IPEM Institute of Physics and Engineering in Medicine

SoR THE SOCIETY OF RADIOGRAPHERS | CoR THE COLLEGE OF RADIOGRAPHERS

The Royal College of Radiologists

Radiotherapy Board

National costs and resource requirements of radiotherapy: costing estimate for England from the ESTRO-HERO project

May 2024

Contents

Executive summary

There are excellent data on the effectiveness of radiotherapy for the cure and palliation of cancers but estimating the cost of radiotherapy is complex because of the large amount of equipment and the many different staff groups required. The ESTRO-HERO project uses a time-driven activity-based model to estimate this cost. A multi-professional group has used this model to estimate the cost of radiotherapy in England in 2017.

The total cost of radiotherapy was £467m. The largest component of this (62%) was radiotherapy equipment, in particular the linear accelerators that deliver most of the treatment. The mean cost of a course of radiotherapy was £3,672.

The Radiotherapy Dataset (RTDS) figures on which the model is based are very accurate but there are other data such as the time taken by staff to perform various tasks which are necessarily estimates. The validity of these estimates has been optimised by involving a multi-professional Working Group representing different sized radiotherapy centres, and sensitivity analyses have been conducted to assess the impact of uncertainty in some key estimates. The RTDS data were from England, but the results of this model are very likely to be applicable to all UK devolved nations.

The outputs of the model can be refined as more data becomes available. The tool can also be used to help predict how changes in dose and/or fractionation regimes in the future might impact the resources required for radiotherapy delivery.

Background

Radiotherapy (RT) is a very effective curative and palliative treatment for cancer, but the cost of radiotherapy in the NHS has never been well established. The cost of cancer drug therapies can be calculated relatively simply by summing the cost of the drug itself, which is often the most expensive part, and the staff and chair time involved in delivering treatment. In contrast, radiotherapy uses few consumables but has large sums of money invested in equipment, housed in complex, specially designed buildings, which should last for many years. Behind each fraction of treatment delivered on a linear accelerator (Linac) is also a huge amount of work for many different groups of healthcare professionals.

The Health Economics in Radiation Oncology (HERO) project was established in 2011 by the European Society for Therapeutic Radiotherapy and Oncology (ESTRO) to develop a knowledge base and a cost-accounting model estimating the national cost of radiotherapy. The overall aim is to provide robust evidence to the European radiation oncology community to support their engagement with governments, funders and decision-makers, and advocate for better funding for RT, better resource planning and ultimately better care for patients with cancer.

In 2018 The Royal College of Radiologists (RCR) agreed to convene a multi-professional Working Group with support from ESTRO to gather data to estimate the cost of radiotherapy in England. This report summarises the ESTRO-HERO methodology, the input data that has been used and the outputs from the model.

Methodology

The ESTRO-HERO model uses a time-driven activity-based costing methodology, a well-established accounting system applied to healthcare.[1] Its aim is to incorporate both the utilisation and costs of RT delivery in a national context, modelling both the total budget and cost estimation for a variety of treatments. It attributes resource costs to a treatment course through the activities performed in the care process. Every resource needed for radiotherapy is detailed – from the time spent by each staff group on each part of the treatment process to the costs of all the equipment, space and consumables required in a radiotherapy department. Each metric is inputted into an online database informing the model. When all data have been collected and thoroughly validated the model can calculate the total cost of radiotherapy and can break down costs by tumour type, fractionation regime etc. The model allows sensitivity analyses to be performed: variables can be altered to a range of values to estimate which have greatest effect on the overall cost. A detailed description of the methodology employed has previously been published by Defourny et al.[2]

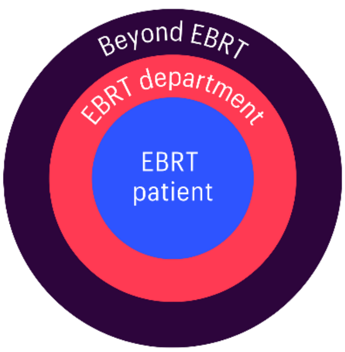
There are three layers to the ESTRO-HERO model, reflecting the elements necessary for a functioning radiotherapy service (see Figure 1).

The central layer represents the core of External Beam Radiotherapy (EBRT) - the patient layer – with those costs directly associated with the treatment of a patient. These costs comprise treatments (the number of courses and fractions of radiotherapy), activities (the time taken for each aspect needed to deliver radiotherapy) and resource costs (staff, equipment and infrastructure).

The EBRT-department layer comprises all the resources and activities necessary for a radiotherapy service but not directly linked to a specific treatment – for example, quality assurance programmes, dosimetry equipment and time to implement new techniques.

The Beyond-EBRT layer represents activity performed by radiotherapy staff not directly related to provision of radiotherapy such as attendance at multi-disciplinary team meetings and provision of non-radiotherapy treatments (for example, systemic therapies).

FIGURE 1: THE THREE LAYERS OF THE ESTRO-HERO MODEL



EBRT patient	**Resources**	Personnel: Clinical, Physics, Imaging, Planning and Delivery Task Groups Equipment: Imaging Equipment, Treatment Machines, Treatment Planning Systems, Patient-Specific Dosimetry Devices (incl. Dedicated Infrastructures)
	Treatments	Per tumour site and intent, per technique, per fractionation schedule
	Activities	EBRT Care Pathway Steps
EBRT department	**Resources**	Personnel: Administrative Personnel, Engineers, Quality Managers, Social Workers, Manager Equipment: Record and Verify Systems, Machine Specific Dosimetry Devices, General IT Equipment General Infrastructures; General Consumables
	Activities	Department Management, Quality Assurance and Quality Management, Radiation Safety, New Technology Implementation, Teaching, Research
Beyond EBRT	**Activities**	Multidisciplinary Tumour Board Meetings, Follow-up Consultations, Chemotherapy, Brachytherapy and Intra-Operative Treatments

The ESTRO-HERO model is intended to estimate national costs. In England, radiotherapy activity data are available at a national level through the Radiotherapy Dataset (RTDS). At study commencement the latest year for which data by tumour site were available was 2017. At this time data were collected for England but not the rest of the UK. For this reason, the ESTRO-HERO model uses 2017 data for England – so staffing, equipment numbers and estimated costs are based on 2017 data for England. Some of these data items are available for the whole nation (total staff group numbers, number of Linacs) but many of them had to be extrapolated from centre data (e.g. number of CT simulators, number of staff per task). As the devolved UK nations have very similar radiotherapy practice, the treatment level data are very likely to be applicable to the whole of the UK.

Some of the cost data that are used are relatively easy to estimate accurately – for example the cost price of a Linac in 2017. Some are more difficult to estimate because of the different funding models used in English Trusts (managed equipment services vs. standard funding) and because of differences in department size (a large department will need more staff and equipment than a smaller one but will be expected to have economies of scale). Members of the Working Group were selected to represent a variety of different sized departments with different funding streams. Where data were derived from a small number of departments, other departments were asked to sense-check these inputs. This was felt to be a more reliable method of estimating national data than simply extrapolating from one centre's data or than trying to collect information from every centre. The centres that contributed data are Guy's and St Thomas' NHS Foundation Trust, Leeds Teaching Hospitals NHS Trust, Mount Vernon Hospital, Norfolk and Norwich University Hospitals NHS Foundation Trust, Nottingham University Hospitals NHS Trust, and Somerset NHS Foundation Trust.

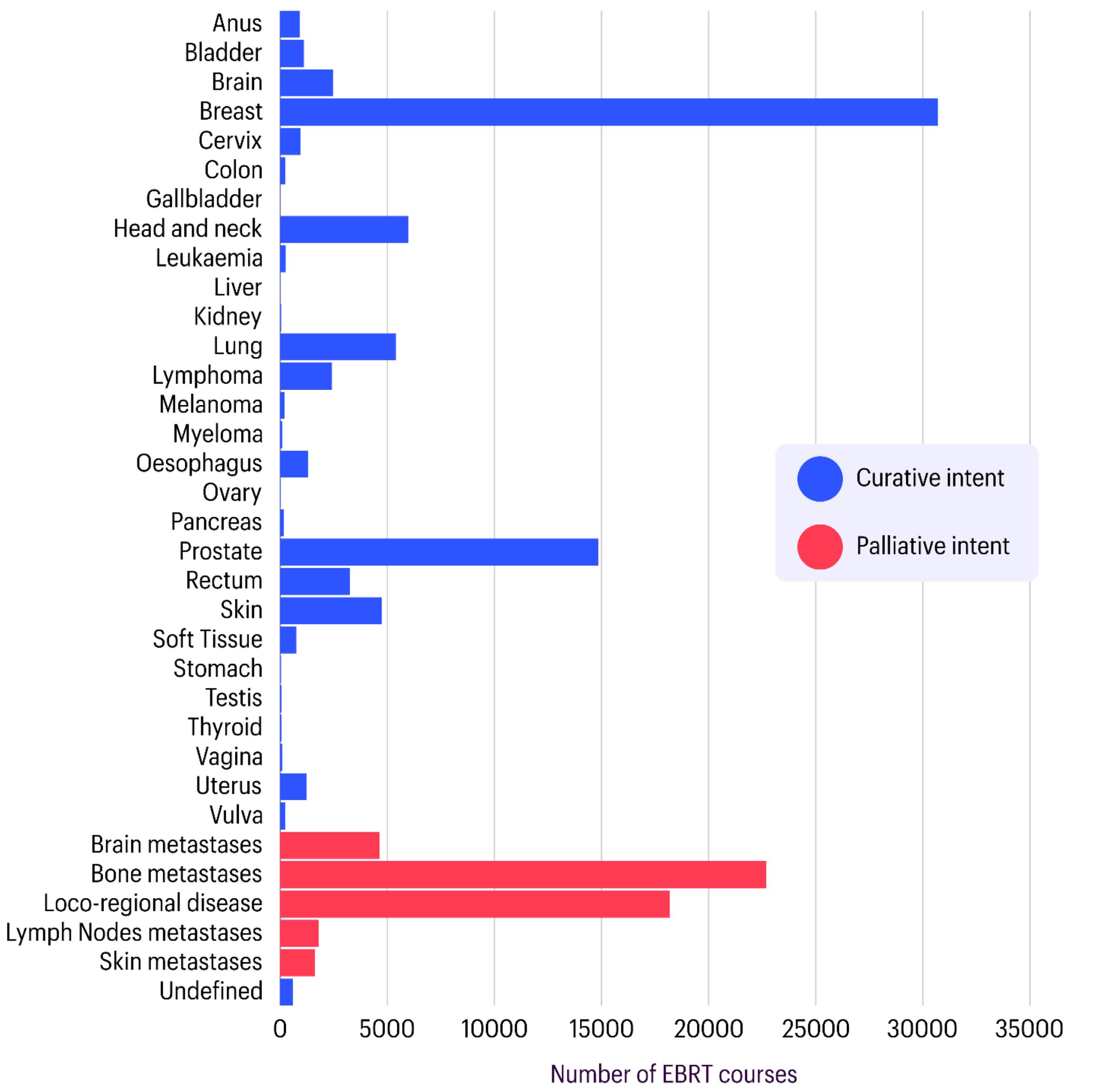
Input data

1. EBRT-patient layer

i) Treatment numbers

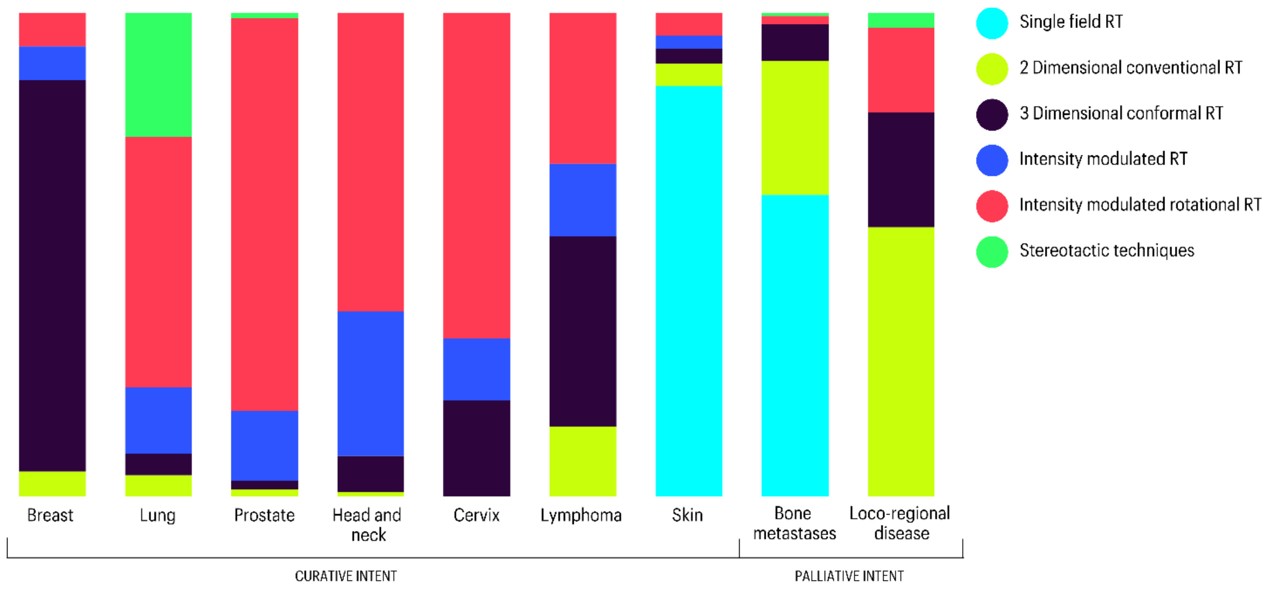
The number of courses and fractions of curative and palliative radiotherapy by tumour site were obtained from RTDS data. 127,275 courses of radiotherapy were delivered in England in 2017 of which 78,386 (61.6%) had curative (or adjuvant) intent. Across all courses, there was an average of 13.96 fractions per course and a total of 1.78 million fractions were delivered in 2017. A breakdown by tumour site and intent is shown in Figure 2.

FIGURE 2: TOTAL RADIOTHERAPY COURSES BY TUMOUR SITE (ENGLAND, 2017)



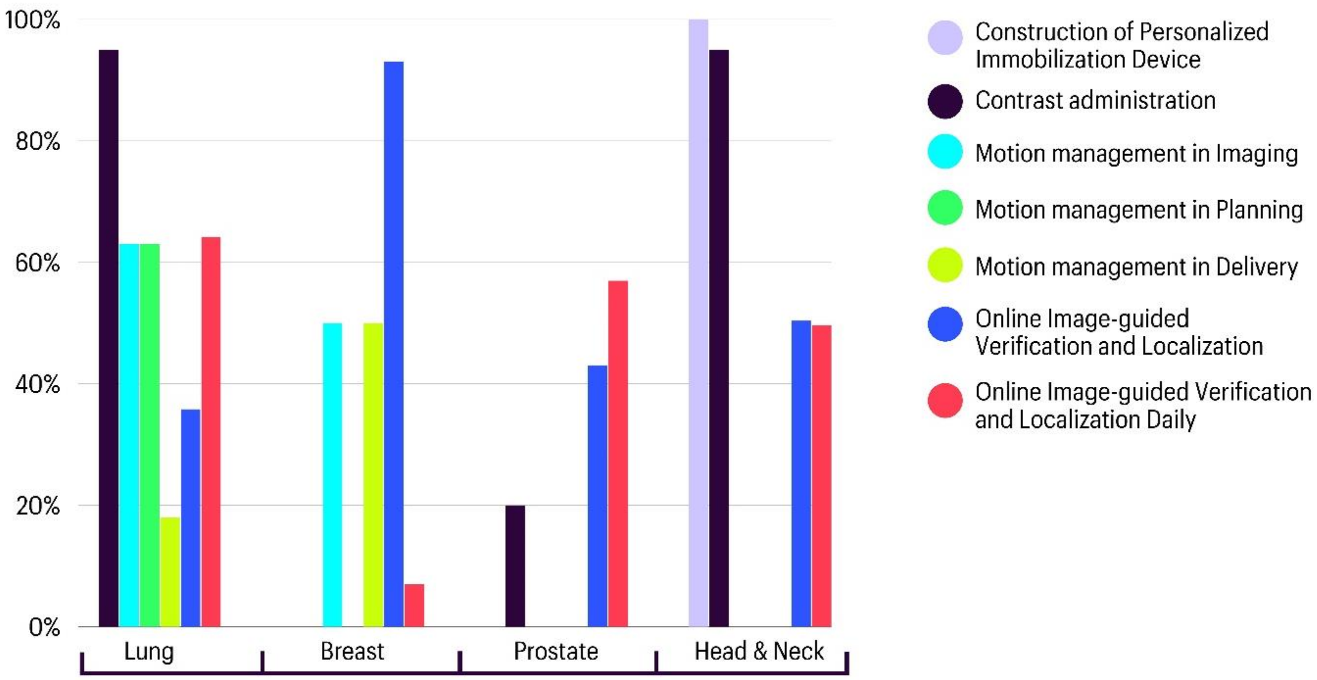
For each tumour type the proportions of treatment by technique (2D, 3D conformal, intensity modulated radiotherapy (IMRT), volumetric modulated arc therapy (VMAT), and stereotactic) were taken from RTDS data, combined with expert consensus where necessary. For example, RTDS 2017 data did not differentiate between IMRT and VMAT and as such these proportions were estimated by expert consensus. The breakdown for selected disease sites is shown in Figure 3.

FIGURE 3: PERCENTAGE OF TREATMENT PER TECHNIQUE BY TUMOUR SITE (ENGLAND, 2017)



Optional techniques such as use of immobilisation devices, use of contrast for planning, use of image guided radiotherapy (IGRT) and motion management in planning and treatment were estimated by expert consensus for each treatment technique and tumour site as required by the model and are shown in Figure 4. None of these data were captured by RTDS in 2017, although subsequent versions have supported this.

FIGURE 4: ESTIMATED NUMBER OF EBRT COURSES REQUIRING OPTIONAL TECHNIQUES (e.g. MOTION MANAGEMENT, IGRT) FOR LUNG, BREAST, PROSTATE AND HEAD AND NECK CANCERS.



ii) Resources

Equipment

The total number of Linacs in 2017 in England was 336 (based on RTDS data). Numbers of other items of equipment such as CT simulators and treatment planning systems were estimated in relation to the total number of departments. Equipment costs were based on replacement costs at 2017 prices. Linac and stereotactic unit purchasing costs were £1,731,010 and £3,840,000 respectively (based on NHS procurement prices) with annual maintenance contracts costing a further 10%. It is not possible within the model to separate Linac from stereotactic unit costs and as such a weighted average was used (assuming a total of 10 stereotactic units). Annual maintenance contracts and equipment lifetime were estimated based on costs of managed equipment service contracts. Bunker costs were estimated based on publicly available business cases for the replacement of estates at 2017 prices. The cost of commissioning equipment, as well as weekly and monthly quality assurance performed by medical physicists/engineers within the radiotherapy provider, is presented in the results under the equipment resource.

Personnel

Clinical oncologist, therapeutic radiographer and physicist whole time equivalent numbers (WTE) were taken from 2017 professional census data. Task groups are used in the model to account for different titles and responsibilities throughout Europe (clinical, physics, imaging, planning and treatment delivery groups). For example, both radiographers and physicists may be in the planning task group as they can both produce radiotherapy plans, and some consultant radiographers are included in the clinical task group. Median 2017 salary points and working patterns were used. Other staff group numbers (for example, engineers, quality managers, administrative and clerical staff) were estimated. The model assumes that staff work at 80% capacity to take account of annual, study and sick leave and natural work breaks. Trainees are not included in the numbers used in the model. Data for workforce are shown in Table 1.

TABLE 1: WTE NUMBERS, WORKING HOURS AND SALARIES FOR EACH TASK GROUP

					Percentage of annual time			
Task group	Sub-category	Number of FTE	Annual wage (£)/ FTE	Paid hour per day	EBRT-patient	EBRT-department	Beyond EBRT	Machine-QC and commissioning
Clinical *		997	£ 88,710	8.58	19%	17%	64%	
	Consultant	729	£107,413	9				
	Consultant radiographer	8	£65,000	7.5				
	Radiographer	260	£37,000	7.5				
Physics		400	£ 50,000	7.5	21%	45%	10%	24%
Imaging		473	£ 37,000	7.5	79%	15%	4%	1%
Planning*		440	£ 37,000	7.5	78%	22%		
	Dosimetrists	295	£ 37,000	7.5				
	Physicists	145	£ 50,000	7.5				
Treatment		1760	£ 37,000	7.5	76%	17%	4%	2%

Consumables

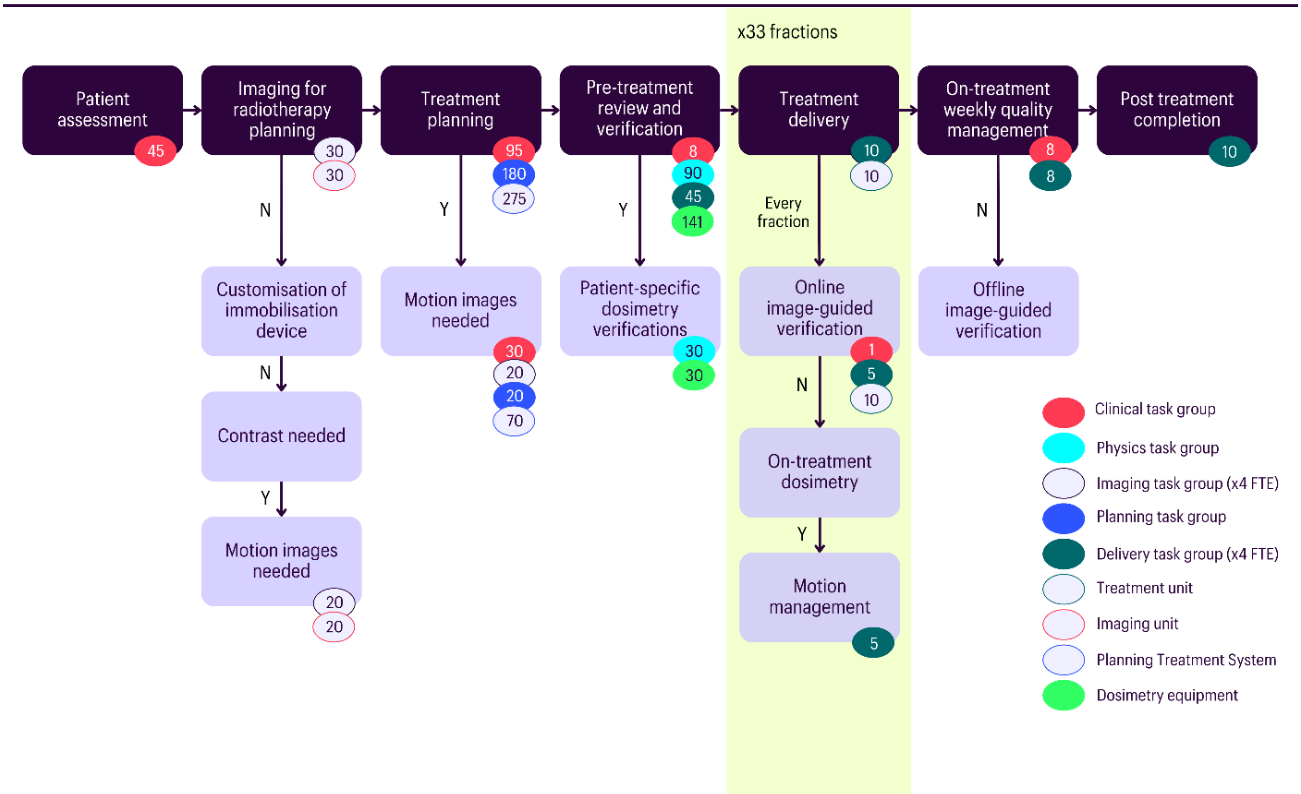
The use and cost of contrast media and immobilisation devices (both reusable and patient-specific) were estimated based on expert consensus for each tumour site.

iii) Activities (pathway timings)

The time taken for every part of the RT process was estimated by technique and by task group. The activities making up each timed step of the pathway were clearly stipulated by the model. For example, the 'treatment planning' step includes everything from image registration to importing the final approved treatment plan with all contouring and plan creation steps in between. Measured timings for some activities were available from Leeds and Guy's for many parts of the pathway. The RCR contouring times survey will help to refine estimates of times taken for contouring and peer review.[3] Figure 5 shows sample times for a curative lung cancer pathway. All estimates were reviewed by the Working Group and modified where appropriate based on consensus.

* Wage reflects a weighted average for each professional group based on NHS contracts. Percentage of annual time spent in direct patient care, the EBRT department and beyond the department are estimated based on expert consensus.

FIGURE 5: ACTIVITY TIMING (IN MINUTES) OF RESOURCE STAFF AND EQUIPMENT FOR EACH STEP OF A 33 FRACTION EBRT TREATMENT COURSE FOR LUNG CANCER USING IMRT, DAILY IMAGE-GUIDANCE AND MOTION MANAGEMENT



2. EBRT-department layer

The EBRT-department layer includes all resources that are not directly required to treat specific patients (i.e. not captured within the EBRT-patient layer) but are essential to maintain quality and safety of care. To appropriately identify the time required to deliver this, for each task group, the time spent on support activities was estimated by expert consensus and using national census data where available (see Table 2). In combination with the estimated total workforce numbers presented above, the overall amount of time (and associated cost) of delivering support activities was calculated.

TABLE 2: PERCENTAGE OF TOTAL TIME ESTIMATED TO BE SPENT ON EBRT-DEPARTMENT ACTIVITIES BY STAFF GROUP

Task Groups	Departmental Management & Team Meetings	Quality Assurance & Quality Management †	Radiation Safety & Radiation Protection	Technology & Techniques Implementation	Teaching (Academic & on-the-job Training)	Research	Total
Clinical	10%	0%	0%	2%	3%	2%	17%
Physics	2%	5%	5%	30%	2%	1%	45%
Imaging	5%	1.5%	1%	4%	3%	0.5%	15%
Planning	10%	1.5%	1%	6%	3%	0.5%	22%
Treatment Delivery	3%	5%	1%	4%	3%	0.5%	16.5%

† Excl. Machine related quality control and breakdowns

In addition to EBRT-departmental workforce resources, general infrastructure and equipment such as waiting rooms and consultation spaces, planning systems, and record and verify information systems are included in this category. Their numbers are estimated indirectly per department or per Linac as appropriate.

3. Beyond-EBRT

The final Beyond-EBRT layer recognises that staff may undertake part of their role outside of the EBRT-department. For most staff groups this mainly relates to brachytherapy. The clinical task group, however, are clinical oncologists and therefore contribute to the delivery of a significant amount of systemic therapy with a much smaller percentage reflecting time spent in brachytherapy. For each staff group, time spent on activities outside EBRT was estimated based on expert consensus (see Table 1 and 3).

TABLE 3: EXPERT CONSENSUS ESTIMATES FOR TIME SPENT ON ACTIVITIES OUTSIDE EBRT BY TASK GROUP

Task Groups‡	Chemotherapy prescribing§	Brachytherapy & Intraoperative Therapy	Follow-up Consultations (including for chemotherapy)	Multidisciplinary Tumour Boards	Total
Clinical	2%	2%	50%	10%	64%
Physics	-	10%	-	-	10%
Imaging	-	4.5%	-	-	4.5%
Planning	-	-	-	-	-
Treatment Delivery	-	4.5%	-	-	4.5%

The total costs related to EBRT-department and Beyond-EBRT are calculated within the model and are then assigned to individual treatment courses in line with previous studies: 20% of the EBRT-department and Beyond-EBRT costs are split between all delivered courses whilst 80% are split between all delivered fractions. This recognises the increased departmental input required to support the delivery of longer courses of radiotherapy.

‡ Clinical task group figures are based on publicly available data and expert consensus within the HERO-RCR team. For the Physics, Planning and Treatment delivery task groups 3-4 individuals from different centres contributed estimates of time spent and consensus figures were determined and reviewed based on these.
§ Clinician time spent on chemotherapy is estimated as the time spent prescribing chemotherapy. Related outpatient consultations are captured in the follow-up consultations field

Handling uncertainties and data limitations

The ESTRO-HERO tool is a model and, as such, will never provide a perfect estimate of radiotherapy cost. There are two main limitations which need to be distinguished: the time-driven activity-based costing model assumptions, and the data on which the estimation is calculated.

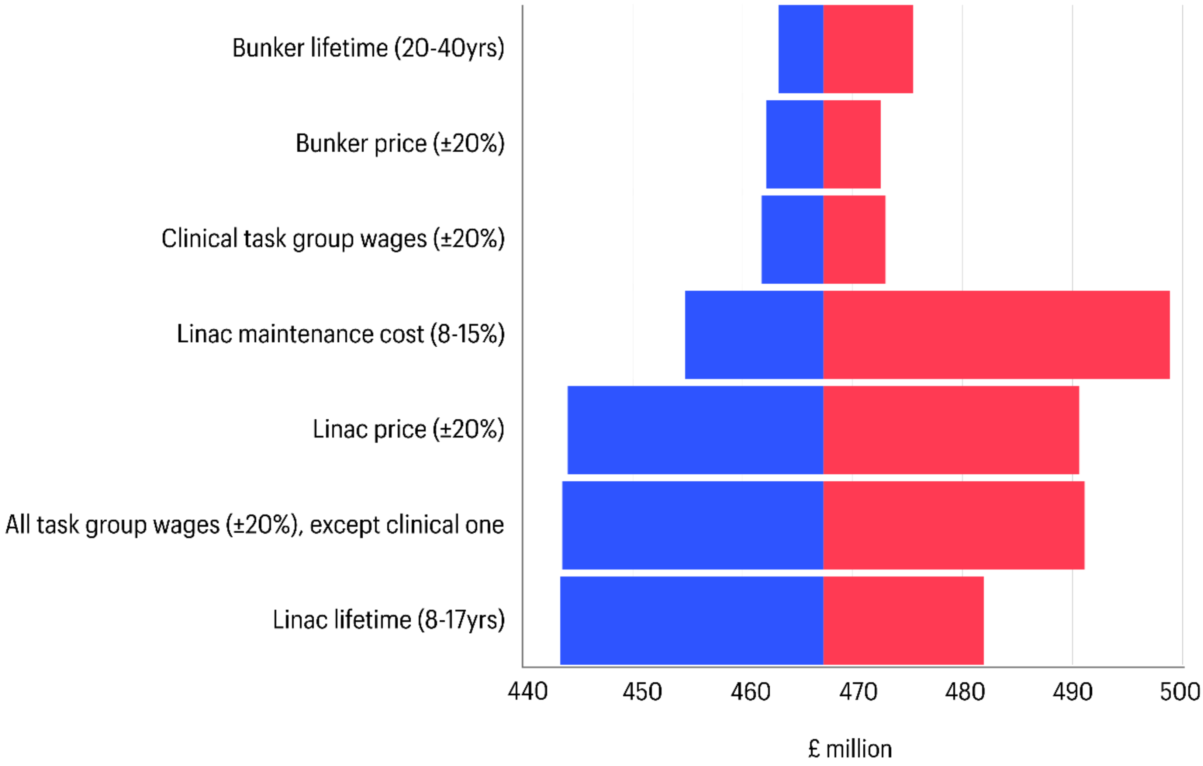
Firstly, the ESTRO-HERO tool bases the cost of equipment on a weighted average of the cost of the various machine types. Whilst complexity maybe recognised through additional activities or time requirements, machine costs are the same irrespective of complexity. Consequently, the cost of treatments which require less complex machines will be overestimated, while the cost of treatments delivered with more complex or dedicated equipment will be underestimated.[4] This cost-shifting is an artefact of the model and has previously been discussed; the artefactual shifting of simple treatments onto more complex machines may not be dissimilar to the reality of radiotherapy delivery in a busy NHS radiotherapy department trying to optimise equipment utilisation.[5]

The second limitation is data collection, but as each input to the model is refined and tested, the output estimations become more accurate. RT estimations can be continually updated, for example as more information about contouring times from the RCR contouring times survey is available, but there are still much data that will remain an estimate. By sense-checking input data with a multi-professional team and by involving multiple English radiotherapy centres of different sizes, we think we have provided estimates that are a close estimation of the true total cost.

Input and output data from the Europalia model have been used as a sense-check for the 2017 England model throughout the process. The Europalia model represents a hypothetical European country with the model populated based on published evidence and expert consensus.[2] The authors explain that these data were used to demonstrate the potential of the ESTRO-HERO model but cannot be generalised nor used as a proxy for national evidence.

Given that some resource inputs are very uncertain there is a need to understand what the impact of inaccuracies in these values could be for the results. This is particularly relevant for resources that contribute a high proportion of the total costs, such as the equipment, maintenance and bunker costs (see Figure 6). To challenge these estimates, sensitivity analyses have been performed. For example, we estimated that the cost of a replacement linac bunker was approximately £1,000,000 with an annual maintenance contract of 10% and a lifetime of 30 years. This estimate could be higher if, for example, private finance initiative investment was required, or lower for legacy buildings. On this basis we varied the cost of a Linac bunker from £800,000 to £1,200,000 to provide an understanding of how much this would be expected to impact the total costs. Imaging bunker costs also varied from £600,000 - £900,000 (+/-20%). Linac prices were based upon NHS procurement prices. However, sensitivity analyses considered a range of prices from £1,384,808 to £2,077,213 (+/-20%) recognising variation in specification and potential for discounts for multiple purchases. Similarly, the annual maintenance contract for a Linac was varied from the base-case of £138,480 to £259,652 and the lifetime of a Linac from 10 years to a range of eight to 17 years to reflect the experience of contributing centres. Such information is not only valuable in interpreting the model outputs but also in informing the procurement of future equipment and estates.

FIGURE 6: SENSITIVITY ANALYSES ON ASSESSING THE IMPACT OF VARIATION IN INDIVIDUAL COST COMPONENTS ON THE ESTIMATED NATIONAL COST FOR EBRT (EBRT PATIENT AND DEPARTMENT)**



** Salary variation separates the clinical task group from other task groups as the salaries of the former are determined by the Consultant contract whilst those of the latter are based on the Agenda for Change salary scale.

Output data

1. National utilisation and costs

The modelled total cost of delivering radiotherapy in England in 2017 was £467 million. This includes EBRT-patient and EBRT-department costs. Beyond-EBRT costs were excluded as they contribute to other parts of the cancer treatment pathway and are commissioned separately.

The EBRT-patient and EBRT-department costs were £323,781,711 and £143,567,455 respectively. In In total, equipment costs made up 62.3% and personnel 28.5%, while 8.9% and 0.3% were attributable to EBRT-department activities and EBRT-patient consumables, respectively (see Figure 7). Of the equipment costs, the cost of treatment equipment (mainly Linacs) was the majority (62%). The total replacement cost of the 336 England Linacs at 2017 price was £581m. The total cost can also be considered for each diagnosis and intent. For example, the total cost of delivering adjuvant radiotherapy for breast cancer was £91,855,833, whilst for lung cancer in the curative setting it was £18,706,833. Further detail of the costs per diagnosis are shown in Figure 8.

FIGURE 7: COSTS FROM ESTRO-HERO IN ENGLAND IN 2017 SPLIT BY LAYERS OF THE MODEL

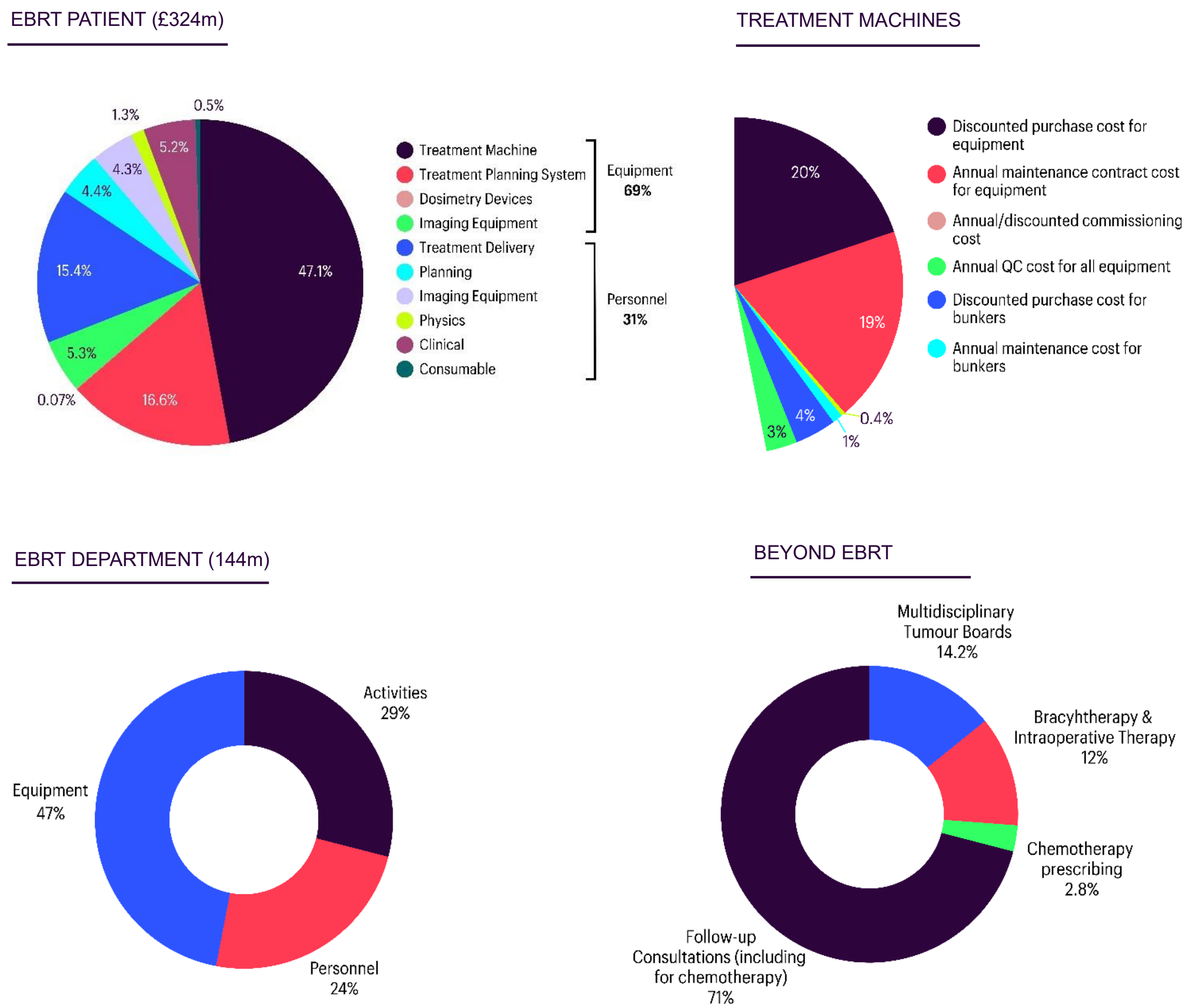
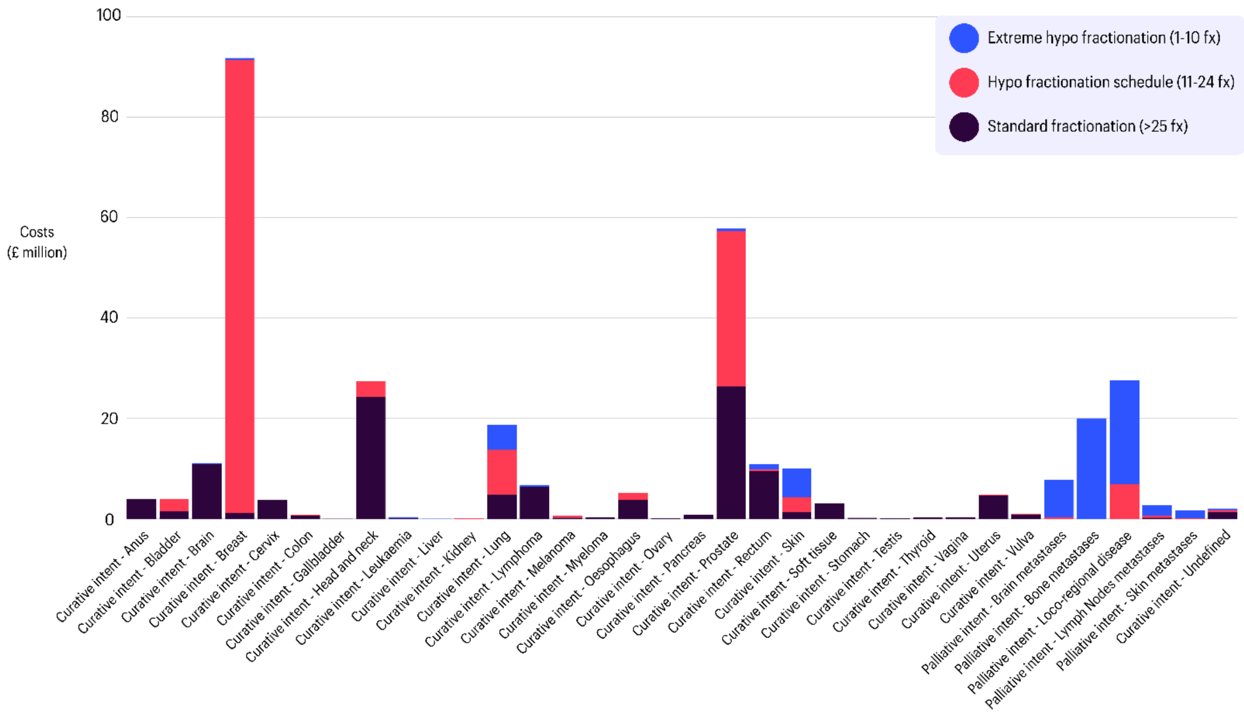


FIGURE 8: TOTAL COST OF RADIOTHERAPY BY TUMOUR TYPE

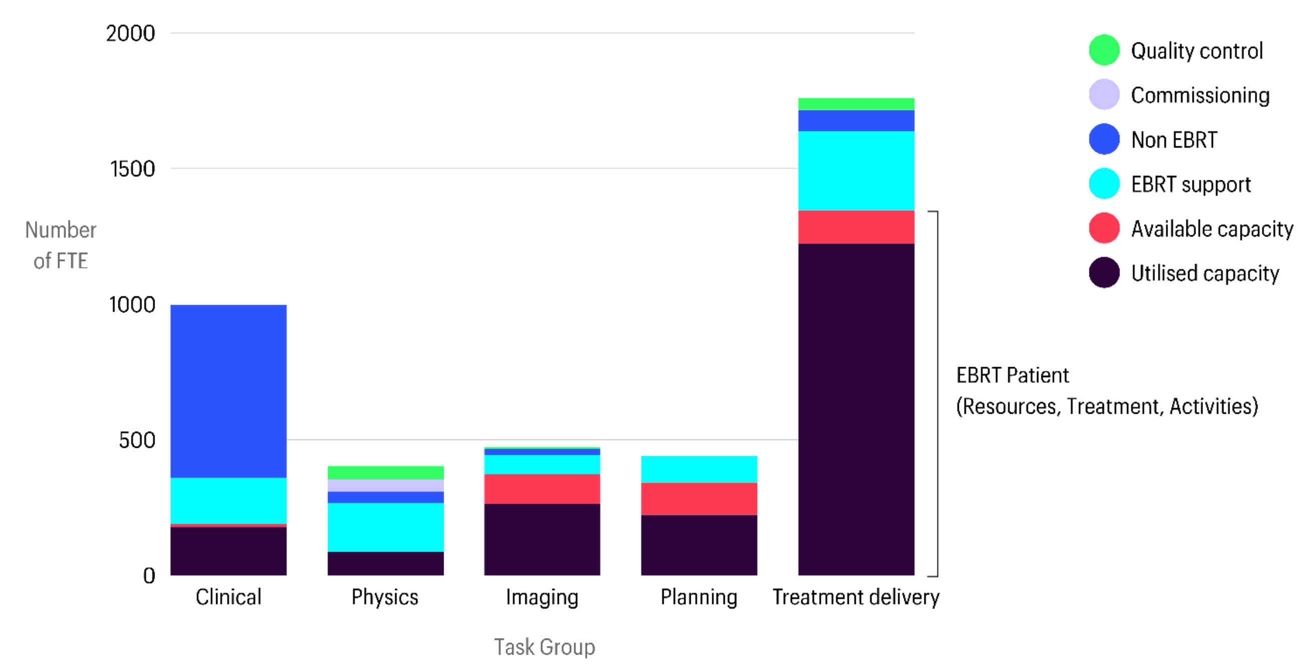


To identify the overall utilisation of staff resources in each task group, we calculated total time available for each task group (based upon the estimated number of whole-time equivalents (WTE) nationally and their available hours (assuming 80% of theoretical time)) and the time spent delivering elements of the Patient and Departmental layers, in addition to that spent Beyond EBRT. This enabled calculation of the percentage of each staff group utilised for various tasks and the remaining available time.

Figure 9 illustrates the distribution of time across the three layers and relative to the available task group capacity. The clinical task group spends much of its time on non-EBRT activities, as expected with a Clinical Oncology workforce who spend significant time managing systemic therapies (captured in ‘follow-up consultations’ in Figure 7) and other aspects of patient care. Other task groups spend most of their time on EBRT-patient or EBRT-department activities. For the physics, imaging and treatment delivery task groups, further time is then ascribed to quality control and commissioning.

The purple bar in Figure 9 represents the sum of the estimates of time attributed to a task group for each EBRT-patient activity in the model. The blue bars represents other activity within the department or beyond it and green and lilac represent time spent on quality control and commissioning. The pink bar is time the model estimates that task group has available for EBRT-patient work which is not accounted for in the sum of all timed activities. There are several possible reasons for this ‘available capacity’. The input data in the model may be incorrect – activities in the patient and departmental layers may take longer than we have assumed or more people from each staff group may be involved in some of the activities. The total WTE capacity may be incorrect if personnel numbers are wrong or, for example, if staff are on maternity or unplanned leave and are not replaced. Or there may genuinely be spare capacity within a task group.

FIGURE 9: DISTRIBUTION AND AVAILABILITY OF TASK GROUP TIME



2. EBRT course costs

Figure 10 shows the average total cost of a course of radiotherapy for each diagnosis by treatment intent (recognising that variation in treatment technique will influence the cost of each individual course). The mean cost was £3,672. More complex techniques using more fractions are more costly, as illustrated in Figures 10 and 11.

FIGURE 10: TOTAL COST PER TUMOUR TYPE AND INTENT

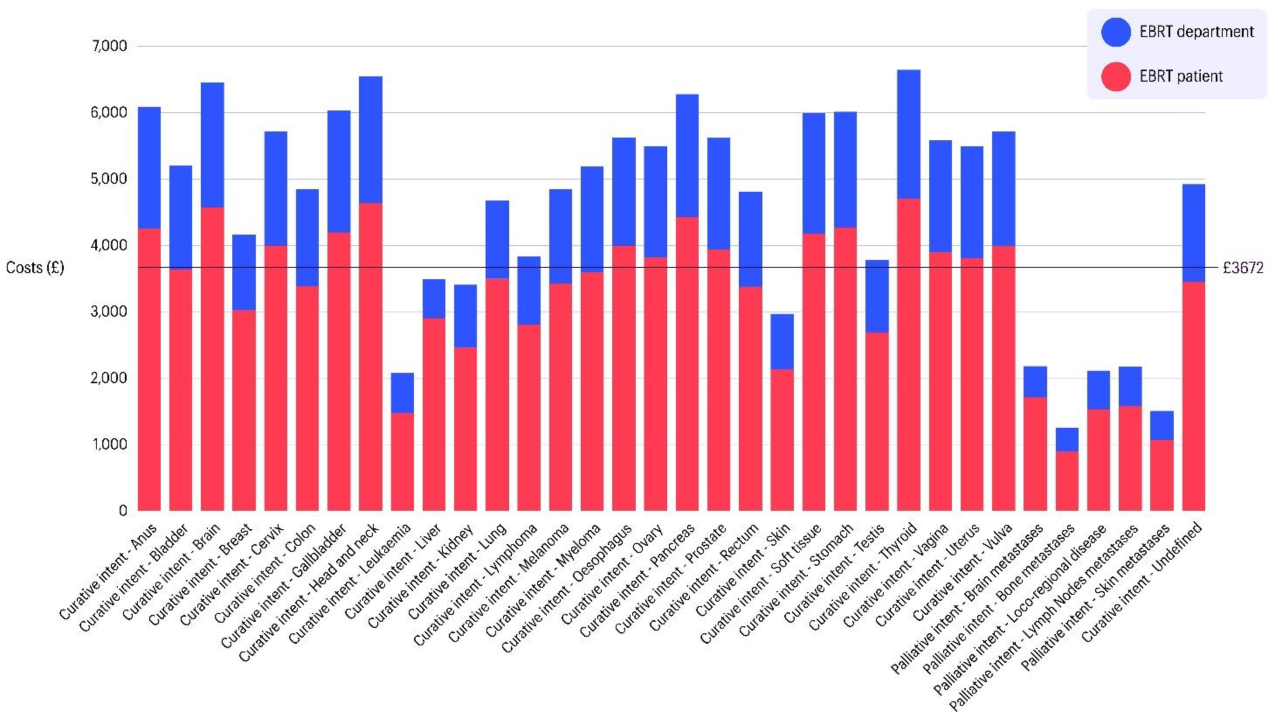
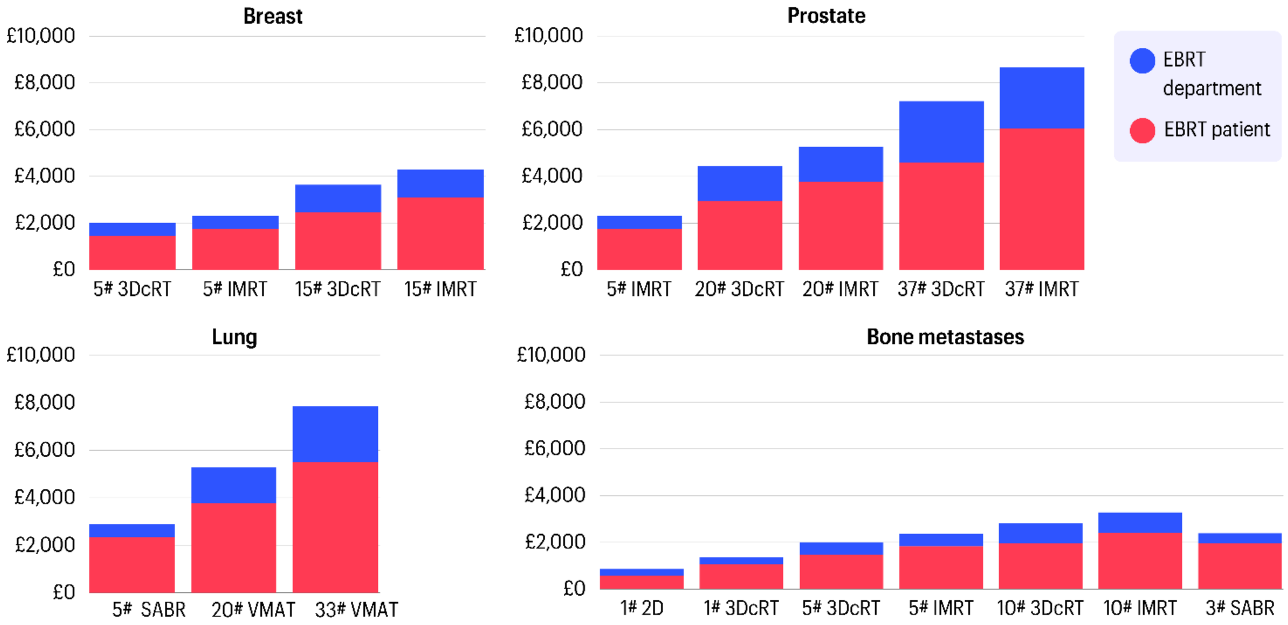


FIGURE 11: EBRT COST (PATIENT AND DEPARTMENT) OF SPECIFIC TREATMENT REGIMENS



Contexts and comparisons

1. Funding for cancer care and other cancer treatments in England

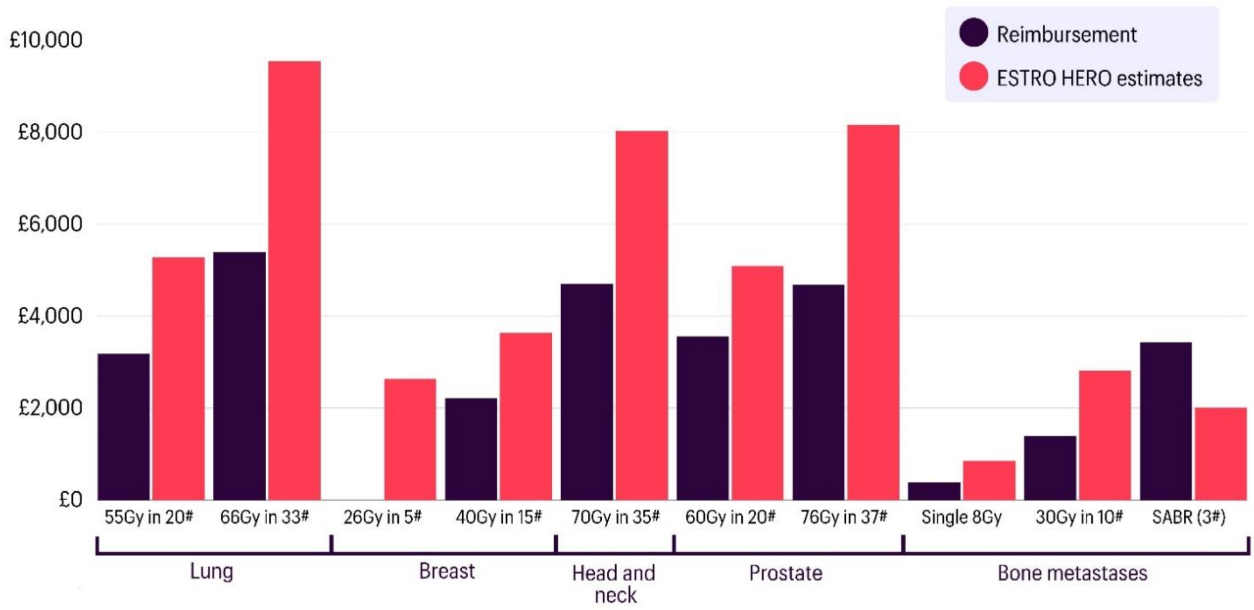
Data on the overall NHS England spend on cancer are not easy to find but the National Audit Office estimated a figure of £6.7 billion for 2012-13.[6] This total includes all elements of the cancer pathway but excluding end of life care where specialist services remain largely charitably funded. It is estimated that in the UK, approximately 40-50% of patients with cancer will require radiotherapy at some point during their care although estimates of observed utilisation in the English NHS are 35-38%.[7,8,9] The ESTRO-HERO model estimates that the total cost of the 127,275 radiotherapy courses delivered in 2017 was £467 million; assuming the overall cancer spend did not rise between 2013 and 2017, radiotherapy accounts for approximately 7% of the total cancer spend.

By way of comparison, at its inception in 2010 the Cancer Drugs Fund (CDF) for England had an annual budget of £50million. This rose rapidly over the subsequent four years reaching over £400m before its reform in 2016. At this point it moved from NHS England, to be overseen by the National Institute for Health and Care Excellence (NICE) providing a means to deliver early access to promising novel pharmaceuticals while ensuring further clinical efficacy data are collected ahead of full technology appraisal. In this setting, drug expenditure in the 2020-21 financial year totalled £336m and a reported 14,022 new patients were registered for treatment.[10,11] The estimated cost per patient is therefore just under £24,000. This figure does not include the costs of prescribing, producing or delivering CDF approved therapies.

2. NHS England Radiotherapy funding

In 2017 English NHS radiotherapy providers were reimbursed in line with a national tariff model. This provided separate reimbursement for planning and treatment delivery with recognition of complexity. In this way, more complex activity (for example, IMRT, VMAT or IGRT) received a greater tariff than a simple non-computer planned treatment. The reimbursement tariff is based on NHS provider submitted reference costs. There are extensive guidelines for the calculation of reference costs which include Trust-level overheads, recognising the location of radiotherapy departments in wider NHS Trusts and supporting, for example, portering services, human resources and information technology. The HERO model does not include these Trust-level costs but does include some other costs which are not included in tariff models. As such, the measures included in the total cost of a course of radiotherapy from tariff and from the ESTRO-HERO model are not quite the same so the comparative modelled figures presented here in Figure 12 should be interpreted cautiously. In addition, as outlined above, it is assumed that all treatments are delivered using the same equipment. This may result in an over-estimate of the cost of simple treatments and a modest under-estimate of more complex treatments.

FIGURE 12: COMPARISON OF NHS ENGLAND TARIFFS AND ESTRO-HERO (PATIENT AND DEPARTMENT) ESTIMATES FOR SPECIFIC TREATMENT REGIMES††



In October 2012 a one off £15 million, which subsequently increased to £23 million, Radiotherapy Innovation Fund in England was announced to help English cancer centres implement IMRT.[12,13] In October 2016, a further £130m was made available for hospitals to purchase new equipment or to upgrade existing hardware.[14] The fact that additional monies have been required to support tariff payments would suggest that tariff alone is not sufficient to fund all aspects of a radiotherapy service. In spite of these extra funds, at least 64 Linacs in England in 2019 were estimated to be more than 10 years old, which is considered to be the latest time they should be replaced.[15,16] Linac cost and maintenance has been shown here to have a significant impact on the total cost of care. As such, a centralised approach might not only ensure timely equipment replacement but also optimise procurement to ensure treatment delivery costs are minimised safely. Similar considerations might be made for investment in bunkers, although greater complexity exists here as these are often part of a wider cancer centre or acute hospital. Nonetheless, capital investment can also be seen to have a significant influence over total cost and optimisation will therefore be crucial, particularly where new or satellite centres are planned.

Early during the COVID-19 pandemic, funding for healthcare in England was changed to a block contract model to protect against variation in demand and to prioritise pandemic response. Under this contract, centres receive a fixed sum for treating all their patients based on activity in the preceding 12 months. This model is still going to be used for 2024-25 while an evaluation of a new mixed tariff/block model is completed. The intention is that this will support the extensive fixed costs of radiotherapy delivery whilst also incentivising departments to innovate. The model presented here uses 2017 data for reasons explained above but given the uncertainties around tariff reform and changes during COVID-19, this comparison is not unhelpful. However, the delivery of radiotherapy has changed significantly in the past seven years, most notably with the widespread implementation of the 26Gy in 5 fraction FAST-Forward regimen in adjuvant breast cancer, whilst there has also been increasing use of VMAT, motion management and online imaging. It is worth noting that while the cost

†† Reimbursement tariff for prostate SABR is based on that of SABR under commissioning through evaluation. No tariff comparison is available for lung SABR (where local commissioning agreements are in place) or for 26Gy in 5# breast cancer treatments (which have been implemented since the changes to commissioning during the COVID-19 pandemic and for which no reimbursement tariff estimate is available).

of delivering a 26Gy in 5 fraction course (£2,640) is indeed lower than that of a 40Gy in 15 fraction course (£3,637), this is only a 27% fall and in no way the two-thirds drop which might naively be expected based on the drop in fractionation. This reflects the finding that a large proportion of the cost of radiotherapy delivery is fixed (reflecting machines and bunkers) or semi-fixed (reflecting staff). Consequently, the rise of hypofractionation will increase the cost of remaining fractions in the absence of previously underserviced demand.[5] The ESTRO-HERO model can be used to explore the impact of these and future changes, bearing in mind that the output estimates described here relate to the 2017 base case.

3. National and international comparisons

The different healthcare funding models used in other countries make international comparisons complex. Comparative European data reported in 2020 suggest annual expenses for radiotherapy, including capital investment, represented between 4.3% and 12.3% of the cancer care budget for 12 countries.[16] The ESTRO-HERO project has also collected data from Belgium.[4,17] Catalonia, France, Spain and Hungary, most of which have not yet been published. While data for Belgium refers to 2014 and that for England refers to 2017, the median number of fractions in the UK is lower than in Belgium with 14 fractions delivered compared to 18 respectively. Equipment and personnel costs are one and a half to two times higher in Belgium. The personnel time dedicated to treating patients is much higher in Belgium for all task groups.

Radiotherapy reimbursement, as with other healthcare, differs across devolved UK nations. There is a National Radiotherapy Plan in Scotland which includes a £45 million rolling programme of ring-fenced capital funding for replacing radiotherapy equipment.[18] Funding for radiotherapy equipment in Wales is less structured – in 2023, there was a £86 million funding investment for radiotherapy, £50m of which was ring-fenced for replacing Linacs in one cancer centre.[19] In Northern Ireland, recurrent funding for radiotherapy is provided from the Department of Health. Where funding development is required, departments must submit a business case but, in the past, commissioners have only looked at business cases that they have requested, presenting difficulties in accessing new funding.

Conclusions and next steps

This report explains how output data for the ESTRO-HERO model for England in 2017 have been derived, alongside the challenges and assumptions of the necessary input data. Sensitivity analyses have been performed to test key elements demonstrating their influence on overall costs and highlighting the importance of optimising procurement of equipment, space and maintenance. Whilst it is important to remember George Box's aphorism that 'all models are wrong, but some are useful', we believe this is the most detailed and complete estimation of radiotherapy cost in England.[20] We will continue to refine the inputs as more data becomes available (for example, the RCR contouring times survey) and any significant deviations to the input or output data will be published on the RCR website.

We hope this report will be useful to radiotherapy professionals and policy makers throughout the UK to stimulate discussion about the cost of radiotherapy. While the benefits of radiotherapy are not quantified here it is clear that, compared to the cost of new cancer drugs, radiotherapy not only offers a curative treatment option to tens of thousands of patients each year but achieves this with relatively modest expense. The RCR and other professional bodies will use the data to continue to advocate for investment in the radiotherapy workforce and equipment.

The ESTRO-HERO data inputs and outputs are stored on-line at https://hero.estro.org which is password-protected. The England data are owned by the RCR on behalf of its members and Fellows and of the Society and College of Radiographers (SCoR) and the Institute of Physics and Engineering in Medicine (IPEM). We wish to encourage others to use the model for further research and resource estimations. Projects which could be considered include:

- Updating the model to reflect more recent data on dose/fractionation
- Using the model to predict how a major change in dose/fractionation in the future, or a new technique, might impact resources required for radiotherapy
- Using data from a single centre or Operational Delivery Network (ODN) to provide more accurate local or regional outputs
- Collaborating with the Malthus team to see how providing optimal access to radiotherapy might alter the resources required for radiotherapy in the future
- Using predictions of changes in cancer incidence (e.g. Globocan) to model resource requirements, including workforce implications
- Formal comparison with data from other countries.

Lead authors

- Dr Noémie Defourny - Belgian Cancer Centre, Scientific Institute of Public Health (Sciensano), Belgium
- Dr Katie Spencer – University Clinical Academic Fellow in Cancer, Leeds Institute of Health Sciences, University of Leeds; Honorary Consultant Clinical Oncologist, Leeds Teaching Hospitals NHS Trust; and National Clinical Lead for Radiotherapy Data, National Disease Registration Service, NHS England
- Dr Tom Roques - Vice President, Clinical Oncology, Royal College of Radiologists and Consultant Clinical Oncologist, Norfolk and Norwich University Hospitals NHS Foundation Trust

Contributing authors

- Isabella Calvert – Senior Policy Adviser, The Royal College of Radiologists
- Patricia Diez – National Radiotherapy Trials Quality Assurance Group, Mount Vernon Cancer Centre, London
- Angela Francis – Head of Radiotherapy Service, Guy's and St Thomas's NHS Foundation Trust
- Sarah Griffin – Professional Standards Project Officer, The Royal College of Radiologists
- Norman Kirkby – Research Fellow, Cancer Sciences, University of Manchester
- Dr Keith Langmack – Chair, British Institute of Radiology & Head of Radiotherapy Physics, NHS Nottingham University Hospitals NHS Trust
- Professor Dr Yolande Lievens – Chair of Department, Department of Radiation Oncology, Ghent University Hospital and Ghent University.
- Catherine Roe – Radiotherapy Dataset (RTDS) Project Lead, National Disease Registration Service, NHS England

Acknowledgements

The authors would like to thank the many radiotherapy professionals in their centres who helped contribute and check the data which are so important for this report, and colleagues in the National Disease Registration Service who helped to collate the activity data, particularly Michael Sharpe and Rebecca Girdler.

This work uses data that has been provided by patients and collected by the NHS as part of their care and support. The data are collated, maintained and quality assured by the National Disease Registration Service, which is part of NHS England.

To request access to the ESTRO-HERO England data, please contact the Radiotherapy Board. The ESTRO-HERO tool is available upon request to ESTRO for scientific purposes.

If you have questions or comments on this report, please contact enquiries@rcr.ac.uk.

References

[1] Kaplan, R. S., & Porter, M. E. (2011). How to solve the cost crisis in health care. *Harvard business review*, *89*(9), .

[2] Defourny, N., Perrier, L., Borras, J. M., Coffey, M., Corral, J., Hoozée, S., Loon, J. V., Grau, C., & Lievens, Y. (2019). National costs and resource requirements of external beam radiotherapy: A time-driven activity-based costing model from the ESTRO-HERO project. Radiotherapy and oncology: journal of the European Society for Therapeutic Radiology and Oncology, 138, 187–194.

[3] Montague, E., Roques, T., Spencer, K., Burnett, A., Lourenco, J., & Thorp, N. (2024). How long does contouring really take? results of the Royal College of Radiologists contouring surveys. Clinical Oncology.

[4] Defourny, N., Hoozée, S., Daisne, J.-F., & Lievens, Y. (2023). Developing time-driven activity-based costing at the national level to support policy recommendations for Radiation Oncology in Belgium. Journal of Accounting and Public Policy, 42(1), 107013.

[5] Spencer, K., Defourny, N., Tunstall, D., Cosgrove, V., Kirkby, K., Henry, A., Lievens, Y., & Hall, P. (2022). Variable and fixed costs in NHS radiotherapy; consequences for increasing hypo fractionation. Radiotherapy and oncology : journal of the European Society for Therapeutic Radiology and Oncology, 166, 180–188

[5] National Audit Office. (2015). Progress in improving cancer services and outcomes in England. Available at: https://www.nao.org.uk/wp-content/uploads/2015/01/Progress-improving-cancer-services-and-outcomes-in-England.pdf. [Accessed March 2024].

[6] Borras, J. M., Lievens, Y., Dunscombe, P., Coffey, M., Malicki, J., Corral, J., Gasparotto, C., Defourny, N., Barton, M., Verhoeven, R., van Eycken, L., Primic-Zakelj, M., Trojanowski, M., Strojan, P., & Grau, C. (2015). The optimal utilization proportion of external beam radiotherapy in European countries: An ESTRO-HERO analysis. *Radiotherapy and oncology : journal of the European Society for Therapeutic Radiology and Oncology*, *116*(1), 38–44.

[7] Williams, M. V., & Drinkwater, K. J. (2009). Geographical variation in radiotherapy services across the UK in 2007 and the effect of deprivation. *Clinical oncology (Royal College of Radiologists (Great Britain))*, *21*(6), 431–440.

[8] Heritage, S., Sundaram, S., Kirkby, N. F., Kirkby, K. J., Mee, T., & Jena, R. (2023). An Update to the Malthus Model for Radiotherapy Utilisation in England. *Clinical oncology (Royal College of Radiologists (Great Britain))*, *35*(1), e1–e9.

[9] National Audit Office. (2015). Investigfation into the Cancer Drugs Fund. Available at: https://www.nao.org.uk/wp-content/uploads/2015/09/Investigation-into-the-Cancer-Drugs-Fund-summary.pdf. [Accessed March 2024].

[10] NHS England. (2021). Cancer Drugs Fund activity update Q4 2020-21. Available at: https://www.england.nhs.uk/wp-content/uploads/2018/01/cdf-q4-20-21-activity-update.pdf. [Accessed March 2024].

[11] Department of Health and Social Care. (2012). Eight thousand patients to benefit from advanced cancer treatment. Available at: https://www.gov.uk/government/news/eight-thousand-patients-to-benefit-from-advanced-cancer-treatment. [Accessed March 2024].

[12] Cancer Research UK. (2013). Sparking the radiotherapy revival. Available at: https://news.cancerresearchuk.org/2013/07/11/sparking-the-radiotherapy-revival/. [Accessed March 2024].

[13] NHS England. (2016). NHS England launches biggest upgrade to cancer treatment in 15 years. Available at: https://www.england.nhs.uk/2016/10/radiotherapy-fund/. [Accessed March 2024].

[14] Radiotherapy4Life. (2021). Age of Radiotherapy Machines in England, July 2021. Available at: https://radiotherapy.org.uk/wp-content/uploads/2022/08/Machine-Data-July-2021.pdf. [Accessed March 2024].

[15] Department of Health. (2012). Radiotherapy Services in England 2012. Available at: https://assets.publishing.service.gov.uk/media/5a7b8b50ed915d131105ff08/Radiotherapy-Services-in-England-2012.pdf [Accessed March 2024].

[16] Lievens, Y., Defourny, N., Corral, J., Gasparotto, C., Grau, C., Borras, J. M., & ESTRO–HERO Consortium Collaborators (2020). How public health services pay for radiotherapy in Europe: an ESTRO-HERO analysis of reimbursement. The Lancet. Oncology, 21(1), e42–e54.

[17] Nevens, D., Kindts, I., Defourny, N., Boesmans, L., Van Damme, N., Engels, H., … Lievens, Y. (2020). The financial impact of SBRT for oligometastatic disease: A population-level analysis in Belgium. Radiotherapy and Oncology, 145, 215–222.

[18] Scottish Government. (2022) National radiotherapy plan. Available at: https://www.gov.scot/publications/national-radiotherapy-plan-scotland/. [Accessed March 2024].

[19] Welsh Government. (2023). £86 million investment to improve cancer radiotherapy services for South Wales. Available at: https://www.gov.wales/86-million-investment-improve-cancer-radiotherapy-services-south-wales. [Accessed March 2024].

[20] Box, George E. P. (1976), "Science and statistics" (PDF), Journal of the American Statistical Association, 71 (356): 791–799