherapy service. From this, the gap in provision can be determined and this will be important for planning services nationally.

Materials and Methods

The RCR audit of waiting times for radiotherapy, undertaken in 2005, collected data on radiotherapy prescription and dose fractionation [2]. This was a web-based audit of all patients commencing a radiotherapy treatment course in the week beginning Monday 26 September 2005. Data were received from all 57 radiotherapy centres in the UK. Data entry was constrained by pick-lists, as shown in Appendix 1. Data on skin cancer were not included in the analysis of waiting times [2] nor in this study. This was because non-melanoma skin cancer was not included in Delayney's model [11,12]. By excluding data on skin cancer, we also excluded melanoma, but it was expected that the impact would be small.

To obtain an estimate of the validity of using a single week's audit to predict radiotherapy activity over the whole year, data were obtained from a single centre with 7 linacs. Figure 1 shows patients commencing radiotherapy by week of the year. The mean was 71 patients per week and the value for the audit

week (week 39) was 68 new patients. A multiplication factor of 52 was applied to obtain figures for 1 year. Validation was obtained from the Radiotherapy Episode Statistics project. A sample of activity for the financial year 04/05 from 36 English centres allows an estimate for the whole of England of 107 219 patients prescribed 1 503 474 fractions (H. Forbes, pers. comm.). Our data give an estimate (from Table 2) of 110 344 patients prescribed 1 414 192 fractions. These estimates agree within 3% for patients and 6% for fractions.

Our data included patients receiving re-treatment and therefore to obtain an estimate of those being treated for the first time (the access rate), a correction was made. In Australia, it has been estimated that of those receiving treatment, 25% are receiving re-irradiation [12]. A Swedish survey showed that 18% of patients were re-treated [1]. We therefore applied a midpoint correction factor of 21.5% for patients undergoing re-treatment. The number of patients receiving initial radiotherapy could then be calculated and consequently the access rate could be estimated.

Results

Table 2 summarises radiotherapy activity for the four countries in the UK, together with data on population and cancer incidence. The radiotherapy activity over the year was estimated as described above. The numbers of patients receiving initial radiotherapy and the access rates were calculated.

Table 3 shows a detailed breakdown of treatment delivered by primary site and treatment intent. Minimum and maximum evidence-based dose fractionation has been modelled [17]. For each cancer site, treatments were categorised by the treating centre into radical or palliative. The number of cases is given, together with the total number of fractions for that indication; from this the mean number of fractions per case was calculated. In the modelling section, the fractionation schedules (minimum and maximum fractions) for which there was evidence and the grade of recommendation [17] are summarised. For most sites, minimum and maximum evidence-based fractionations have been modelled to show consequent changes, either as an increase or a decrease. The main exceptions to this are indicated in the footnotes and are described in more detail below.

Palliative Radiotherapy

For many sites there is little evidence for optimal fractionation other than expert opinion (grade D recommendation). The minimum has been modelled as five fractions and the maximum as 10 for most sites, but it is recognised that this is an arbitrary decision. The only exceptions are bladder cancer and cerebral tumours. Lung cancer is discussed below.

Head and Neck Cancer

Twenty-fraction radiotherapy regimens have been used for stage I and II laryngeal cancer on the basis of level 2 evidence [18], but not for more advanced malignancies. Current

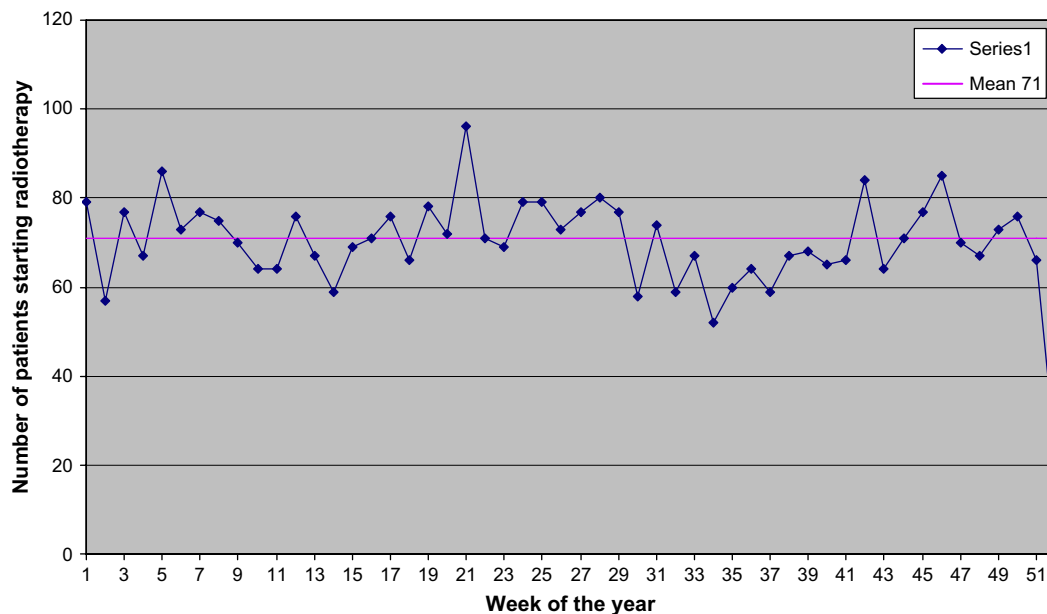


Fig. 1 – New patient starts for 2005 for a 7 linac centre.

practice has therefore been modelled as the minimum fractionation. In addition, there is little information on dose fractionation for local palliative treatment, the management of neck nodes and the management of metastatic disease so that again current practice has been modelled both as minimum and maximum fractionation: consequently there is no change and this is recorded as 'nil'.

Palliative Treatment of Lung Cancer

There is a large number of clinical trials of treatment for different indications [17]. These are summarised for modelling purposes with a minimum of five and a maximum of 10 fractions.

Palliative Treatment of Lymphoma

There is evidence for a range of different regimens in different settings [17] and these have been modelled as falling between five and 10 fractions.

Prostate Cancer

Twenty-fraction regimens are supported only by a grade D recommendation and the correct dose remains uncertain, whereas for more fractionated regimens a grade A recommendation can be made [17]. Therefore, we did not consider it reasonable to model 20 fractions as an acceptable treatment for all cases. For both radical and palliative

Table 2 – Radiotherapy activity in the UK (2005)

	UK	England	Scotland	Wales	Northern Ireland
Demographics					
Population (millions)*	60.217	50.434	5.097	2.964	1.722
Cancer incidence†	275 280	227 065	25 999	15 479	6 737
Incidence/million	4571	4502	5101	5222	3912
Audit results					
Patients irradiated in audit week‡	2610	2122	276	141	53
Fractions given in audit week‡	34 194	27 196	3880	1780	866
Courses/million/year	2254	2188	2816	2474	1600
Fractions/million/year	29 528	28 040	39 584	31 228	26 151
Access rates					
Crude access rates§	49.3	48.6	55.2	47.4	40.9
Corrected access rate	38.7	38.2	43.3	37.2	32.1

*Government Actuary Department mid-2005 population projections. †Cancer Research UK incidence data for 2002 (excluding non-melanoma skin cancer). ‡Skin cancer was excluded. UK total includes 18 patients (472 fractions) not coded by country. §Radiotherapy courses/million/year divided by cancer incidence/million. ||Corrected for re-treatment rate of 21.5% ($\times 0.785$).

Table 3 – Radiotherapy fractionation in the UK (2005) by treatment intent

	Survey data			Minimum fractions				Maximum fractions			
	No. of cases	No. of #s	Mean #	Minimum #	Evidence grade	Modelled minimum #s	% change in #s	Maximum #	Evidence grade	Modelled maximum #s	% change in #s
Bladder											
Radical	23	489	21	20	B	460	-6	32	B	736	51
Palliative	22	99	5	3	A	66	-33	3	A	66	-33
Breast											
Radical	588	10437	18	15	B	8820	-15	25	B	14700	41
Palliative	20	169	8	5	D*	100	-41	10	D	200	18
Breast boost	40	275	7	8	C	320	16	8	C	320	16
Metastases	28	242	9	5	D	140	-42	10	D	280	16
Central nervous system											
Radical	38	1006	26	30	A	1140	13	30	A	1140	13
Palliative	14	107	8	6	B	84	-21	6	B	84	-21
Gastro-oesophageal											
Radical	22	469	21	25	B	550	17	30	D	660	41
Palliative	37	235	6	5	D	185	-21	10	D	370	57
Gynaecological											
Radical	88	1917	22	20	C	1760	-8	28	B	2464	29
Palliative	19	215	11	5	D	95	-56	10	D	190	-12
Metastases	13	102	8	5	D	65	-36	10	D	130	27
Head and neck											
Radical	112	2808	25	20	C	2808	Nil	35	A/B	3920	40
Palliative	19	172	9			172	Nil			172	Nil
Neck nodes	11	183	17			183	Nil			183	Nil
Metastases	7	120	17			120	Nil			120	Nil
Lung											
Radical	79	1618	20	20	C	1580	-2	36	A	2844	76
Palliative	217	1209	6	5	†	1085	-10	10	†	2170	79
Metastases	33	109	3	5	D	165	51	10	D	330	203
Lymphoma											
Radical	63	1075	17	15	B	945	-12	20	B	1260	17
Total body irradiation (TBI)	9	63	7	6	C	54	-14	8	C	72	14
Palliative	30	199	7	5	‡	150	-25	10	‡	300	51
Prostate											
Radical	190	5321	28	20	D§	5321	Nil	38	A	7220	36
Palliative	15	103	7			103	Nil			103	Nil
Metastases	28	83	3	5	D	140	69	10	D	280	237
Rectal (and colon)											
Radical 5#s	11	55	5	5	A	55	0	5	A	55	0
Radical others	62	1491	24	25	A	1550	4	25	A	1550	4
Palliative	17	93	5	5	D	85	-9	10	D	170	83
Metastases	10	81	8	5	D	50	-38	10	D	100	23
Sarcoma											
Radical	14	336	24	30	C	420	25	33	C	462	38
Palliative	12	122	10	10	D	120	-2	15	D	180	48
Unknown primary											
Radical	5	113	23	25	D	125	11	25	D	125	11
Palliative	17	61	4	5	D	85	39	10	D	170	179
Metastases	1	10	10	5	D	5	-50	10	D	10	0
Other											
Radical	24	476	20	25	D	600	26	25	D	600	26
Palliative	21	107	5	5	D	105	-2	10	D	210	96
Metastases	2	10	5	5	D	10	0	10	D	20	100

(continued on next page)

Table 3 (continued)

	Survey data			Minimum fractions			Maximum fractions				
	No. of cases	No. of #s	Mean #	Minimum #	Evidence grade	Modelled minimum #s	% change in #s	Maximum #	Evidence grade	Modelled maximum #s	% change in #s
Total radical	1368	27949	20			26508	-5	27.9		38128	36
Total palliative	460	2891	6			2435	-16			4385	52
Total metastases (by site)	133	940	7			878	-7			1453	55
Bone metastases	512	1507	3	1	A¶	1507	Nil	1	A¶	1507	Nil
Brain metastases	126	832	7	5	A**	832	Nil	10	A	1260	51
Total metastases	771	3279	4			3217	-2			4220	29
Grand total	2599††	34119	13			32160	-6	18.0		46733	37

#, fraction. Nil, current practice has been used to reflect minimum or maximum recommendation in view of a weak evidence base. *Palliative radiotherapy for all sites other than bone and brain metastasis has been modelled as a minimum of five and a maximum of 10 fractions on the basis of a grade D recommendation. †Palliative fractionation for lung cancer has a complex literature depending on the indication — see text for details. ‡Palliative radiotherapy for lymphoma has a complex literature depending on the indications — see text for details. §Radical radiotherapy for prostate cancer using only 20 fractions has a poor evidence base and current practice has therefore been used to reflect the minimum achievable — see text for details. ¶Palliative radiotherapy for sarcoma has a weak evidence base but has been modelled between 10 and 15 fractions — see text for details. ¶Minimum and maximum fractionation for bone metastasis has been modelled as current practice — see text for details. **Brain metastases: minimum has been modelled as current practice — see text for details. ††The total included is lower at 2599 than that in Table 2 (2610) because 11 patients lacked some of the data required for classification.

treatment for prostate cancer, current practice has been modelled as the minimum fractionation.

Palliative Radiotherapy for Sarcoma

This has a weak evidence base and has been modelled with a range between 10 and 15 fractions [17].

Bone Metastasis

There is strong evidence to make a grade A recommendation for the use of single fractions for this indication. This does not extend to re-treatments, postoperative management, the treatment of fractures nor the management of spinal cord compression. Current practice averaging three fractions has therefore been modelled as the minimum achievable, although some reduction might be possible [19].

Brain Metastasis

Current practice is to give an average of seven fractions and there is evidence to support a grade A recommendation for treatment ranging between five and 10 fractions [17]. Current practice has therefore been modelled as the minimum fractionation.

Minimum and Maximum Estimates

At the bottom of Table 3, the overall change in fractionation based on minimum acceptable practice is estimated as a 6% reduction; this is a reduction of 1959 fractions. The largest reduction of 1617 fractions arises from the proposed change to 15 fractions for breast radiotherapy (see below for discussion). By contrast, the maximum fractionation, for which there is stronger evidence in the literature, permitting a higher grade of recommendation for several sites, would entail an increase in fractions of 37%.

Discussion

The aim of this study was to determine the gap in radiotherapy provision in the UK between evidence-based demand and current capacity. Table 2 shows that access rates for the four countries in the UK are substantially below the evidence-based recommendations of 52% derived by Delaney *et al.* [11,12]. They also fall short of the rates achieved in Sweden, where access rose from 32 to 47% in surveys in 1992 and 2001 [1].

Our estimates of under-provision depend critically on the proportion of patients who are attending radiotherapy departments for re-treatment. Evidence from Australia and Sweden is consistent in determining the re-irradiated proportion to be between 18 and 25% [1,12]. We have used a midpoint figure of 21.5%. A subset of the UK Radiotherapy Episode Statistics data identified 51 325 prescriptions from 18 centres where data were available over a 4-year period. Sixteen per cent of prescriptions (9% of fractions) were given to patients who had previously received radiotherapy (H. Forbes, pers. comm.). However, this figure only provides a lower estimate, as it was limited to a maximum of 4 years and excluded retreatment on machines not linked to the same data system in the same or another centre. Using the figure of only 16% re-treatment would result in higher estimates of access of 41% for the UK, 41% for England and 47% for Scotland, but we consider these to be overestimates.

Table 2 also shows that the number of courses per million population per year is lower than recommended by previous authors and that the figure is lower than our estimate from published work of a reasonable planning assumption of 58 000 fractions per million population per year.

Table 3 shows that UK practice is broadly consistent with the minimum fractionation for which some support can be obtained from published studies [17]. The major reduction in

radiotherapy fractionation identified in this model would be a change in practice in the management of breast cancer. Fifteen-fraction treatments now dominate clinical practice in the UK [20] rather than 25 fractions, which are used elsewhere in Europe and in North America. However, there is evidence to support a grade B recommendation for both approaches [17] and recent publications have provided evidence that normal tissue effects and tumour control are equivalent [21,22]. Nevertheless, before recommending a change to 13- or 15-fraction treatments, the results of the START trials are required: these data are expected at the end of 2007.

Figure 2 shows the percentage increase in radiotherapy fractions required to change current practice to provide the maximum fractionation supported by published evidence [17]. The change required is least for rectal cancer, where both pre- and postoperative radiotherapy are given according to evidence-based practice. The largest increase in provision required is for lung cancer at 76% because of the current predominance of 20-fraction regimens [20], which are only supported by a grade C recommendation [17]. Figure 3 shows the percentage change in total radiotherapy fractions required to implement such change for both radical and palliative treatment. These results are influenced by both the size of the change for individual malignancies and by their frequency. The greatest effect is therefore on the management of breast, lung and prostate cancer. Note that breast cancer has been modelled as receiving a maximum of 25 fractions; the evidence for this was discussed above.

Table 3 indicates that a similar grade of recommendation supports the modelled minimum and maximum fractionation for several sites. The main exceptions to this are gynaecological, head and neck, lung and prostate cancer, where higher numbers of fractions are supported by a higher grade of recommendation (A or B). If the model is reworked using minimum fractionation unless the grade of recommendation is higher for more fractionated regimens, then the increased resource required for radical radiotherapy falls to 12.7% and the overall increase required is 8%. If the modelling for breast cancer is changed to 15 fractions, then the overall increase required is 20%, but this is not yet established practice. We argue that this provides a poor basis for planning and agree with Erridge *et al.* [13,14] that the higher estimate should be used to avoid repeating the errors of the past.

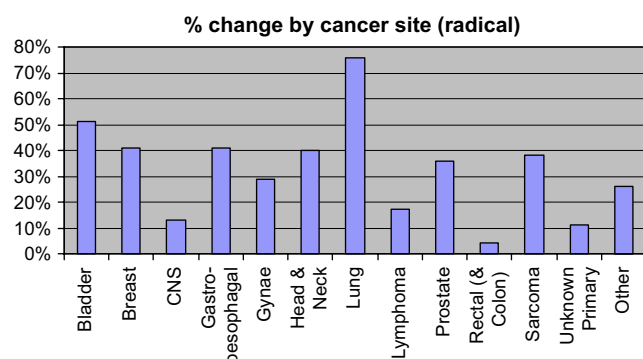


Fig. 2 – Modelling of maximum evidence-based fractionation: percentage change in resource required by cancer site.

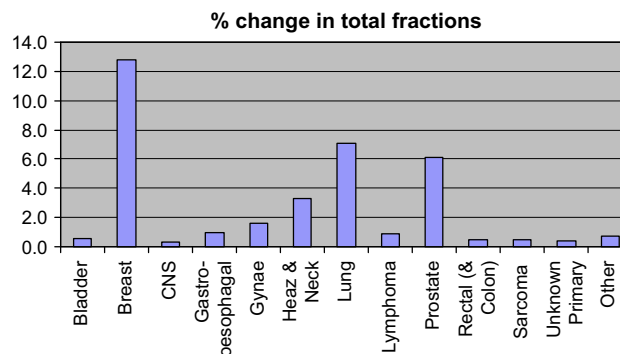


Fig. 3 – Modelling of maximum evidence-based fractionation: contribution required expressed as the percentage change in total fractions.

The Scottish Executive has published a report on radiotherapy activity planning [14]. This models the projected increase in cancer incidence and the resource required to apply best practice in radiotherapy. The fractionation modelling used in the document was closely similar to that recommended in the RCR report [17]: maximum estimates were used as the basis for planning [13,14]. The report focuses on requirements in 2015, but by taking into account the increase in cancer incidence over the intervening period it can be calculated that the current shortfall in activity in Scotland is 60% (data not shown). Our overall estimate for Scotland is an increase of 61% ($1.22 \times 1.32 = 1.61$). This is made up of 22% to increase access from 43 to 52% (Tables 2, 4) and a further increase of 32% to deliver optimal fractionation. A detailed breakdown of the figures for England, Scotland and Wales are given in Appendices 2–4. A similar calculation for England gives an increase of 37% to increase access rates from 38 to 52% (Table 2) and an increase of 40% to provide optimal fractionation (Appendix 2): multiplying these two percentages gives a total increase required for England of 92% ($1.37 \times 1.40 = 1.92$).

These estimates do not take into account the variations in demand that result in the inevitable wastage of some capacity and thus a gap between activity and demand [3,23]. A 10% increase in capacity is required to account for this: if no allowance is made, waiting lists will still build up [3,13,14,23].

Table 4 summarises the results of this study in terms of waiting times, as determined by the percentage of patients waiting longer than 28 days to commence radical or adjuvant radiotherapy treatment [2,24]. Access rates and the increase in resource required to improve access and to provide optimal fractionation are also shown by country. The overall percentage increase in activity required ranges from 97% for Wales to 61% for Scotland. This discrepancy is reflected in the waiting times data. Also shown is the recommended provision in the number of fractions per million per year, which ranges from 54 000 to 64 000, in line with the differences in cancer incidence in each country (Table 2).

The situation in the UK can be compared with radiotherapy activity world-wide. Access rates have been reviewed by

Table 4 – Radiotherapy access, fractionation and wait for treatment (2005)

	UK	England	Scotland	Wales	Northern Ireland
% radical and adjuvant waits >28 days	54	55	44	74	64
Access rate (%)	39	38	43	37	32
% increase required to reach access rate of 52%	33	37	22	42	—
% increase to account for fractionation	37	40	32	39	—
% increase required overall	82	92	61	97	—
Current fractions/million/year	29 528	28 040	39 584	31 228	—
Recommended fractions/million/year	53 741	53 837	63 730	61 519	—

Delaney *et al.* [12] who have shown substantial variation between countries and across different cancer sites. Access was low in the UK based on cancer registry data (Delaney, NYCRIS) and Sweden had the highest access rates at 47% rather than the recommended 52% [1,12]. Data on radiotherapy fractionation have been published from Sweden and practice centres on the use of 2 Gy fractions [1]. In the UK, the distribution of fraction size is bimodal with peaks at 1.8–2.0 Gy and 2.7 Gy, reflecting the use of fewer fractions of larger size [20]. Sweden was one of three countries found to have over 90% of the radiotherapy equipment predicted to be required by its population [9] and access rates rose from 32 to 47% in surveys in 1992 and 2001 [1].

The present results can be compared with the analysis undertaken by Bentzen *et al.* [9] on data collected in 2003. They found that the UK had only 53% of the radiotherapy capacity that their model predicted was required to treat the population. Correcting this deficit would require an increase of 89%. Our work shows that this gap arises in two ways. First, radiotherapy access rates are low in the four countries of the UK (Tables 2, 4). Access rates overall of 39% for the UK (Table 2) fall substantially short of the 52% recommended from the work of Delaney *et al.* [17]. An increase of 33% in activity would be required to address this gap. The other shortfall is in the radiotherapy fractionation offered to patients who actually attend for treatment. Our analysis of minimum fractionation shows that practice is highly constrained in the UK and largely conforms to the most economical regimens for which there is evidence in published studies. An increase in radiotherapy fractionation to the maximum modelled in Table 3, which in general represents practice supported by higher grades of recommendation, would require a further increase in provision of 37%. Combining these two factors by multiplying them together ($1.33 \times 1.37 = 1.82$) gives a total increased requirement for radiotherapy provision of 82%. This is similar to the estimate of 89% by Bentzen *et al.* [9], based on data collected 2 years earlier.

The RCR review of radiotherapy dose fractionation was only able to make 10 grade A recommendations for radical treatment [17] and it is clear that the testing of different radiotherapy regimens has not been a research priority. This is now changing with the FAST trial, which will examine hypo-fractionation in the management of breast cancer, and with the CHIPP trial, which is examining hypo-fractionation in prostate cancer. Establishing a firm research base should be a high priority, but significant investment will be required because timescales for these trials are long.

It is clear from the work reported here that there is substantial radiotherapy under-provision in the UK. Long-term planning could be improved by using the bottom-up methods that have been developed in Canada, Australia and Scotland [10–14]. This approach involves first modelling the projected population growth over a decade and second determining predicted cancer incidence. This is best done using the age/period/cohort method, which gives more reliable estimates than straightforward linear analysis projections. Evidence-based estimates of radiotherapy fractionation are then required to complete the model [13,14,17]. Such work has been commissioned by the English National Cancer Director and the English National Radiotherapy Advisory Group is using it as the basis for modelling of radiotherapy demand and capacity.

Conclusion

Radiotherapy requirements have been persistently underestimated both by modelling (see Table 1) and by professional bodies [5–9]. This is in part because the indications for treatment and cancer incidence have increased faster than expected. Our analysis shows substantial under-provision of radiotherapy services across the UK. Planning to address this issue is well advanced in Scotland and we welcome work in England under the National Radiotherapy Advisory Group to address the funding, workforce, training and equipment issues to remedy this gap. For patients this would mean that all those who could benefit from treatment would access it in a timely way and receive optimum treatment regimens as used elsewhere in the developed world. This would allay patient anxiety and improve outcomes. Increased capacity would also address the problem of interruptions to treatment, which inconveniences patients and, more importantly, can allow tumour progression with worse outcomes.

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Appendix 1

RCR Re-audit of Radiotherapy Waiting Times 2005 Data Collection Proforma			
Centre ID number (as allocated by the RCR)			
Patient ID number:			
Patient diagnosis:			
	Bladder		<input type="checkbox"/>
	Breast		<input type="checkbox"/>
	Central nervous system		<input type="checkbox"/>
	Colorectal		<input type="checkbox"/>
	Gynaecological		<input type="checkbox"/>
	Head and neck		<input type="checkbox"/>
	Lung		<input type="checkbox"/>
	Lymphoma (inc. leukaemia and myeloma)		<input type="checkbox"/>
	Prostate		<input type="checkbox"/>
	Sarcoma		<input type="checkbox"/>
	Skin		<input type="checkbox"/>
	Upper gastrointestinal		<input type="checkbox"/>
	Unknown diagnosis		<input type="checkbox"/>
	Other (inc. renal, germ cell etc.)		<input type="checkbox"/>
Site treated:			
	Abdomen		<input type="checkbox"/>
	Axilla		<input type="checkbox"/>
	Bladder		<input type="checkbox"/>
	Bone		<input type="checkbox"/>
	Brain		<input type="checkbox"/>
	Breast only		<input type="checkbox"/>
	Breast with nodes		<input type="checkbox"/>
	Breast boost		<input type="checkbox"/>
	Chest		<input type="checkbox"/>
	Chest wall		<input type="checkbox"/>
	Chest wall with nodes		<input type="checkbox"/>
	Head and neck (± nodes)		<input type="checkbox"/>
	Limb (inc. sarcoma)		<input type="checkbox"/>
	Pelvis (not bone)		<input type="checkbox"/>
	Prostate		<input type="checkbox"/>
	Skin		<input type="checkbox"/>
	Total body irradiation		<input type="checkbox"/>
	Other (excluding bone metastases)		<input type="checkbox"/>
Prescribed dose:		Please check prescription details, in the last audit there seemed to be some errors, probably due to the wrong field being filled in.	
	_____ Gy		
	_____ #		
	_____ #s per week		
Date of booking request:		Date the booking request form is completed.	
	___/___/___		
Date patient able to start treatment:		If patient not ready to start treatment then the oncologist should define a separate ready to start date.	
	___/___/___		
Date radiotherapy commenced:		The date of the first fraction of treatment.	
	___/___/___		
Was there an elective delay? No <input type="checkbox"/>		If yes why?	
		Chemotherapy/hormone therapy	<input type="checkbox"/>
		Recovering from surgery	<input type="checkbox"/>
		Patient request (holidays etc)	<input type="checkbox"/>
		Post-chemotherapy delay	<input type="checkbox"/>
		Intercurrent illness	<input type="checkbox"/>
		Don't know	<input type="checkbox"/>
		Other (please specify)	
Patient ID number:			
Treatment intent		Waiting list status	
	Radical skin	<input type="checkbox"/>	Emergency (within 24 hours)
	Radical non-skin	<input type="checkbox"/>	Urgent (category 1)
	Palliative	<input type="checkbox"/>	Routine (category 2)
	Adjuvant pre-operative	<input type="checkbox"/>	Don't know
	Adjuvant post-operative	<input type="checkbox"/>	
[Local definitions should be used]			
Is this the patient's first definitive treatment for cancer?		No <input type="checkbox"/>	
[the first intervention which is intended to remove or shrink the tumour]		Don't know <input type="checkbox"/>	
		Yes <input type="checkbox"/>	
		If yes: Date of urgent referral by GP ___/___/___	
		[date the GP signs the request form]	
		Date of decision to treat ___/___/___	
		[date of the consultation in which the patients and clinician agree the treatment plan for the first treatment]	

Appendix 2. Survey of radiotherapy in England (2005) by treatment intent

	Survey data			Minimum fractions				Maximum fractions			
	No. of cases	No. of #s	Mean #	Minimum #	Evidence grade	Modelled minimum #s	% change in #s	Maximum #	Evidence grade	Modelled maximum #s	% change in #s
Bladder											
Radical	20	414	21	20	B	400	-3	32	B	640	55
Palliative	14	88	6	3	A	42	-52	3	A	42	-52
Breast											
Radical	502	8686	17	15	B	7530	-13	25	B	12 550	44
Palliative	14	89	6	5	D	70	-21	10	D	140	57
Breast boost	29	226	8	8	C	232	3	8	C	232	3
Metastases	26	217	8	5	D	130	-40	10	D	260	20
Central nervous system											
Radical	34	903	27	30	A	1020	13	30	A	1020	13
Palliative	9	55	6	6	B	54	-2	6	B	54	-2
Gastro-oesophageal											
Radical	18	386	21	25	B	450	17	30	D	540	40
Palliative	33	195	6	5	D	165	-15	10	D	330	69
Gynaecological											
Radical	74	1606	22	20	C	1480	-8	28	B	2072	29
Palliative	14	140	10	5	D	70	-50	10	D	140	0
Metastases	12	92	8	5	D	60	-35	10	D	120	30
Head and neck											
Radical	72	1733	24	20	C	1733	Nil	35	A/B	2520	45
Palliative	17	163	10			163	Nil			163	Nil
Neck nodes	7	127	18			127	Nil			127	Nil
Metastases	6	86	14			86	Nil			86	Nil
Lung											
Radical	61	1262	21	20	C	1220	-3	36	A	2196	74
Palliative	171	878	5	5	*	855	-3	10	*	1710	95
Metastases	22	80	4	5	D	110	38	10	D	220	175
Lymphoma											
Radical	50	852	17	15	B	750	-12	20	B	1000	17
TBI	9	63	7	6	C	54	-14	8	C	72	14
Palliative	26	160	6	5	†	130	-19	10	†	260	63
Prostate											
Radical	150	4149	28	20	D‡	4149	Nil	38	A	5700	37
Palliative	13	80	6			80	Nil			80	Nil
Metastases	21	74	4	5	D	105	42	10	D	210	184
Rectal (and colon)											
Radical 5#s	3	15	5	5	A	15	0	5	A	15	0
Radical others	61	1326	22	25	A	1525	15	25	A	1525	15
Palliative	11	39	4	5	D	55	41	10	D	110	182
Metastases	7	56	8	5	D	35	-38	10	D	70	25
Sarcoma											
Radical	10	242	24	30	C	300	24	33	C	330	36
Palliative	9	77	9	10	D§	90	17	15	D§	135	75
Unknown primary											
Radical	3	83	28	25	D	75	-10	25	D	75	-10
Palliative	13	48	4	5	D	65	35	10	D	130	171
Metastases	1	10	10	5	D	5	-50	10	D	10	0

Appendix 2 (continued)

	Survey data			Minimum fractions				Maximum fractions			
	No. of cases	No. of #s	Mean #	Minimum #	Evidence grade	Modelled minimum #s	% change in #s	Maximum #	Evidence grade	Modelled maximum #s	% change in #s
Other											
Radical	21	413	20	25	D	525	27	25	D	525	27
Palliative	20	106	5	5	D	100	-6	10	D	200	89
Metastases	2	10	5	5	D	10	0	10	D	20	100
Total radical	1117	22 359	20			21 458	-4			31 012	39
Total palliative	364	2118	6			1939	-8			3494	65
Total metastases	104	752	7			668	-11			1123	49
(by site)											
Bone metastases	424	1256	3	1	A	1256	0	1	A	1256	Nil
Brain metastases	98	640	7	5	A¶	640	0	10	A	980	53
Total metastases	626	2648	4			2564	-3			3359	27
Grand total	2107	27 125	13			25 961	-4			37 865	40

#, fraction. Nil, current practice has been used to reflect minimum or maximum recommendation in view of a weak evidence base. *Palliative fractionation for lung cancer has a complex literature depending on the indication — see text for details. †Palliative radiotherapy for lymphoma has a complex literature depending on the indications — see text for details. ‡Radical radiotherapy for prostate cancer using only 20 fractions has a poor evidence base and current practice has therefore been used to reflect the minimum achievable — see text for details. §Palliative radiotherapy for sarcoma has a weak evidence base but has been modelled between 10 and 15 fractions — see text for details. ||Minimum and maximum fractionation for bone metastasis has been modelled as current practice — see text for details. ¶Brain metastases: minimum has been modelled as current practice — see text for details.

Appendix 3. Survey of radiotherapy in Scotland (2005) by treatment intent

	Survey data			Minimum fractions				Maximum fractions			
	No. of cases	No. of #s	Mean #	Minimum #	Evidence grade	Modelled minimum #s	% change in #s	Maximum #	Evidence grade	Modelled maximum #s	% change in #s
Bladder											
Radical	3	60	20	20	B	60	0	32	B	96	60
Palliative	3	13	4	3	A	9	-31	3	A	9	-31
Breast											
Radical	52	1086	21	15	B	780	-28	25	B	1300	20
Palliative	2	15	8	5	D	10	-33	10	D	20	33
Breast boost	10	41	4	8	C	80	95	8	C	80	95
Metastases	2	25	13	5	D	10	-60	10	D	20	-20
Central nervous system											
Radical	2	60	30	30	A	60	0	30	A	60	0
Palliative	1	6	6	6	B	6	0	6	B	6	0
Gastro-oesophageal											
Radical	4	83	21	25	B	100	20	30	D	120	45
Palliative	4	40	10	5	D	20	-50	10	D	40	0
Gynaecological											
Radical	9	185	21	20	C	180	-3	28	B	252	36
Palliative	4	65	16	5	D	20	-69	10	D	40	-38
Metastases	1	10	10	5	D	5	-50	10	D	10	0

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Appendix 3 (continued)

	Survey data			Minimum fractions				Maximum fractions			
	No. of cases	No. of #s	Mean #	Minimum #	Evidence grade	Modelled minimum #s	% change in #s	Maximum #	Evidence grade	Modelled maximum #s	% change in #s
Head and neck											
Radical	16	391	24	20	C	391	Nil	35	A/B	560	43
Palliative	3	37	12			37	Nil			37	Nil
Neck nodes	3	29	10			29	Nil			29	Nil
Metastases	1	34	34			34	Nil			34	Nil
Lung											
Radical	14	267	19	20	C	280	5	36	A	504	89
Palliative	32	184	6	5	*	160	-13	10	*	320	74
Metastases	5	15	3	5	D	25	67	10	D	50	233
Lymphoma											
Radical	7	153	22	15	B	105	-31	20	B	140	-8
TBI	0	0	0	6	C	0	N/A	8	C	0	N/A
Palliative	3	29	10	5	†	15	-48	10	†	30	3
Prostate											
Radical	22	627	29	20	D‡	627	Nil	38	A	836	33
Palliative	0	0	0			0	Nil			0	Nil
Metastases	1	3	3	5	D	5	67	10	D	10	233
Rectal (and colon)											
Radical 5#s	0	0	0	5	A	0	N/A	5	A	0	N/A
Radical others	5	125	25	25	A	125	0	25	A	125	0
Palliative	3	21	7	5	D	15	-29	10	D	30	43
Metastases	2	20	10	5	D	10	-50	10	D	20	0
Sarcoma											
Radical	3	69	23	30	C	90	30	33	C	99	43
Palliative	1	5	5	10	D§	10	100	15	D§	15	200
Unknown primary											
Radical	0	0	0	25	D	0	N/A	25	D	0	N/A
Palliative	1	1	1	5	D	5	400	10	D	10	900
Metastases	0	0	0	5	D	0	N/A	10	D	0	N/A
Other											
Radical	2	38	19	25	D	50	32	25	D	50	32
Palliative	1	1	1	5	D	5	400	10	D	10	900
Metastases	0	0	0	5	D	0	N/A	10	D	0	N/A
Total radical	149	3185	21			2928	-8			4222	33
Total palliative	58	417	7			312	-25			567	36
Total metastases (by site)	15	136	9			118	-13			173	27
Bone metastases	47	119	3	1	A	119	0	5	A	119	Nil
Brain metastases	12	85	7	5	A¶	85	0	10	A	120	41
Total metastases	74	340	5			322	-5			412	21
Grand total	281	3942	14			3562	-10			5201	32

#, fraction. Nil, current practice has been used to reflect minimum or maximum recommendation in view of a weak evidence base. *Palliative fractionation for lung cancer has a complex literature depending on the indication — see text for details. †Palliative radiotherapy for lymphoma has a complex literature depending on the indications — see text for details. ‡Radical radiotherapy for prostate cancer using only 20 fractions has a poor evidence base and current practice has therefore been used to reflect the minimum achievable — see text for details. §Palliative radiotherapy for sarcoma has a weak evidence base but has been modelled between 10 and 15 fractions — see text for details. ||Minimum and maximum fractionation for bone metastasis has been modelled as current practice — see text for details. ¶Brain metastases: minimum has been modelled as current practice — see text for details.

Appendix 4. Survey of radiotherapy in Wales (2005) by treatment intent

	Survey data			Minimum fractions				Maximum fractions			
	No. of cases	No. of #s	Mean #	Minimum #	Evidence grade	Modelled minimum #s	% change in #s	Maximum #	Evidence grade	Modelled maximum #s	% change in #s
Bladder											
Radical	0	0		20	B	0		32	B	0	
Palliative	1	1	1	3	A	3	200	3	A	3	200
Breast											
Radical	25	480	19	15	B	375	-22	25	B	625	30
Palliative	3	45	15	5	D	15	-67	10	D	30	-33
Breast boost	1	8	8	8	C	8	0	8	C	8	0
Metastases	0	0		5	D	0		10	D	0	
Central nervous system											
Radical	0	0		30	A	0		30	A	0	
Palliative	0	0		6	B	0		6	B	0	
Gastro-oesophageal											
Radical	0	0		25	B	0		30	D	0	
Palliative	0	0		5	D	0		10	D	0	
Gynaecological											
Radical	2	43	22	20	C	40	-7	28	B	56	30
Palliative	1	10	10	5	D	5	-50	10	D	10	0
Metastases	0	0		5	D	0		10	D	0	
Head and neck											
Radical	7	175	25	20	C	140	-20	35	A/B	245	40
Palliative	1	15	15			1	-93		D	1	-93
Neck nodes	0	0				0			D	0	
Metastases	0	0				0			D	0	
Lung											
Radical	1	20	20	20	C	20	0	36	A	36	80
Palliative	9	72	8	5	*	45	-38	10	*	90	25
Metastases	3	28	9	5	D	15	-46	10	D	30	7
Lymphoma											
Radical	8	95	12	15	B	120	26	20	B	160	68
TBI	0	0		6	C	0		8	C	0	
Palliative	5	26	5	5	†	25	-4	10	†	50	92
Prostate											
Radical	15	385	26	20	D	300	-22	38	D/A	570	48
Palliative	1	5	5			1	-80			1	-80
Metastases	2	2	1	5	D	10	400	10	D	20	900
Rectal (and colon)											
Radical 5#s	0	0		5	A	0		5	A	0	
Radical others	2	50	25	25	A	50	0	25	A	50	0
Palliative	3	33	11	5	D	15	-55	10	D	30	-9
Metastases	1	5	5	5	D	5	0	10	D	10	100
Sarcoma											
Radical	1	25	25	30	C	30	20	33	C	33	32
Palliative	1	20	20	10	D	10	-50	15	D	15	-25
Unknown primary											
Radical	2	30	15	25	D	50	67	25	D	50	67
Palliative	4	9	2	5	D	20	122	10	D	40	344
Metastases	0	0		5	D	0		10	D	0	

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Appendix 4 (continued)

	Survey data			Minimum fractions				Maximum fractions			
	No. of cases	No. of #s	Mean #	Minimum #	Evidence grade	Modelled minimum #s	% change in #s	Maximum #	Evidence grade	Modelled maximum #s	% change in #s
Other											
Radical	1	25	25	25	D	25	0	25	D	25	0
Palliative	4	12	3	5	D	20	67	10	D	40	233
Metastases	0	0		5	D	0		10	D	0	
Total radical	65	1336	21			1158	-13			1858	39
Total palliative	33	248	8			160	-35			310	25
Total metastases (by site)	6	35	6			30	-14			60	71
Bone metastases	25	68	3	1	A	25	-63	5	D	125	84
Brain metastases	8	61	8	5	A	40	-34	10	A	80	31
Total metastases	39	164	4			95	-42			265	62
Grand total	137	1748	13			1413	-19			2433	39

#, fraction. *Palliative fractionation for lung cancer has a complex literature depending on the indication — see text for details. †Palliative radiotherapy for lymphoma has a complex literature depending on the indications — see text for details.

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